

# On Episodic Memory in Experiential Learning for Flightcrew Training

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## ABSTRACT

The training community has relied upon theory and data on memory and learning from the cognitive sciences in its collective practices and research. However, episodic memory (EM) and related constructs have been largely overlooked in the training literature, particularly in the flightcrew training domain. In this article, we illustrate how the concept of episodic memory may lead to a richer conceptualization of experiential learning implemented using extended reality (XR) simulations. We outline the importance of this issue given growing optimism over the use of extended reality configurations for unfulfilled niches in the flightcrew training cycle. We describe episodic memory and its empirical underpinnings in the cognitive sciences and discuss how this concept may be used to understand, design, and support the implementation of experiential learning in flightcrew training contexts. Illustrating the practical applications of this work, we describe how the concept of episodic memory can be applied to enhance the instructional design features of virtual reality training for the external preflight inspection of a generic B-737 aircraft. We conclude with a summary of the importance of episodic memory in flightcrew training and propose a set of future directions for research and development addressing episodic memory in extended reality simulations.

## ABOUT THE AUTHORS

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## INTRODUCTION

Simulation training has often been considered an experiential learning (EL) approach that emphasizes “learning-by-doing” (McGowin et al., 2021) in a cycle of experience, reflection, abstraction, and experimentation (Kolb, 2015). Recently, extended reality (XR) systems have been advocated as a means of providing efficient and effective training experiences that facilitate learning and transfer through their affordance of varying degrees of fidelity, immersion, interactivity, and other constructs of interest to the training community (McGowin et al., 2021; 2023; Stanney et al., 2021a). Anticipating broader adoption of XR technologies in flightcrew training, it is vital to consider one aspect that makes experiential learning so powerful, namely the role that *episodic memory* (EM) plays in making experiential learning effective.

Our goal in this paper is to discuss EM, how it facilitates experiential learning, and how the consideration of EM may lead to a richer conceptualization of training experiences in XR systems. Consequently, we briefly describe the concept of EM, outline its conceptual underpinnings from the cognitive sciences literature, and discuss how EM can be used to understand, design, and support the implementation of experiential learning in XR, specifically in flightcrew training contexts. As a practical example, we outline a series of design concepts for supporting EM within an external preflight inspection simulation delivered via virtual reality, one subcategory of XR. We conclude with a summary of the importance of episodic memory in flightcrew training and propose a set of future directions for research and development addressing EM in XR simulations.

## MEMORY SYSTEMS

A substantial body of research on human memory argues for the existence of multiple types of systems for encoding information into long-term memory (LTM; c.f. De Brigard, 2022). One classification of LTM breaks it up into procedural, semantic, and episodic systems, which function interactively and interdependently to facilitate LTM (Anderson, 2015; Ferbinteanu, 2019; Laird, 2021; Tulving, 1985; see also Baddeley et al., 2021). *Procedural memory*, associated with psychomotor skills and automatized action execution (e.g., typing, manual flight control), has been conceptualized as a symbolic network of conditional “if-then” structures (i.e., rules) of condition-states and actions (Seow et al., 2021). *Semantic memory*, associated with declarative knowledge of facts, concepts, and abstractions (e.g., names and descriptions of flight instruments), has been conceptualized as a rigid network of symbolic representations for propositional associations and relational metadata (Laird et al., 2017). The third category and focus of this paper, *episodic memory* (EM), may be concisely defined as “a neurocognitive memory system that enables people to remember past happenings” (Tulving, 1993, p. 69), which “receives and stores information about temporally dated episodes or events, and temporal-spatial relations between them (Tulving, 1984, p. 223). What makes episodic memory unique is its association with specific events, including temporally tagged information and contextual features of the experience, including emotion and place details, allowing one to re-experience some past via recollection (Tulving, 1984; 2002).

### Episodic Memory (EM)

The two defining characteristics of EM most relevant to training are *time* and *context* (Fiore & Nicholson, 2007). Regarding time, the EM system allows for the reconstruction of personal experiences from the past (Tulving, 1985; 2002) such as recalling one’s first flight (i.e., retrospection; Suddendorf & Corbalis, 1997). EM also allows for the mental construction of possible events in the future, discussed as *prospection* (Bulley, 2018), *episodic future thinking* (Schacter et al., 2015; 2017), and *mental simulation* (Rivera et al., 2016). Regarding context, the EM system encodes the spatiotemporal characteristics and relations of events (Tulving, 1985), due to our sensorimotor embodiment

(Garbarini & Adenzato, 2004), such that spatial memory may be a feature of episodic memory (Eichenbaum, 2003; Ranganath, 2019). The experiences in EM are closely tied to one's goals (Conway, 2009; Conway & Loveday, 2015) and become an indispensable resource for achieving training- and work-relevant outcomes (Fiore et al., 2007b; Fiore & Nicholson, 2007). Further, the EM system has been associated with the structuring of schemata including templates (Kimball & Holyoak, 2000), mental models (Andonovski, 2022; Conway, 2009), narratives (Cohn-Sheehy et al., 2022; Dings & Newen, 2021; Ezzyat & Davachi, 2011) and constructs of the autobiographical/conceptual self (e.g., attitudes, beliefs, values, self-schema) (e.g., Brown, 2020; Conway & Loveday, 2015; Ochs & Capps, 1996).

