Immersive Aviator Training Design Inspired by the Science of Learning

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ABSTRACT

Due to advances in immersive technologies' realism and affordability, military pilot training curricula continue to incorporate more immersive tools. These immersive technologies are often used as pre-training for more costly operational flight trainer and flight events. The U.S. Air Force and Navy established Pilot Training Next and Naval Aviation Training Next, respectively, to integrate additional virtual reality and extended reality systems into training curricula. Initial studies indicate immersive training devices are effective early training tools and enhance live flight performance. While initial results show the potential of immersive training, cognitive psychology studies conclude that massed and blocked practice are less effective than other methods for long-term retention. Analysis of the integration of immersive training devices through the science of learning may yield increased efficacy and efficiency in aviation training. This paper explores the application of multiple immersive technologies in two distinct phases of military pilot training: undergraduate jet training and FA-18 Super Hornet replacement aircrew training. This paper first discusses immersive training technologies such as immersive content, traditional operational flight trainers, virtual and extended reality flight simulators, and live, virtual, constructive (LVC) environments. Second, the science of learning will be explored through cognitive psychology, instructional systems development, and learning experience design (LXD) to understand the strategies and development of successful learning. Finally, the paper will present a framework to apply the science of learning to align educational and instructional objectives, incorporate effective learning strategies, and integrate immersive training technologies to create environments for aviators to learn the skills required to operate tactical military aircraft. This framework can be applied across platforms and services to refine military aviator training and integrate emerging immersive technologies to produce effective results. Military aviator training cannot fully realize the value of immersive technologies unless the instructional design incorporates the learning experience and science of learning.

ABOUT THE AUTHORS

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The creation of the Link Trainer in 1929 marked the beginning of immersive technologies designed for pilot training. New technologies such as advanced flight simulators, virtual reality, and live, virtual, constructive (LVC) environments are tools available to increase training efficacy and efficiency. Training curricula often use immersive technologies as one-for-one replacements or pre-trainers for traditional airborne instruction. However, the full value of immersive technology can only be realized if properly implemented into training curricula. A thorough understanding of cognitive psychology, learning theories, and instructional design provides insight into the appropriate application of immersive technologies in military pilot training curricula.

Fighter pilot manning is a persistent and cross-service issue. In 2022, the U.S. Navy shortage was approximately 100 fighter pilots, and the U.S. Air Force shortage was approximately 1,100 fighter pilots (Everstine, 2022). While retaining qualified pilots remains a separate issue, prolonged training of tactical jet pilots delays entry to initial tours and creates potential negative consequences for career timing and leadership tours (Seech & Natali, 2022, p. 9). Data from May 2021 to April 2022 showed that the average time to train an FA-18 Super Hornet pilot from pre-flight indoctrination to completion of FA-18 replacement aircrew training was 4.5 years (Seech & Natali, 2022, p. 10). The application of immersive technologies should not be viewed as purely a means to reduce time-to-train and cost but rather to create training curricula using available technology and the science of learning to achieve the same student performance with fewer resources.

During a panel discussion at I/ITSEC 2021, Rear Admiral John Meier, Commander of Naval Air Force Atlantic, stated, “The cost per flight hour is pretty staggering, the cost to maintain our aircraft is staggering, and one of the areas that I’ve got a laser dot on is, how can we reduce some of that flying hours and increase more on the simulation side?” (Eckstein, 2021). Rear Admiral Meier also discussed Strike Fighter Squadron ELEVEN’s (VFA-11) training and use of simulators which resulted in a kill-to-death ratio 2.5 times greater than comparative strike fighter squadrons during its five-week carrier air wing training in Fallon, Nevada. During a personal interview with Commander Matthew Enos, the Executive Officer of VFA-11 during that training, he affirmed, “The squadron used much of its free time executing fundamentals in the simulators. We practiced the basics to create habit patterns, making the time in the plane even more effective.” VFA-11 had resource, personnel, and time constraints similar to other squadrons yet achieved greater success. This paper frames the training and methods to achieve effective results in naval aviation training.

