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Artificial Cognitive Systems and Aviation Training

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ABSTRACT

The research objectives are to (1) provide a complete assessment of extended reality technologies and (2) discuss the viability of these technologies for use in US college aviation training programs. The field of educational services is one of the many that can benefit from utilizing extended reality technology due to its versatility. Learning and general performance of student pilots and flight trainees can benefit from applying extended reality technologies in flight training, which can be advantageous when using these technologies. We examine the utilization of XR technologies by looking at them from an educational theoretical framework and analyzing their applicability across several industries and simulations in Purdue Artificial Intelligence Laboratory. A comprehensive literature review resulted in four subtopics, which are as follows: educational theoretical foundation, XR technologies across industries; XR technologies in education; and XR technologies in aviation. Results show that the use of XR technologies has the potential for enhancing learning and performance in safe flight instruction environments, a possible reduction in student pilot turnover mainly due to the elimination of the fear factor involved during initial training when compared to flying in the actual airplane, and an overall low cost for both flight training organizations and trainees due to the high levels of portability. These findings led us to propose using XR technologies as having the potential to enhance learning and performance in safe flight instruction environments. A comprehensive understanding of the possibilities offered by XR technology is necessary for the continuation of aeronautical psychology research offered at Purdue AI laboratory.

Keywords: XR technologies, Education, Artificial intelligence, Psychology research

INTRODUCTION

Kaplan *et al.* (2020) reviewed the available extended reality (XR) technologies and their effectiveness as training tools. They noted that XR technologies are particularly advantageous for training in situations where hazards or cost prevents the utilization of traditional, hands-on training. This study aims to present a selective collection of current literature on XR technologies as a preliminary document for conducting research on the applicability of XR technologies as viable alternatives to, or supplemental to, hands-on flight instruction. The purpose of this study is twofold: (a) conduct a literature review of the current state of XR technologies and their application to instruction and (b) determine the challenges and opportunities to the application of such technologies in collegiate flight instruction programs. The first part of this study will focus on three distinctive correlated aspects of the literature review. Firstly, this study provides a review of foundational learning theories from a broad educational perspective across the full spectrum, although not exhaustive. Then, it reviews some of the related learning theories within the context of emerging technologies for instruction found in current literature. This first part then ends with a final literature review that is specific to current literature related to the technical aspects of XR technologies, their strengths and weaknesses, and specific challenges and opportunities associated with their use in education as instructional tools. The second part of this study will focus on the literature associated with the application of XR technologies that are specific to the flight instruction environments.

XR technologies have in recent years seen a rapid increase in their use across many industries where novel XR applications are constantly being developed for a wide variety of reasons and applications. Ariso (2017) describes XR technologies as gaining great relevance in fields such as "robotics, engineering, education, entertainment, manufacturing, medicine, archaeology, tourism, the military or urban modeling, among others.". From its initial birth as a technology in the 1960s to a relative time of "silent" in the first decade of the 21st century, XR technologies seem to be an aggressively pervasive constant everywhere. Three important factors have been largely identified as being responsible for this current trend, those being, the advance of technology in general terms around the world, accessibility to the technology due to novel and more robust networks of communications on a global scale, and cost of acquisition of the technology itself (Wohlgenannt *et al.*, 2020). While most XR technologies' applications have been focused on operational tasks in their respective industries, XR technologies are starting to show promising applications in training and learning; however, such applications may be ahead of appropriate theoretical foundations and rigorous assessment of their effectiveness, thus the reason for this study. Firstly, from within the overall perspective of the current educational frameworks being used, and their stand and levels of adaptability on the adoption of emerging technologies for educational purposes, where the psychology of man-machine interactions is still undergoing the process of being understood. Second, from a human factors perspective in aviation and the impact of new emerging technologies, specifically XR technologies. And finally, from a perspective that requires a consistent approach regarding newly adopted roles being played by humans because of technological advances and human interaction with novel technologies in a wide variety of human factors' domains. For instance, Mosier and Fischer (2010) explain that the role of operators has evolved from one which was characterized mainly by sensors and motor skills to one that now delves more into cognitive skills and decision-making processes.