Despite its relevance to learning and performance, EM has been underemphasized in the training literature, particularly in the aviation domain. Instead, the emphasis there has been predominantly on the semantic and procedural systems, on declarative knowledge and psychomotor skills, assessed using approaches tailored for associated memory systems (e.g., knowledge tests, behavior observations). Current practices and guidance tend to focus on supporting memory as a singular construct (e.g., LTM) or adopt a reductionist classification without due consideration of the unique contributions of EM (Ferbinteanu, 2019). In flightcrew training, this is most evident in the literature on learning of procedures, or procedural tasks, that is, of ordered sets of goal-directed actions performed in a specific environmental context (Konoske & Ellis, 1986). Behavioral demonstration may be required of frequent or particularly high-risk procedures, but proficiency in many tasks may also be assessed only based on a learners' declarative knowledge of the steps of a given procedure. However, in abnormal and emergency situations, flightcrew members must rely on more than the declarative knowledge of steps of a procedure and their automatic execution of psychomotor skills; instead, they must be capable of exhibiting adaptive expertise (Hoffman et al., 2013). As described by Fiore and colleagues (2012), adaptive expertise requires that one draw on prior experience and "use it in novel situations or transfer it to a different domain – as in solving a problem via analogy or when a [team] dynamically replans to coordinate actions for an unforeseen event" (p. 327). Such adaptive expertise relies on the functions of the EM system—as detailed in findings, for example, supportive of template theory and recognition-primed decision making (Gobet & Simon, 1998; Kimball & Holyoak, 2000; Klein, 1993).

Although EM has been underemphasized in flightcrew training, various instructional features currently used in air carrier training indirectly address EM as described here. By explicitly acknowledging the cognitive mechanisms, specifically of EM, we may have a richer conceptualization upon which to base the design of XR simulations to influence learning and transfer across timescales at the social and organizational level (Anderson, 2002; Newell, 1990). In support of this contention, we continue in the next section by aligning experiential learning (Kolb, 2015) to the properties of episodic memory (Conway, 2009) within flightcrew training. From this we derive a set of learning principles for instructional designers and researchers. Drawing from the empirical and theoretical literature, we then propose an initial set of design principles for EM in experiential learning within XR simulations. Finally, we use this to provide examples of instructional features (e.g., strategies, tactics; Rosen et al., 2010; Singer et al., 2006) that illustrate the practical implementation of those principles, grounded by the embedded, embodied, enactive, and extended (4E) cognition of learners in XR environments (McGowin et al., 2021; 2023). 4E cognition is a framework from the learning sciences that, in short, views cognition as involving a dynamic relationship between the brain, body, and environment (Choi & Donaldson, 2023). While it is not the central focus of this paper, it would be inappropriate to omit given its relevance to learning within XR simulations (McGowin et al., 2023). While we describe the relationship of the features of 4E cognition to EM and experiential learning in this paper, we also provide a table of formal definitions, adapted from McGowin et al. (2023) and derived from Schiavio & Van der Schyff, (2018), in our supplemental material (**Appendix A**).

### **Episodic Memory in Experiential Learning**

In this section we provide more direct linkages between experiential learning and episodic memory. As described in the literature, experiential learning emphasizes direct and hands-on experiences to better acquire knowledge and skills and improve understanding. This direct experience affords active engagement and experimentation with the instructional material. It similarly requires one to reflect on these experiences and analyze them to better understand what happened as well as extract meaning and connect theory and practice through a process of abstraction (Kolb, 2015). We next describe how these phases not only draw from EM, but require it, to produce effective learning.