This paper explores the application of multiple immersive technologies in two distinct phases of military pilot training: undergraduate jet training and FA-18 Super Hornet replacement aircrew training. In order to narrow the discussion, this paper will highlight applications to U.S. Navy strike fighter training; however, other services and communities can apply the same principles to their training curricula. This paper first discusses immersive aviator training technologies such as immersive content, operational flight trainers, virtual reality flight simulators, and LVC environments to increase training opportunities for military aviators of all experience levels. Second, the science of learning will be explored through cognitive psychology and instructional systems development to understand the strategies and development of successful learning. Finally, the paper will present a framework to apply the science of learning to align educational and instructional objectives, incorporate effective learning strategies, and integrate immersive training technologies to create environments for aviators to learn the skills required to operate tactical military aircraft. Just as the advantages of new aircraft and weapons are not fully realized without tactics, the benefits of immersive technologies are not reached without carefully considering the training objectives, required skills, and instructional design.

IMMERSIVE TECHNOLOGIES FOR AVIATOR TRAINING

Over the past twenty years, immersive technologies for military aviator training have vastly improved from locally networked operational flight trainers to distributed network simulations and environments. In addition, virtual reality technology progressed to provide a cost-effective training means, and simulation environments can now meld live and virtual entities. Immersive technologies available today and in the near future will be discussed in order to understand the capabilities and limitations of their use in aviator training.

Immersive Content

360-degree and interactive videos are two forms of immersive content that may provide effective training to aviators. 360-degree videos can take pilots into the cockpit virtually to observe previous training events such as formation flight, aircraft carrier operations, landing patterns, and local airfield course rules to build situation awareness for future training. Similarly, several collegiate and professional American football teams integrate STRIVR's virtual reality system into their training programs for players to learn plays, analyze formations, and review game footage; however, research must still be conducted to provide evidence of performance impacts. A review of 12 research articles on the effectiveness of 360-degree videos compared to two-dimension videos used in education found that while users indicated high levels of interest and engagement, results were mixed on the actual impact on learning (Snelson & Hsu, 2020, p. 410). While results were mixed, 360-degree videos are relatively low-cost to produce and allow users to experience all aspects of dynamic flight environments. Therefore, evidence suggests that immersive content should not replace traditional instructional methods but may be used as additional resources for students to review procedures practiced in simulator and flight events.

Operational Flight Trainers

Most military aviator training programs use Operational Flight Trainers (OFTs) for high-fidelity simulator training. These devices typically include fully-functional replica cockpits, 270-degree projected visuals, accurate flight characteristics modeling, and an instructor station for scenario control. Similar systems for combat aircraft are typically referred to as Tactical Operational Flight Trainers (TOFTs), which can network with other TOFTs for multi-ship training. OFTs and TOFTs provide high-fidelity flight simulation with acquisition and operational costs at a fraction of live flight training. Additionally, instructors can create training scenarios for various geographic locations, weather, and time of day, against various threats with no actual aircraft mishap safety concerns. Due to the proliferation of virtual reality systems, many of the traits of OFTs are now available in smaller, lower-cost flight simulators commonly referred to as Immersive Training Devices.

Immersive Training Devices

The U.S. Air Force's Pilot Training Next and the U.S. Navy's Naval Aviator Training Next use multiple technologies to revolutionize aviator training. The most innovative technology is the Immersive Training Device (ITD), built from commercial off-the-shelf (COTS) components, including a computer, monitor, gaming seat, VR headset, control stick, throttle, and rudder pedals (see Figure 1). ITDs' smaller footprint of approximately 36 square feet and relatively lower cost of approximately $50,000, compared to OFT's initial cost of over $2 million, allow for the acquisition of greater numbers and permit greater availability for self-guided practice when not in use for syllabus events (Severe-Valsaint et al., 2021, p. 9). ITDs were first integrated into Pilot Training Next in 2018 for use with the T-6A Texan II and later integrated into Naval Aviation Training Next's Project Avenger for use with the T-6B Texan II in 2020. While Pilot Training Next has yet to integrate ITDs into T-38 Talon jet training, Naval Aviation Training Next's Project Corsair integrated ITDs into T-45 Goshawk undergraduate jet training. Beyond undergraduate flight training, the 355th Training Squadron incorporated ITDs into A-10 Thunderbolt II initial training, providing pilots with 22 more simulators in addition to four OFTs (Trevithick, 2021). While simulators can reproduce the visual, tactile, auditory, and cognitive aspects of flight, they cannot replicate the high g-forces associated with strike fighter maneuvering. Live, virtual, constructive environments seek to exploit the efficiencies of computer-generated entities in live flight training.