Theoretical Foundation Foundational Learning Theories

Rushby and Surry (2016) explain that it took several years of deliberation before The Association for Educational Communications and Technology (AECT) through its Definition and Terminology Committee came to a final

Table 1. A supportive literature review by topic.

Relevant Contextual Areas (XR)	Paper/Book/Conference
Education- Theoretical Foundation	10
XR Technologies- Across Industries	23
XR Technologies in Education	20
XR Technologies in Aviation	10

consensus on a single-sentence definition of educational technology: "Educational technology is the study and ethical practice of facilitating learning and improving performance by creating, using and managing appropriate technological processes and resources" (Rushby and Surry, 2016). In a review of key papers related to education theories, Gottlieb *et al.* (2017) point out several correlated key aspects of educational environments in education, as part of a faculty incubator program within Emergency Medicine academic education. One of those key aspects relates to how educators often hypothesize about the optimal strategies for teaching while making assumptions that may not always be valid or reliable for what is to be the most efficient pathway to learning. A loud complaint resonates throughout the above-referenced article, regarding how often many academic faculty members, who happen to be educators, lack sometimes familiarity with key education theories, for a better-informed practice (Gottlieb *et al.*, 2017). McInerney (2005) argues that there is a need for establishing a strong link between educational psychology theorizing, research, and teaching-learning processes, in the development of what is to be considered best practices. McInerney (2005) goes on to express that the framing of context and limitations in time for educational constructs is an important practice since in the past other practices have not endured the test of time, have been misguided, or were simply generated upon flawed research. McInerney (2005) explains that such practices have also undergone major transformations. It would only be reasonable to continue to explore and adopt relevant applications that as in the past, have allowed us to better understand our nature across different epochs according to the context in time. In a book written in 1976 called Foundations of Lifelong Education: Some Methodological Aspects, Dave (1976) provides a wonderful capsule time while explaining the significance of the new idea of lifelong education. When placed into our context today, it does sound like a repeat of what the world had already experienced some 45 years ago. Another interesting interpretation centered around the learner-centered model, coming from a broadly comparative international education perspective, is the one described by Michele Schweisfurth in her book called Learner-Centered Education in International Perspective: Whose Pedagogy for Whose Development? In it, Schweisfurth (2013) explains that how humans learn is a mix of an individual's cognitive physiology, and how that individual has learned to learn during formative years. Furthermore, it is argued that human learning is also the product of "policy choices that shape the education we experience, and the practice of the teachers who influence us" plus any contextual realities involved (Schweisfurth, 2013).

XR Technologies Learning Theories and Emerging Technologies

According to Rotolo *et al.* (2015), five specific attributes must be identified to properly define what is to be considered an emerging technology. More specifically, an emerging technology must present a radical novelty, relatively fast growth, coherence, prominent impact, and uncertainty and ambiguity. Special attention is to be observed on two of the attributes that emerging technologies such as XR technologies present; namely, their prominent impact and grade of coherence across applications and their possible uses. Educational goals in general, are considered as being relatively stable in terms of shifting from the specific emphases they procure (Yawson, 2013). Important issues such as the development of critical thinking skills, problem-solving, and lifelong learning capabilities remain for the most part constant, regardless of the models, methodologies, or set of tools being used (Yawson, 2013). The prominent impact and coherence of emerging technologies as Rotolo *et al.,* (2015) explains, are both crucial aspects for present and future assimilation, and further development of not only the theories involved but also their applicability within the education sector. Emerging technologies are also defined as "tools, concepts, innovations, and advancements utilized in diverse educational settings to serve varied education-related purposes" (Veletsianos, 2010). From that perspective, Czerkawski (2013) expresses that these emerging technologies do not necessarily facilitate or advance any of the learning processes, instead, it is the integration of teaching strategies, and the incorporation of appropriate methodologies being applied in the learning processes, that do. Overall, emerging technologies are, however, disrupting patterns of teaching and learning that have dominated higher education for many decades, if not centuries (Johnson *et al.*, 2015). Two important technology trends are responsible for driving these changes; on one hand is the unprecedented wave of private investment in classroom technology (Burch and Good, 2014), and on the other, the rising public interest in lowering education costs and improving student achievement. An interesting approach for better coping with emerging technologies within the context of educational environments, that appears best suited when compared to existing models, is the heutagogical approach. Cook and Gregory (2018) argue that learning requires believing in the assumption that learning should never be considered a complete full circle through the glass of what educators do, the technologies used, or how one communicates knowledge to students. In exploring the literature related to different models of learning such as that of andragogy, a student-centered approach (Knowles, 1988), transformative style learning approaches (Daily-Hebert & Dennis, 2014), and the heutagogical approach to learning (Hase and Kenyon, 2013), several aspects came to light concerning the adoption of newly emerging technologies.