### **Experience & Experimentation Phases**

Conway (2009) conceptualized EM as being composed of experiential summaries of perceptual and cognitive processing—representative of embodied *experiences* and enactive *experimentations*, such that sensory details may be

inhibited (e.g., if not meaningful via relevance to goals) or activated (e.g., environmentally or semantically primed) during reconstruction/recollection with a variable degree of accuracy (e.g., confabulation/counterfactual thinking (Schacter et al., 2015; see also Wilson 2002). This property of the EM system results from *embodied cognition*, such that the grounding of cognition in sensorimotor processing facilitates the encoding and retrieval of EM (Fiore et al., 2006; Wilson, 2002), and from *enactive cognition*, such that learners with active control over an experience develop richer experiential summaries (Markant et al., 2016; Sauzéon et al., 2012; see also McGowin et al., 2023). These experiential summaries, referred to as *episodic elements* by Conway (2009, p. 2308), are interpreted and successively chunked into memories of episodes and events through the *frames* provided by higher-order structures (e.g., goals, but also models, narratives, etc., Conway, 2009; Conway & Loveday, 2015; Klein et al., 2007). Without the attribution of value (e.g., goal relevance) from these frames, precise details of the experience beyond relative time and context become subject to inhibition and loss (i.e., they are forgotten; Conway, 2009; Vogel-Walcutt et al., 2010). Whereas the EM system represents short-time slices of experience (Conway, 2009; Tulving, 1985), goals provide the context maintaining those memories within a broader frame of reference (Fiore, 2008).

Here we can see the connection to training in that, during the experience phase of experiential learning, the EM system may be viewed as responsible for constructing the primitive models of the meaningful sensory, spatiotemporal, and affective elements of the simulated environment and task (Andonovski, 2022; Eichenbaum, 2003; Ranganath, 2019). These experiential summaries are visually represented in the EM system (Conway, 2009), and the spatiotemporally rich information provided through experiential learning (particularly via XR simulations) is congruent with generating spatiotemporally rich visual representations and models within in the EM system. Such simulations support trainees' enactive experimentation, by allowing trainees to introduce friction and test their extant mental models and frames of an experience under different conditions and contexts (e.g., through repetitions in performance or novel behaviors; Owens & Goldberg, 2022), building within the EM system a repertoire of representations and associated frames for application to the operational domain (Conway, 2009; Klein et al., 2007). Supporting "breaches of the canonical" (Bruner, 1991, p. 12) during experimentation may be beneficial for resolving trainees' misconceptions (Stanney et al., 2021b), but careful consideration should be given to manage the introduction of unexpected events (Monteiro & Sibbald, 2020) and optimize the associated cognitive load, emotions, and stress of trainees relative to the training context (Graesser, 2020; Hampton & Tawfik, 2020; Shields et al., 2017). How a simulation may be designed to optimize trainees recall and framing of particular details and memories in EM is a clear concern for practitioners.

### Reflection & Abstraction Phases

During the *reflection* phase of EL, we suggest it is the EM system that aggregates and consolidates the experiential summaries of meaningful sensory, spatiotemporal, and affective elements of the simulated environment and task (Conway, 2009; see also Andonovski, 2022). Through reflection, episodic elements are successively chunked into memories of episodes and events and integrated within other higher-order structures (e.g., templates, narratives, attitudes; Conway, 2009; Conway & Loveday, 2015). Reflection requires constructing a retrospective simulation of an experience (cf. Perrin, 2021), a recollection of the experiential summary and related meaning (e.g., emotions, goals; Holland & Kensinger, 2013), reinforcing the neural traces encoded during the original experience (Wiltshire et al., 2015; Michaelian & Sant'Anna, 2021). During recollection, the visual representations are recalled with a specific perspective. Specifically, one can recall EM from what Conway (2009) calls a "field" perspective (first person) or "observer" perspective (third person). The first-person perspective may be associated with recency and recollective salience of the episodic elements of the experience, while a third-person perspective may be associated with the antecedence and genericness of the experience (Bruner, 1991; Fiore et al., 2007a; Tulving, 1985). This capacity for perspective illustrates the role of *embedded cognition*, such that perspective signifies the extent to which the memory is situated in the environmental and sociotechnical context in which it was encoded (McGowin et al., 2021; 2023; Schiavio & Van der Schyff, 2018). Observational learning follows a similar process, in that the intersubjective and enactive perception of social observation may be recollectively experienced through episodic simulation (Gallagher, 2008; Gallese, 2007), illustrating the role of *extended cognition*. Perspective here remains a function of the salience and particularity of the experience, given an attunement of the observers' mirror system through exposure and expertise (Gallagher & Allen, 2018).