Figure 1. T-6B Immersive Training Device

Live, Virtual, Constructive Environments

Live, virtual, constructive (LVC) environments link live and virtual participants with constructive entities. Live participants are actual platforms such as fighter aircraft, bomber aircraft, command and control aircraft, surface command and control platforms, and adversary aircraft. Virtual participants are human-in-the-loop simulation systems typically operated by personnel trained in the platform. Constructive entities are computer-generated agents either controlled by models or with basic inputs by personnel during the training event (Best & Rice, 2018, p. 60). LVC entities can be orchestrated to participate as either friendly, adversary, or neutral forces and positioned as desired for the training event. LVC environments can provide numerous benefits, such as virtual and constructive entities operating outside airspace boundaries, increased number of adversary assets, simulated electronic attack, and simulated attrition of enemy systems (Neville et al., 2015, p. 85). The advantages are appealing; however, bandwidth, platform integration, and multiple levels of classified information exchange present challenges to universal use (Best & Rice, 2018, p. 63). Additionally, aircraft sensors do not physically detect virtual or constructed entities; therefore, live participants may observe unrealistic sensor detection and tracking of adversary aircraft and cannot visually engage them at close range. The U.S. Air Force and Navy demonstrated a joint-service LVC environment using Secure Live Virtual Constructive Advanced Training Environment (SLATE) with externally mounted pods to integrate the LVC environment into aircraft software in 2018; however, the system has yet to reach operational capability (Hunter, 2022). An LVC environment currently in use is the Navy Continuous Training Environment (NCTE), which U.S. Navy surface and aviation assets use for unit-level and large force training (see Figure 2) (Ball, 2021).

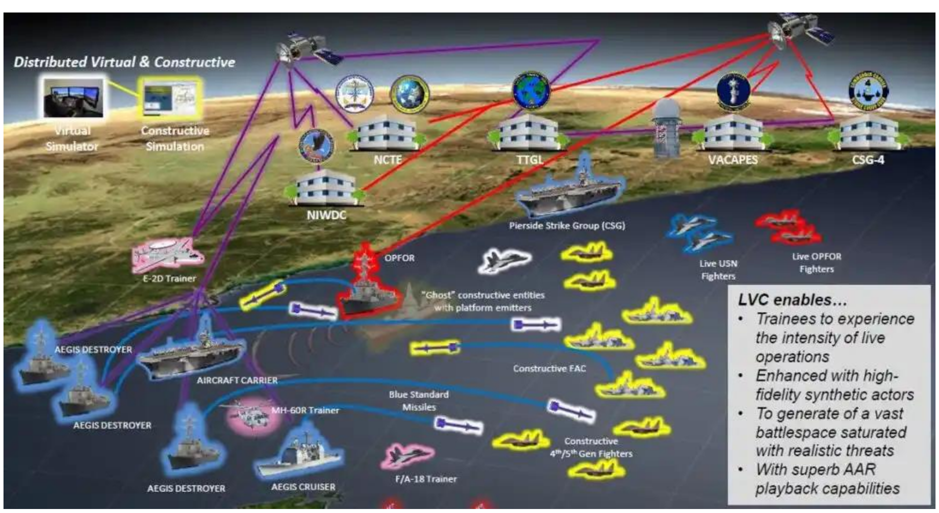

Figure 2. Navy Continuous Training Environment (NCTE) Overview

THE SCIENCE OF LEARNING

Before implementing new technologies into curricula, institutions should leverage research on effective learning. The science of learning is an interdisciplinary field focused on teaching and learning, including cognitive psychology, neuroscience, education, instructional development, and design studies (Sawyer, 2008, p. 1). This section explores cognitive psychology, educational objectives, and instructional systems development to build a framework to analyze training curricula.