Extended Reality Technologies Across Industries

In gathering the literature review related to XR technologies, a solid and growing trend of the theoretical foundation for its different uses and applications was found across most industries. For instance, Aguayo et al. (2021) explain the impact that XR technologies are having in areas such as that

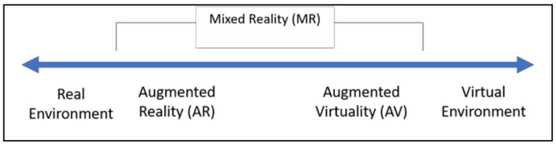

Figure 1: Extended Reality (XR) Full Spectrum of Technologies. Note: "3D telepresence for remote collaboration in extended reality (XR) application" by Fadzli, F. E., Kamson, M. S., Ismail, A. W., & Aladin, M. Y. F. (2020).

clinical simulation, paramedicine, and healthcare education. Anderson et al. (2021) comment on the broad adoption of XR technologies in engineering and design, where the utilization of virtual reality for product design and assembly has been widely explored through the development of virtual versions of physical hardware which, has demonstrated high levels of utility in the design process. Bailenson (2018) author of the book Experience on Demand describes the power behind XR technologies through applications of virtual reality in sports, trauma, and rehabilitation and the profound ways in which XR technologies can be used. Another relevant area of interest where XR technologies are having a profound impact is architecture. Alizadeh Salehi *et al.* (2020) discuss how construction project simulations in multidimensional digital models while presenting multiple aspects of a project are assisting architects throughout all stages of projects. Fadzli et al. (2020) observe how XR technologies are enhancing capabilities such as those of 3D telepresence in remote collaborations, where mixed reality, a distinctive element within the full spectrum of XR technologies has been found capable of providing interactions between users in the real world while still maintaining images and communication between users and the virtual world.

Extended Reality Technologies in Education

XR technologies have been in use for training purposes across a wide spectrum of industries for many years. More recently, XR technologies are showing a wider implementation although in its early stages, for training purposes by the military and in aviation training. In the greater context of the global impact that emerging XR technologies applications across industries represent, is that of the role being played by some powerful enablers at play. Enablers such as machine learning, AI, predictive analytics, quantum computing, and other technologies have a powerful impact on the design, development, and implementation of XR technologies across a broad spectrum of contexts. In essence, the current and future way in which most everything is and will be taking place at a global scale can be at hand. The related implications for the aviation industry in terms of pilot training, require our full attention moving forward. As of 2018 for instance, Boeing has been experimenting and working in several use cases in this space, including the building, repair, and maintenance of commercial and military aircraft, and pilot training for vehicle and device operations (Laughlin, 2018). An important aspect of recent advances in XR technologies is the dramatic reduction in overall costs associated with many areas of training when

Top Hierarchy	Design Requirements		Physical Requirements		Interface Requirements		Implementation Requirements	
Facets	Educational Purpose	Type of Experience	Delivery Technology	Back-End Technology	User Interaction	System Interaction	Production Technology	Type of Gamification
Categories	Training Teaching Observing	Virtual Reality Augmented Reality Display	Screen Head Mounted Display	Stationary Mobile Cloud	General Purpose Controller User Tracking Specialized Controller No Interaction	Dialog System Intelligent Agents No Interaction	Modeling Cinematography	Reward Based Serious Games No Gamification

Figure 2: "Taxonomy of Virtual and Augmented Reality Applications in Education" by Motejlek, J., and Alpay, E. (2021).