During the *abstraction* phase, we also see a strong connection to memory theory in that knowledge, meaning, and spatiotemporal relations across events are rapidly integrated into the respective memory systems (Ezzyat & Davachi, 2011), driven by semantic assimilation and proceduralization (Anderson, 1981; Fiore & Nicholson, 2007). That is,

invariant patterns are distilled from EM structures—declarative knowledge of facts, concepts, and abstractions distilled from EM structures are integrated into semantic memory (e.g., as sets of propositions), while associations for condition-states and actions (e.g., rules) are automatized within procedural memory (e.g., as sets of conditional statements). Bruner’s (1991) work aptly captures the result of this—such that generic experiences may become amalgamated with extant models of similar events, while details of particularly meaningful experiences persist. Following the abstraction phase, what remains of EM might be loosely described here (until a better operationalization is reached) as *tacit knowledge*—imperfectly articulable knowledge of situations and spatiotemporal relations accessible through analogical reasoning, metaphor, and narrative as manifest in actions, outcomes, or shared understanding (Taylor, 2007; see also Asher & Popper, 2019; Linde, 2001). Conway’s (2009) properties of EM related to temporal order and linearity, temporal bounding by goals, and the grounding/framing of episodes (e.g., of and by higher-order structures) are also important for the reflection and abstraction phases of experiential learning. Although the EM system is known to represent short time-slices of experience (Tulving, 1985), Conway (2009) proposed that goals provide the context of this bounding—the opening boundary for a given episode is a goal-directed action, with the closing boundary defined by the outcome of that action relevant to some goal. With respect to training, EM and goal setting are inexorably linked (Fiore, 2008; Madore & Wagner, 2022). How goals are delineated and leveraged to frame episodes during experience and reflection impacts the higher-order structuring of that information (e.g., events, models, narratives) during the bottom-up processes of abstraction (Conway, 2009; Conway & Loveday, 2015).

### **Learning and Design Principles for EM in Experiential Learning via XR**

We now discuss how Conway’s focus in conceptualizing EM on the accumulation of autobiographical knowledge, helps to strengthen connections between EL and memory. Specifically, there are clear implications for experiential learning—namely, that the very cycle of experience, reflection, abstraction, and experimentation implicitly facilitates: (a) the grounding and framing of higher-order structures of the self (e.g., autobiography, identity, attitudes, and goals) within the EM system’s representations of embodied processing through the *transformation* of experimentation and reflection, and (b) the assimilation of invariant knowledge (Fiore & Nicholson, 2007) and proceduralization of spatiotemporal relations across events (Anderson, 1981; Andonovski, 2022) through the *grasping* of experience and abstraction (Kolb, 2015).

Based on our discussion of the properties of the EM system, a series of learning principles to account for the role of the EM system in the experiential learning cycle may be derived (see **Table 1**). These learning principles restate the properties of EM outlined by Conway (2009) as actionable considerations across the phases of the experiential learning cycle outlined by Kolb (2015). The rationale for the alignment is based on the appropriateness of the consideration for each phase of the experiential learning cycle. For example, learners’ encoding of experiential records would be assumed to occur during the Experience and Experimentation phases rather than the Abstraction and Reflection phases following a traditional information processing paradigm (e.g., Baddeley et al., 2021). Further, using XR simulations as the means of implementation, these design principles illustrate how EM can strengthen EL as an instructional strategy. In our supplemental material (**Appendix B**), we provide a more in-depth discussion of these principles.

**Table 1. Alignment of EM properties with learning & design principles and instructional features**

Properties of EM	Learning Principles for EM in EL	Design Principles for EM in XR	Instructional Features for XR
#1: EM consists of summaries of experiential processing.	#1: Promote trainees’ experiential records of perceptual-cognitive processing during the Experience and Experimentation phases of EL.	#1: Optimize the presence of trainees in XR simulations.	#1. Balance immersion and interactivity with other moderating factors [Embedded & Embodied]
#2: EM is subject to differential activation / inhibition.	#2: Leverage trainees’ activation/inhibition of sensory details during the Abstraction and Reflection phases of EL.	#2: Optimize the salience of meaningful information and stimuli in XR simulations.	#2. Increase the salience of relevant information through attentional cues (e.g., highlight, point, volume) and contextual information (e.g., annotation, enrichment) [Embedded]
#3: EM involves visual representation.	#3: Support trainees’ visual representation during the Experience and Abstraction phases of EL.	#3: Provide graphical representations of conceptual information in XR simulations.	#3. Provide graphical representations (e.g., diagrams, models) as advance organizers and at the point-of-need. [Extended]
#4: EM has perspective.	#4: Leverage trainees’ perspective during the Experience and Reflection phases.	#4: Support multiple perspectives of events in XR simulations.	#4. Prioritize 1st-person POV, consider using 3rd-person POV for observation and evaluation objectives, use perspective of alternate roles to support coordination. [Enactive]
#5: EM is temporally bounded (by goals).	#5: Promote effective goal-setting and regulatory behaviors throughout the Experiential Learning cycle.	#5: Provide supports to facilitate learners’ SRL in XR simulations.	#5. Facilitate SRL through system-initiated and learner-initiated supports [Extended]
#6: EM has temporal order/linearity.	#6: Support the schematization of spatiotemporal relations across events during the Experience and Experimentation phases.	#6: Retain spatiotemporal realism through interaction fidelity in XR simulations.	#6. Facilitate interaction fidelity by providing a self-avatar and supporting learner control within the environment. [Embodied & Enactive]
#7: EM is subject to rapid forgetting.	#7: Facilitate trainees’ retention of meaningful information throughout the Experiential Learning cycle.	#7: Provide trainees with access to comprehensive case libraries of XR simulations.	#7. Ensure that trainees have access to an appropriate quality and breadth in XR training by using emerging technologies for virtual production [Embedded & Enactive]
#8: EM grounds—and is framed by—goals & self-concepts.	#8: Leverage top-down/bottom-up EM processes in the Abstraction and Reflection phases.	#8: Use narrative techniques to frame events and support schema development in XR simulations.	#8. Promote framing through self-narrative (e.g., reflection) and others’ narratives (e.g., expert POV, hangar talk) [Embedded & Extended]
#9: EM is recollectively experienced.	#9: Leverage the recollective experience of EM in the Reflection phase.	#9: Encourage retrospection and prospection in XR simulations	#9. Encourage reflection and mental simulation before and after training [Enactive]