Cognitive Psychology

Applying cognitive psychology to training curricula is critical to understanding and creating effective means of learning. Cognitive psychology is the study of the inner mental processes that occur between the stimulus, or input, and the behavior, or output. Learning is often misunderstood; students and instructors alike form perceptions of effective learning techniques based on personal experiences. Massed and blocked practice are some of the least productive learning strategies and fail to produce true mastery or durable learning (Brown, 2014, p. 3). It is a common belief by students and instructors that focused and repetitive practice is effective, as evidenced by quick gains; however, those gains are transitory and quickly fade (Dunlosky et al., 2013, p. 39). Cognitive psychology relies on empirical research to define and confirm learning strategies. Through these studies, cognitive psychologists identified that some of the most effective strategies for effective learning are interleaving, spacing, and retrieval practice which share the common trait of introducing difficulty into the learning environment (Brown, 2014, p. 3).

Desirable Difficulty

Conditions that increase difficulty make learning more effortful and increase long-term retention (Roediger & Karpicke, 2006, p. 199). While studies show that difficulty increases long-term retention, instruction should aim for desirable difficulty through the regime of competence and zone of proximal development. The regime of competence refers to a degree of difficulty that is challenging yet feasible to accomplish. Learning that continually pushes learners to the edge of their regime of competence is exciting and rewarding, whereas learning that occurs well outside their regime of competence can be too difficult and cause frustration (Gee, 2008, p. 70). The zone of proximal development is the area between the actual developmental level, what a student can execute independently, and the potential developmental level, what a student can execute with guidance (Vygotsky & Cole, 1978, p. 86). Difficulty introduced outside of the regime of competence or potential developmental level will likely impair learning. Interleaved practice introduces desirable difficulty by varying the tasks to be learned.

Interleaved Practice

Popular belief is that students should use blocked practice to master a single skill and then proceed to the next skillset; however, interleaving the training of two or more subjects strengthens mastery and retention (see Figure 3). Blocked practice may be required for initial learning, but additional practice should be interleaved to produce durable learning (Roediger, 2013, p. 3). Interleaving tasks and varied conditions have been shown to impair initial performance in training but enhance long-term performance (Bjork, 1994, p. 189). For example, in a 2016 study, students that interleaved practice solved 60 percent of problems correctly compared to solving 89 percent of problems in the group that blocked practice; however, during a test a week later, the students that interleaved practice performed 215 percent better than their blocked practice counterparts (Rohrer & Taylor, 2007, p. 492). In a 2001 study, interleaved practice produced slightly slower acquisition of motor skills but vastly improved performance a week later compared to blocked practice (Simon & Bjork, 2001, p. 911). Additionally, the study found that interleaved practice participants underestimated their performance while blocked practice participants overestimated their performance, showing learners' bias toward blocked training despite its actual effectiveness. While interleaved practice initially produces slower gains, the effortful learning creates long-term retention. Interleaved practice also inherently benefits from spacing, which allows time between retrieval.

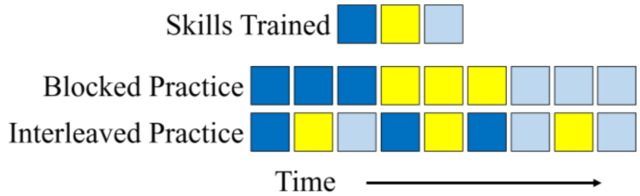

Figure 3. Blocked versus Interleaved Practice

Spaced Practice
Military training often attempts to increase time efficiency through repetitive massed practice; however, spaced practice is shown to be more effective for long-term retention (see Figure 4). A meta-analysis of 29 studies indicated a strong benefit (g = 0.74) from spaced retrieval practice compared to massed retrieval practice (Latimier et al., 2021, p. 959). Massed practice rapidly builds competency but focuses on short-term memory, whereas long-term memory is formed through memory consolidation, which occurs hours to days after instruction (Brown, 2014, p. 49). The time between retrieval increases consolidation, enabling stronger learning. While consolidation can occur for hours and days, students should revisit material before it must be relearned. Retrieval practice through self-testing, such as flashcards or quizzes, and instructor-led assessments can be an effective means of spaced practice while also benefiting from the testing effect.