compared to other systems currently in use. The adoption of virtual reality in flight simulation into the training curriculum for the certification of new pilots is perhaps one of the best examples of how costs can be reduced. According to Laughlin (2008), some positive preliminary results suggest that training costs for new pilots could be reduced by as much as 70% when student pilots learn and practice fundamental piloting skills remotely, due to a reduction in the amount of time a student pilot spends training in a full-motion simulator. Ryoo and Winkelman (2021) report that XR technologies have been identified as key emerging technologies in education. XR resources are being praised as having capabilities for enhancing instruction and learning experiences in different environments which extend outside of the common classrooms (Ryoo and Winkelmann, 2021). However, the real power behind XR technologies is in their perceived capability for providing a seemingly solid foundation for the incorporation of new types of learning environments and experiences. A paradigm shift in terms of traditional instructional methodologies in use. Another portrayed advantage exists in its inherent ability to create unique communities of inquiry and practice (Ryoo and Winkelmann, 2021). Ziker et al. (2021) state that early evidence exists in interactions with XR applications as being effective in corporate training environments, reaffirming what Maxwell and McLennan (2012) had found, which suggested that adult learners experience enhanced transfer, possibly due to being able to experience training where immediate real-world applications are being provided. Although researchers are still in the initial stages of discovering and understanding how the full power of XR can be optimized, the future expectations of a wide array of possibilities for use in educational environments are encouraging (Ziker *et al.,* 2021). Bailenson (2018) brain studies have provided evidence on early data pointing to the fact that the brain is made to believe that while in training, XR activities experienced are happening, rendering internal biochemical changes of learning at par with real experiences in the physical environment. Motejlek and Alpay (2021) provide a taxonomy of virtual and augmented reality applications in education (see Fig. 2) across different facets and categories, from the design to the implementation requirements of the methodologies and technologies recommended for use.

Extended Reality Technologies in Aviation

The present and future use of XR, more specifically, VR training currently being conducted within the context of aviation for training purposes is

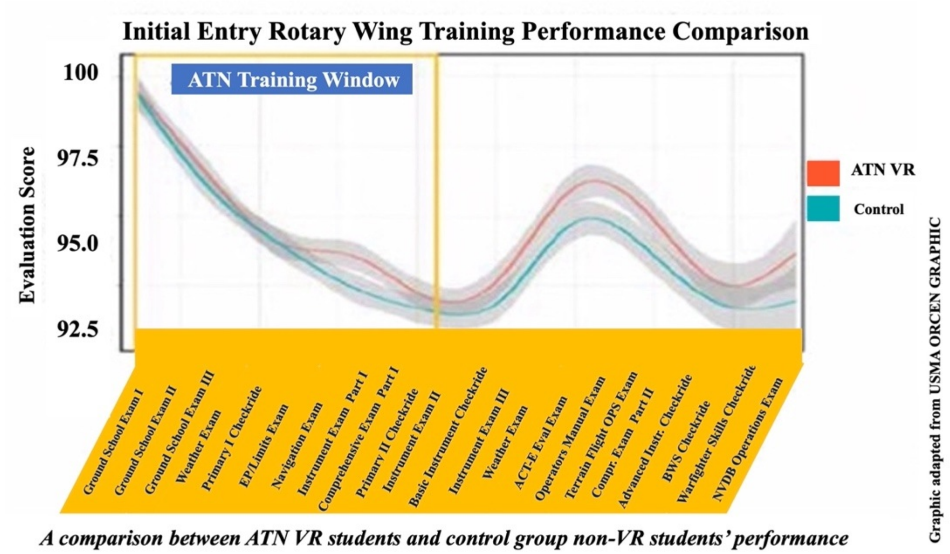

Figure 3: "Initial Entry Rotary Wing Training Performance Comparison" by ARMY AVIATION (2020). Training Army Aviators...today and tomorrow, July 31, 2020, Vol. 69, *No. 7.*