**APPLYING EPISODIC MEMORY IN FLIGHTCREW TRAINING SIMULATIONS**

While learning and design principles for EM in experiential learning via XR simulations may be generically useful for training, another way to examine the concept of EM is by considering how the EM system aligns with tasks and training events in flight deck operations. To illustrate the relationship between the types of tasks involved in commercial flight deck operations (for which flightcrews are being trained), we adapt the distinction between taskwork and teamwork from the team training literature (e.g., Cannon-Bowers et al., 1995) to examine how the different memory systems uniquely support that task performance and illustrate the contributing role of EM in technical and nontechnical aspects of flight deck operations.

**Table 2. Contributions of EM to flightcrews’ taskwork and teamwork**

		Type of Memory		
		Procedural	Semantic	Episodic
Type of Work	Task	“How” knowledge Manual flight Procedural tasks	“What” knowledge Systems Checklist & memory items	“Context” knowledge Retrospection/Prospection Task concern
	Team	Crew coordination Flight path management Automation management	CRM principles PF/PM roles PIC/SIC authority	Retrospection/Prospection Coordination & Collaboration Beliefs & Values (e.g., assertiveness)

As depicted in **Table 2**, procedural memory is conventionally associated in taskwork with the “how-to” of procedural knowledge and skill, such as that involved in manual control of the aircraft and the completion of procedural tasks, such as cockpit flows and approach procedures, or scripted responses to calls and alerts. In work as a crewmember, procedural memory may also be involved in flightcrews’ coordination and crew resource management (CRM); for example, through the scan paths used to monitor the instrument panel in support of flight path management or in trained responses in support of automation management (e.g., engaging auto-throttle through use of the takeoff/go-around (TO/GA) button/switch). Using the same principles, semantic memory would conventionally be associated in taskwork with the “what-is” declarative knowledge of facts and concepts, such as systems knowledge, checklist/memory items, and aviation phraseology. In teamwork, semantic memory can be considered as associated with remembering CRM principles, knowledge regarding the roles and responsibilities of the pilot flying and pilot monitoring across different phases of flight, and authority of the pilot-in-command during normal, abnormal, and emergency situations.

We argue here that EM also has a unique role in both technical and nontechnical aspects of flight deck operations. Regarding taskwork, we posit that the EM system is involved in a flightcrew member’s reflection on prior training events (e.g., remembering an abnormal situation covered in a special purpose operations training scenario), their mental simulation (e.g., of approach/landing following diversion procedures), and their attitudes, values, and goals associated with task concern, as developed over a succession of prior flight and training experiences (Conway, 2009). One way that documents such as the FAA Flight Training Handbook (FAA, 2020) already encapsulate one of the principles is through its reference to the “law of effect” in training which states that memorable or impactful experiences are remembered and recalled better. Given the interdependence of these memory systems, the EM system is not just involved in a crewmembers’ reflection on taskwork, but in the structuring of frames supporting automaticity in their execution of skills in response to operational cues (Conway, 2009; Gobet & Simon, 1998; Klein et al., 2007).