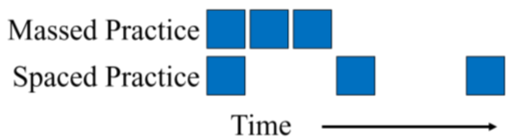

Figure 4. Massed versus Spaced Practice

Testing Effect
Retrieval practice and corrective feedback support learning by multiplying the neural routes to recall information later, strengthening learning retention, and calibrating learners to areas that require improvement (Brown, 2014, p. 43). Known as the testing effect, retrieval through testing creates effortful and deeper encoding and promotes long-term retention (Roediger & Karpicke, 2006, p. 199). Retrieval practice builds strong connections to materials to increase retention even without re-exposure. Feedback is a critical portion of the testing effect to ensure learners recall the correct information and to amend illusions of knowing the material. Because immediate feedback on each action or answer prevents a pattern of performance, the learner can become dependent on continuous corrections. Delayed feedback may initially appear counterintuitive, but it allows the learner to recall information as they would in the real world without correction. Like removing training wheels on a bicycle, delayed feedback requires the entire retrieval process and produces better results than immediate feedback. Studies show the importance of testing, but it is essential that the assessments are aligned with the educational objectives.

Bloom's Taxonomy of Education Objectives

Published in 1956, *The Taxonomy of Educational Objectives, The Classification of Educational Goals, Handbook 1: Cognitive Domain*, commonly known as Bloom's Taxonomy, is often used as the framework for education and learning. In 2001, a group of cognitive psychologists, curriculum theorists, instructional researchers, and testing and assessment specialists published a revision titled, *A Taxonomy for Teaching, Learning, and Assessment* to "refocus educators' attention on the value of the original" and to "incorporate new knowledge and thought into the framework" (Anderson et al., p. XXII). The revision updated the taxonomy to two dimensions: cognitive process and knowledge. The taxonomy defines the six categories of the cognitive process dimension as remember, understand, apply, analyze, evaluate, and create. The four categories of the knowledge dimension are factual, conceptual, procedural, and metacognitive. This taxonomy can be used to inform the curriculum, instruction, and assessments to achieve the desired learning objectives. The curriculum, instruction, and assessments must be aligned to ensure that instructors teach the intended information and that assessments reflect the desired objective (Anderson et al., 2001, p. 10).

Objectives can be classified as global, educational, and instruction, each becoming more specific. A global objective provides a vision and often takes years to attain. An example of a global objective for undergraduate jet training may be to safely operate an aircraft in various environmental conditions and specific strike fighter missions. Educational objectives focus on a curriculum of weeks or months. An example of an educational objective may be to safely operate an aircraft in formation flight. Finally, an instructional objective is narrow in scope to facilitate a specific lesson or event, such as to safely join the lead aircraft and maintain parade position.

The taxonomy integrates and aligns the objectives, instruction, and assessments. First, the objective must guide the instruction. When exercises and events do not align with the objective, students may not achieve the desired results. Additionally, instructors should not frame the objective as the instructional activity (Anderson et al., 2001, p. 243). For example, the instruction should focus on how to analyze and respond to inflight emergencies rather than demonstrate emergency procedures. Assessments can be categorized into formative, to evaluate learning to adjust instruction, and summative, to measure student performance. Similar to instructional alignment, the curriculum must align assessments with objectives to ensure assessments reflect the effectiveness of instruction and learning. (Anderson et al., 2001, p. 233). This framework can be used in conjunction with instructional systems development to achieve the desired learning objectives.