promising. Ongoing and recent experimental training conducted by US military personnel (USAF, 2021) is showing some positive and relevant insight into the world of virtual reality training for aviation training. The Airforce has found for instance that, "experimental virtual reality fighter pilot training is working best for students who want to fly the service's most advanced stealth platforms" (USAF, 2021). The US Army through an "Aviator Training Next" experiment that sought to determine if low-cost, low-fidelity commercial-off-the-shelf virtual reality (VR) technologies could be used effectively to train pilots, reported that during the initial phase of flight training for several classes with 296 students using VR devices (See compiled data in Fig. 3), enough evidence was found which indicates that Aviator Training Next (ATN) is a valid training methodology, and continued research is to be expected to better understand the adaptability of the technology into other areas of training (ARMY AVIATION, 2020). Alaska Airlines is perhaps the most recent major airline anywhere in the world to announce its adoption of virtual reality technology for training purposes (VRPILOT, 2022). Alaska Airlines' Managing Director of Flight Operations Training explains that in most recent training settings for Alaska Airlines "pilot's basic training typically goes from learning in a classroom to half simulations, then graduating to a full simulation before getting into a real plane" (K5, 2022). With VR however, "now the virtual reality (VR) is being introduced in the first part of textbook training", which in essence has incorporated not only a new technology into its training, but also, an applied educational paradigm shift for training purposes in aviation.

The aviation industry has been a pioneer in the development and adaptation of simulation capabilities that have been profusely utilized across many aviation training environments. However, this has not been the case in terms of XR technologies' applications. Surely there are several factors at play, which are determinants in the perception and adoption of XR technology in education, in general. It is also very likely that many other factors would have to be added to the list on the use of XR technologies in aviation training environments, especially, in aviation training collegiate programs. In prompting the suggested research around XR technologies, our intention is in adding to the current literature and studies that are taking place today, since solutions for furthering the advancement in learning processes and performance related to aviation training are possibly just waiting to be discovered and within reach. A better understanding of the capabilities and possible applications of XR technologies is required. The innate requirements related to safety, and the provision of the best possible training in aviation since its early days for enhancing learning processes and overall performance, demand a more focused and systematic approach to be in place. At Purdue University, and through its Center for Aviation Research and Education (CARE), embracing emerging technologies such as VR for aviation training in its search for developing better solutions that provide flight training that constantly meets the requirements of present and future generations of pilots is a constant and a pivotal point, both. Purdue's aviation ecosystem which includes cross-collaboration around the globe, with stakeholders in academia, the military, governments, and the aviation industry at large, sustainability of the world's aviation "ecosystem" through discovery and innovation is the main focus. A big part of such effort and essential importance is the ability to recognize associated challenges related to XR technologies. One of many challenges is the relative lack of understanding regarding the potential uses and benefits these technologies signify, more specifically, those related to education and training. A truly critical steppingstone in the dynamic environment in which aviation training takes place. Technology diffusion is one of several theories that has been studied for decades and several other prominent theories, including the diffusion model (Rogers, 1962), the technology acceptance model (Davis, 1989), and the technological pedagogical and content knowledge model (TPaCK) (Mishra & Koehler, 2006), which have been explicitly developed to explain the conditions necessary for educators to integrate new tools into their teaching set of tools, it is surely a critical element applicable to the aviation training environment as well. A holistic understanding of these models has helped over the years, in "demystifying" the process of learning for the successful adaptation of new technologies by professors, designers of professional development, university faculty, and researchers in the scholarship of teaching and learning (Sutton and DeSantis, 2017).

CONCLUSION

Lastly, and in looking at the global issue that the aviation industry has been suffering through without an immediate solution in sight, that of a pilot shortage, one possible and unexpected solution to the problem is virtual reality (VR). Recent studies show that VR training in aviation has emerged as an effective learning modality (AIN ONLINE, 2022). The consulting firm "Price Waterhouse Cooper released a study in June 2021 that showed VR learners mastering content four times faster than in a classroom setting" (AIN ONLINE, 2022). Even with such evidence being available today, the need for an appropriate theoretical foundation and a standardized (certifiable) methodology for the review of current and newly emerging XR technologies is needed. Further studies and research are necessary to include experimental testing of various types/levels of technologies and their effectiveness in corresponding levels of learning and performance for flight instruction. Furthermore, specific advantages and barriers in terms of learning effectiveness, cost, and time are also in need of being assessed. More specifically, and within the context of this paper, collegiate flight instruction programs should follow a "flight path" that is more in line with the industry as an integral part of the natural development of novel emerging technologies in aviation as drivers of change, for both, the military and civilian sectors. Moving forward, a new framework model is required, for determining the relevancy, specific applicability, and rightful place of such technologies for aviation training purposes.

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