Respective to teamwork, the EM would be involved in a flightcrew member’s retrospective memory of experiences with current/prior crewmembers (Fiore et al., 2003; Fiore et al., 2006), shaping their CRM behaviors during flight deck operations, and their prospection and episodic future thought regarding a potential emergency and how they would communicate and coordinate with their co-pilot and cabin crew to perform the associated emergency procedure. Following Conway’s (2009) model, the EM system would have a role in shaping the flightcrew member’s identity and CRM-relevant attitudes associated with, for example, their ability for assertiveness in the PM role. Such examples do not present a comprehensive analysis of situations where the EM system contributes to the technical and nontechnical aspects of flight deck operations—rather, our intent is to advocate that consideration of the role of EM within the performance environment, from which training objectives are derived, may help training practitioners and researchers identify where the EM system serves a function operationally such that may be informative for the design and delivery of flightcrew training.

**Table 3. Episodic memory functions, experiential learning, & flightcrew training**

<b>Episodic Memory</b>	Assimilating Knowledge	Encoding Experience	Consolidating Episodes
<b>Experiential Learning</b>	Abstraction	Experimentation & Experience	Reflection
<b>CRM Training</b>	Indoctrination & Awareness	Practice	Feedback & Reinforcement
<b>LOS Training</b>	Briefing	SPOT Session	Debriefing

**Table 3** illustrates how the functions of EM align with the experiential learning cycle across two flightcrew training examples—CRM training and LOS exercises. The *abstraction* phase may be generalized to the indoctrination and awareness phase of CRM training and is operationalized, among others, in pre-LOS briefings. Specifically, in CRM indoctrination/awareness, the EM system may be understood to facilitate the bottom-up assimilation of invariant knowledge across training experiences into the SM system (Fiore & Nicholson, 2007). In pre-LOS briefings, there is a similar assimilation of knowledge—here, the trainee may retrospectively recall prior training experiences related to the target objective(s) and prospectively simulate the LOS scenario and develop a plan for accomplishing those objectives.

The *experience* and *experimentation* phases of the experiential learning cycle may be generalized to the recurrent training and practice phase of flightcrew CRM training and localized to a given SPOT session. The primary role of EM in these facets of flightcrew training may be understood to be the encoding of experiential processing. Finally, the *reflection* phase of may be understood as similar to the feedback and reinforcement phases of CRM training, operationalized through a LOS debriefing. The primary role of the EM system in these phases of flightcrew training may be understood to be the bottom-up consolidation of episodic elements into higher-order structures—events, mental models, self-concepts, goals, and other (conventionally) affective outcomes. Demonstrating the practical applications of this work, we use the next section to illustrate how the concept of EM can be applied to enhance the instructional design of a virtual reality (VR) simulation for training external preflight inspection of a B-737 aircraft.

### **Design Concepts for Supporting EM within a VR External Preflight Inspection Simulation**

The Flight Procedures Experimental Training (FlightPET) simulation testbed was developed to support research to identify: (1) which combinations of training technologies and approaches should be used for flightcrew-relevant topics/tasks, (2) under what contexts, and (3) how to leverage these configurations to provide an equivalent level of training and safety to conventional air carrier training methods (Sonnenfeld et al., in press). FlightPET currently includes a module for training preflight inspection of a B-737 aircraft which may be delivered using a VR headset. The purpose of this preflight inspection task is to ascertain the general airworthiness of the aircraft, its components, and parts. It is an important but error-prone part in flight operations, which may vary between air carriers and aircraft, and operators have been found to primarily rely on spatial and environmental cues in the execution of the procedure (Drury & Watson, 2002; Larock & Drury, 2003). FlightPET was originally developed using a conventional instructional systems design process, grounded in learning and instructional design theories which do not explicitly address the role of EM in training. Many instructional features and practices used in flightcrew training align with the properties and functions of EM. We consider these here and discuss a use case of how the concept of EM could be used to enhance FlightPET's instructional features.

#### **Design Concept #1: Immersion & Interactivity to Optimize Presence**

Designers and developers of XR simulations for flightcrew training may optimize the presence of trainees (Design Principle #1) to promote trainees' experiential records of perceptual-cognitive processing in the EM system during the Experience and Experimentation phases (Learning Principle #1) by increasing the immersion and/or interactivity afforded by the system (Instructional Feature #1), as supported by the concepts of embedded and embodied cognition (McGowin et al., 2023) and demonstrated by Smith and Mulligan (2021) among others. We currently promote experiential processing in FlightPET largely through immersion of the visual modality through use of a VR headset, and through interactivity by enabling trainees to vary the form of representation of content (e.g., text, audio, images, animations, tips & hints, cues & clues) corresponding to level 3 interactivity in McGowin et al.'s (2023) interactivity framework. We could further increase immersion by providing inclusive, extensive, surrounding, and vivid stimuli for the auditory and/or haptic modalities, and further increase interactivity to optimize presence in support of EM by incorporating adaptive intelligence within the external preflight inspection training through the implementation of feedback and micro-adaptivity (e.g., real-time guidance), as demonstrated by Stanney et al. (2021b).