Instructional Systems Development (ISD)

The systematic approach to instructional design began during World War II when psychologists and educators researched the most effective means to train large numbers of recruits. In 1975, Branson et al. published *Interservice Procedures for Instructional Systems Development* for the U.S. Army Combat Arms Training Board, outlining a five-phase model to design and create instruction. The five phases originally consisted of analyze, design, develop, implement, and control. In the late 1980s, Grafinger and Rossett both referenced the last phase as evaluate, which eventually became universally adopted. The ADDIE model is now the most widely used process for instructional systems development.

ADDIE Model

The ADDIE model contains five phases and 19 blocks with the goal of developing instructional systems. The first phase, analyze, intends to define the tasks required for instruction, performance standards, complementary or redundant courses of instruction, and the desired instructional setting. The design phase focuses on identifying the required steps, sequence, and assessments to achieve the terminal learning objective, previously referred to as the educational objective by Anderson et al. The third phase, develop, aims to classify learning objectives to identify and create the appropriate means to deliver instruction. The implement phase discusses the procedures to ensure instructors, resources, facilities, and managers are prepared to conduct training. The final phase, evaluate, is designed to identify areas to improve the students' learning through internal and external feedback. These five phases present a model to explore the use of immersive training devices viewed through the lens of instructional systems development to provide systematic, cohesive, and effective training.

Learning Experience Design (LXD)

Learning experience design (LXD) is the process of creating a learning experience focused on the student achieving the desired objective. While similar to instructional design (ID), LXD takes a human-centered approach and concentrates on the learners' experience. According to Clark, "learning is the primary goal, selecting the right experiences the means to that end and design the process of creating those experiences" (2017, p. 1). LXD emphasizes the emotional response to the learning experience, often increasing attention and motivation. LXD intends to create a positive and meaningful learning experience, yet it is essential to incorporate the science of learning. An instructional system purely based on the learners' desires may not include strategies such as spacing and interleaving, which are known to produce effortful, durable learning. Clark states that "what matters is not the experience but what remains after the experience in memory and behavior" (2017, p. 7). LXD may include several techniques to engage learners in challenging experiences to accelerate learning.

Techniques such as chunking, assessments, and feedback can lead to effortful and successful learning. Working memory only lasts about 20 seconds; without time to process and encode, information will not be retained in long-term memory (Clark, 2017, p. 121). Chunking is an effective means to break learning into smaller segments, separated by retrieval practice. One clinical trial revealed that video chunking with retrieval practice resulted in a 61.5 percent increase in retention compared to longer segments without retrieval practice. Students often have an illusion of learning when instruction lacks active engagement, difficulty, and cognitive effort. Students may passively observe a video or lecture and retain much of the information in working memory; however, without cognitive effort, this information is rarely processed into long-term memory (Clark, 2017, p. 32). Students believe they have learned the information; however, when tested, scores reveal they have retained much less than they assumed. Several techniques can be used to increase cognitive effort, such as retrieval practice, reflection, and engagement. Retrieval practice and assessments that increase difficulty may initially result in failure, but corrective feedback actually strengthens learning. Lastly, critical failure allows learners to continue a simulation or event to the point of failure. Failure provides the learner with internal feedback, repetition, and motivation for the learner to progress (Clark, 2017, p. 218). Learning experience design provides multiple methods to create an environment tailored to effective learning.

APPLYING IMMERSIVE TRAINING TECHNOLOGIES

The framework for applying immersive aviator training technologies builds upon the principles discussed in the science of learning, instructional systems development, and learning experience design. This section will explore undergraduate jet training and FA-18 replacement aircrew training. The framework is based on the first three phases of the instructional systems development model ADDIE. In addition to the principles within the ADDIE model, the framework applies educational objectives to the analyze phase, cognitive psychology to the design phase, and LXD to the develop phase. Through this framework, training curricula can be structured to intelligently incorporate immersive training technologies and increase the use of the science of learning to achieve the desired objectives.