#### **Design Concept #2: Attentional Cues & Context for Information Salience**

Designers and developers of XR simulations for flightcrew training may optimize the salience of meaningful information (Design Principle #2) to leverage trainees' variable activation/inhibition of episodic elements in the EM system during the Reflection and Abstraction phases of experiential learning (Learning Principle #2) by using attentional cues and contextual information to increase the salience of relevant information and stimuli (Instructional Feature #2), as demonstrated by Limbu et al. (2019) and supported by literature on embedded and extended cognition (McGowin et al., 2023; Scaife & Rogers, 1996). We currently leverage activation/inhibition of EM in FlightPET by enabling trainees to draw attention to components relevant to the exterior inspection procedure through visual cues (e.g., highlighting, pointing) and contextual information (e.g., text/audio descriptions, animations). We could better apply context to leverage activation/inhibition in EM by enabling an instructor or virtual agent to provide guidance and feedback to trainees, as demonstrated by Severe-Valsaint et al. (2022) and depicted in **Figure 1**.

#### **Design Concept #3: Interaction Fidelity for Spatiotemporal Realism**

Designers and developers of XR simulations for flightcrew training may retain spatiotemporal realism through interaction fidelity (Design Principle #6) to support the schematization of spatiotemporal relations across events during the Experience and Experimentation phases of the experiential learning cycle (Learning Principle #6) by providing a

self-avatar and supporting learners’ embodied control over their actions within the environment, as supported by literature on embodied and enactive cognition (McGowin et al., 2023), such that learners with active control over an experience has been found to improve outcomes associated with EM (e.g., false recognition rates) (Markant et al., 2016; Sauz on et al., 2012). We currently leverage retain spatiotemporal realism by allowing trainees to conduct the entire walkaround without constraining their navigation or movement within the virtual environment, and by enabling trainees to use the VR system controllers to trigger different interface functions, such as animations showing the function of relevant exterior aircraft components. We could further increase spatiotemporal realism by matching the interaction fidelity of psychomotor motions with these interactions—for example, having trainees perform the manual motions of opening doors, operating switches vs. dials, etc., as depicted in **Figure 1**.

**Design Concept #4: Narrative & Story to Frame Events**

Designers and developers of XR simulations for flightcrew training may use narrative techniques to frame events and support schema development (Design Principle #8) to leverage complementary top-down/bottom-up EM processes in the Abstraction and Reflection phases of experiential learning (Learning Principle #8) by using instructional features such as contextual narratives, informal narratives, and personal narrative (Instructional Feature #8), as supported by literature on embedded and situated cognition (McGowin et al., 2023; Stanney et al., 2023). We currently leverage narrative techniques in FlightPET through narrative vignettes in a pre-/post- procedural knowledge assessment. We could better leverage narrative techniques by: (1) providing videos demonstrating specific narrative vignettes for each of the exterior aircraft systems, or (2) employing informal hangar-talk to provide recordings of experts’ personal stories related to inspection of exterior aircraft systems. For example, an experienced pilot might detail a personal account of the consequences of foreign object debris (FOD) on the runway as it causes damage to the aircraft, provide a recording of an instructor/evaluator (I/E) demonstrating what they look for during that facet of the walkaround, or demonstrate the consequence of a failure to retract the landing gear after takeoff or retraction on the ground, because of a failure to check the safety pin (see Rosen et al., 2010), as depicted in **Figure 1**.



**Figure 1: Illustration of design concepts for supporting EM in exterior inspection training via VR**

**DISCUSSION**

**Directions for Research & Open Questions**

Because the episodic system has, heretofore, been largely ignored within contemporary training literature—particularly in the aviation and flightcrew training domains—there are several areas in which additional data and theory on EM could help flightcrew training practitioners and researchers make more informed decisions in the implementation of experiential learning through XR training simulations. The recent emergence of the learning engineering paradigm, exemplified within the interdisciplinary and convergent methods and practices of XR simulation design and development efforts, provides an opportune justification for critically reassessing the theories, principles, and assumptions underlying learning and the translation of findings to practice in high-risk domains such as flight operations. Based on the theories, findings, and applications discussed here, we propose a set of eight research questions for further examining the role of EM in experiential learning via XR simulations (**Table 4**).

**Table 4: Open questions & directions for research for EM in Experiential Learning via XR Simulations**

Open Questions Concerning EM in Experiential Learning via XR Simulation
Q1: How should the training community analyze EM functions distinct from those of the procedural/semantic systems?
Q2: How should the training community operationalize and assess tacit knowledge as distinct from declarative/procedural knowledge?
Q3: How should the training community define design requirements for the elicitation and assessment of data relevant to EM?

<b>Q4:</b> How should the training community account for EM in the description and indexing of metadata for learners and learning objects?
<b>Q5:</b> How might the training community account for the potential nonlinear influence of EM on the repetition/novelty of behaviors?
<b>Q6:</b> How might the training community account for EM in the learner, domain, and instructional models of training systems?
<b>Q7:</b> How might the training community clarify the relationship of the EM system to 4E cognition in XR simulation contexts?
<b>Q8:</b> How might the training community apply the EM concept to content creation—what standards or workflows could be implemented?

In this paper, we described one potential use case for how the concept of EM could be used to enhance the instructional design of VR training simulation for the external preflight inspection of a B-737 aircraft, based on our discussion of the role of EM in experiential learning using XR simulations. Given the context-specificity of the instructional features discussed (e.g., designing for specific perspectives, crafting specific narratives), future work in this area will need to address the scalability of these concepts. By helping to address these open questions, our next projects in this area will seek to focus on this issue of scalability, for example, through the proposal of workflows to help designers/developers apply and scale the concept of EM across different training contexts, tasks, and domains. Additionally, we would like to conduct the experiments needed to verify the applicability of the theory and recommendations established herein.

## CONCLUSIONS

Memory has always been an important construct in training science, instructional design, human factors, and related disciplines—supported by data and theory derived from the cognitive sciences. As the methods and practices of these disciplines converge within the concept of learning engineering—exemplified in the interdisciplinary processes driving the systematic design of XR simulations for training—it is important to critically reassess the theories, principles, and assumptions underlying training and their translation into practice in high-risk domains such as flight operations.

We have made the case that there has been an underemphasis of episodic memory (EM) in aviation training, which has predominantly focused on semantic and procedural systems. The current practices in flightcrew training often assess proficiency based on declarative knowledge of procedures, but in atypical situations, adaptive expertise is crucial. We showed how adaptive expertise relies on the functions of episodic memory, which allows individuals to draw on prior experiences and apply them to novel situations. Further, despite the lack of attention to episodic memory theory, we illustrated how certain instructional features indirectly address episodic memory in flightcrew training. By aligning experiential learning and episodic memory within flightcrew training we are able to provide learning principles for instructional designers and researchers. We additionally provided design principles for episodic memory in experiential learning within extended reality (XR) simulations and discuss examples of instructional features that implement these principles.

We conclude and emphasize the need for collaboration between flightcrew members and instructors/facilitators, and empirical studies and theory on the relationship between EM and instructional features. In this way we can ensure more ecologically sound experiential learning that facilitates the development of EM in training simulations, and the coupling of the body and environment with the EM system during XR simulation training. As XR training simulations become more ubiquitous at air carriers and other organizations, it is critical to reconsider the role of the EM system in experiential learning and how it may help training researchers and practitioners in these domains better understand how constructs relevant to contemporary simulation training (e.g., narrative, presence) may be leveraged to facilitate training outcomes.

## Practitioner Take-Aways

- Episodic memory (EM) is a robust concept from the cognitive sciences that may provide a richer conceptualization of experiential learning (EL) using extended reality (XR) simulations in flightcrew training contexts.
- A breadth of proven instructional features relevant to experiential learning using XR simulations may be grounded in the properties and functions of the EM system. We propose a set of learning and design principles, aligned with these instructional features, emphasizing the use of instructional features such as narrative, perspective, presence, and interaction fidelity.
- Future research needs to address open questions and issues related to the application of the EM concept to training and evaluation at scale.

## ACKNOWLEDGEMENTS

This research was supported by the US Department of Transportation/Federal Aviation Administration (FAA) collaborative research agreement 692M151940002; program manager: FAA ANG-C1, the NextGen Human Factors Division; program sponsors: FAA AVS, the Aviation Safety Office, and FAA AFS-280, the Air Transportation Division - Training & Simulation Group. The views expressed herein are those of the authors and do not reflect the views of the United States (U.S.) Department of Transportation (DOT), FAA, or the University of Central Florida. We also express deepest thanks to our reviewers and the development team at E2i Creative Studio in the Institute for Simulation & Training.

## SUPPLEMENTAL MATERIAL

See Appendix B of the following online supplemental material (Sonnenfeld, 2023).for a rationale of design principles and instructional features for XR simulations based on episodic memory: [Supplemental-Material\\_23396.pdf](#)

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