Undergraduate Jet Training

All Student Naval Aviators (SNAs) first complete primary flight training in the T-6B. Based upon performance, preferences, and Navy requirements, SNAs continue to one of several community-based follow-on training syllabi. Prior to 2020, SNAs selected for tactical jets would then complete advanced tactical jet training before transitioning to FA-18, F-35, or EA-18G aircraft. While other communities, such as the E-2 Hawkeye and the CMV-22 Osprey, incorporated intermediate training, the tactical jet syllabus did not. Naval Aviation Training Next's evolution of aviation training includes three lines of effort: Project Avenger, Project Hellcat, and Project Corsair. All three projects within Naval Aviation Training Next seek to leverage student-centered learning, ITDs, smaller class sizes called detachments, and more one-on-one instruction. Project Avenger modified primary flight training. Project Hellcat created an intermediate training phase in the T-6B for SNAs selected for tactical jet training, aimed at reducing training in the T-45C. Finally, Project Corsair revamped advanced tactical jet training using the Naval Aviation Training Next principles.

Project Corsair is broken into three phases: pre-flight, qualification, and mission. The pre-flight phase focuses on the fundamentals of T-45 operations and includes 40 simulator events and no live flight events. The qualification phase transitions SNAs to solo-piloted T-45 operations, all-weather instrument procedures, and formation flight. This phase includes 31 simulator events and 53 T-45 events. The mission phase consists of 33 simulator events and 69 T-45 events for strike and fighter mission training and initial carrier qualification. Due to instructor lead and chase aircraft requirements, an additional 52.4 hours of T-45 flight time are assumed per SNA (Chief of Naval Air Training, 2022, p. 11). Live flights are more prone to weather and maintenance cancellation, subject to aircraft availability, and increased time for flight gear donning, aircraft maintenance review, and pre-flight and post-flight inspection. Therefore, effective learning achieved through simulator use and learning strategies could reduce overall course length and associated costs of T-45 operation and maintenance for both the SNA and instructor lead and chase requirements.

Analyze

The Prototype Corsair Syllabus defines the course mission as "to qualify graduates for follow-on flight training in operational fleet aircraft … they will have mastered basic flying skills and possess an understanding of basic and advanced concepts as applied to the operation of advanced aircraft" (Chief of Naval Air Training, 2022, p. 5). Over the past 50 years, technological advances dramatically changed the skills required to operate advanced aircraft. During the Vietnam War era, third-generation fighter flight leads expected wingmen to support in visual formation; now, fourth and fifth-generation wingmen are expected to operate outside of visual formation, maintain battlespace awareness, and execute with more autonomy (Hubbard, 2023). Several of the learning objectives of Project Corsair remain highly focused on psychomotor skills such as visual formations, dive bombing, and carrier landings. However, modern aircraft, weapons systems, and tactics increase the need for cognitive skills such as information processing, situational awareness, and autonomous decision-making to prepare SNAs for tactical jet aircraft.

Regarding educational objectives, current undergraduate jet training focuses on executing (the cognitive process of apply) advanced jet procedures (procedural knowledge). In order to be prepared to operate modern aircraft systems and execute current air warfare tactics, undergraduate jet training should adapt to analyzing (the cognitive process of analyze) aircraft information and its relationship to the environment (metacognitive knowledge) (see Table 1). Applying procedural knowledge would remain fundamental, especially in the pre-flight and qualification phases. As these skills are learned, educational activities to develop analysis and metacognition can be introduced to attain the terminal objective.

Table 1. Taxonomy Table for Proposed Advanced Jet Training

	Cognitive Process					
Knowledge	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual						
Conceptual						
Procedural		Pre-flight Phase	Qualification Phase			
Metacognitive				Mission Phase / Objective		

Design

Training events must be sequenced and structured around the objective. Implementing learning strategies within the training sequence may yield increased retention and efficiencies. While tactical jet aviators still require visual formation skills, the reliance on visual formations for tactical execution continues to decrease, yet Project Corsair has 35 events dedicated to formation training. SNAs could benefit from the principles of interleaved and spaced practice in formation training after using blocked and massed practice to initially acquire the skill. For example, SNAs may execute introductory formation training events during the qualification phase and proceed with mission phase training. Throughout the mission phase, the instructional objectives should include formation flight tasks executed en route to the designated airspace.

Dive bombing was once a vital skill for fighter and attack aviators; however, the proliferation of guided munitions released from level flight has significantly reduced dependency on dive deliveries except for air-to-surface gunnery. While air-to-surface employment remains a critical mission set, the challenge is often processing information from multiple sources, operating weapons and sensors, and maintaining battlespace awareness. Furthermore, except for an externally-mounted cannon, unguided weapons are not integrated with the F-35B/C, and the EA-18G is not equipped with a cannon. The mission phase includes 28 events focused on dive bombing in a circular pattern at various angles and formations. In order to acquire the skills required to effectively transition to tactical jet aircraft, Project Corsair's mission phase should instead focus only on the fundamentals of dive deliveries and then incorporate additional task loadings such as close air support and strike fundamentals. Coordinate entry, target acquisition, routing, alternate routing for pop-up threats, air-to-surface timeline management, and time-on-target tasks increase cognitive processes, introduce adaptation in training events, and take advantage of varied practice.

Prior to the development of advanced flight control system modes, pilots required rigorous training on the throttle and control stick inputs to execute aircraft carrier landings accurately. Delta Flight Path (DFP) in the F-35 and Precision Landing Mode (PLM) in the FA-18 and EA-18G reduce pilot workload through flight control system modes in which control stick inputs automatically adjust the aircraft's flight path and maintain the appropriate angle of attack for carrier landing. These modes reduced the number of pilot corrections in the last 18 seconds before landing from 300 to approximately 20 (Hunter, 2020). The U.S. Navy is exploring removing initial carrier qualification training from T-45 training and instead executing initial carrier qualification during initial fleet aircraft training (Hunter, 2020). While removing initial carrier qualification training from undergraduate jet training would reduce cost and time-to-train, approach turns and high sink-rate landings remain fundamental to carrier landings and should be emphasized in both the undergraduate jet training and FA-18 replacement pilot training.

Develop

Naval Aviation Training Next incorporates student-centered learning principles, immersive technologies integration, and competency-based flexible training. Project Corsair includes 40 Virtual Training Device (VTD) and 64 OFT events to supplement 122 live flights. Some T-45Cs are also retrofitted with the Virtual Mission Training System (VMTS), which simulates air-to-air and air-to-ground radar modes and weapons. This live, constructive environment is networked to a ground station to control the mission and constructive entities. The extensive use of VTDs and live, constructive environment training increases student training opportunities. While research on Project Corsair's effectiveness is not yet available, a study of Project Avenger training effectiveness concluded that SNAs reached safefor-solo in fewer flights, SNAs completed the syllabus in less time, and "IPs and SNAs believed Project Avenger successfully developed a generalized aviator with strong critical thinking skills, who could fly complex missions and respond appropriately to contingencies" (Mishler, 2022, p. 92). Naval Aviation Training Next's methods and tools to reach learning objectives can serve as a model for follow-on aviator training in fleet aircraft.

FA-18 Replacement Aircrew Training

After completing undergraduate jet training, pilots report to a Fleet Replacement Squadron (FRS) for initial training in their operational aircraft. Initial FA-18 Super Hornet training is approximately ten months in length and includes 68 simulator and 73 flight events. The FA-18 replacement aircrew syllabus trains both pilots and weapon systems officers (WSOs) and is divided into five basic elements: familiarization, strike, basic fighter maneuvering (BFM), fighter weapons, and carrier qualification. Upon completion, aviators are designated air combat training continuum (ACTC) level I FRS complete and transfer to operational squadrons for a 33-month tour. Through their fleet tours, FA-18 aircrew continue to train and progress through ACTC syllabi, typically completing level II combat wingman, level III combat section lead, and level IV combat division lead.

Analyze

The objective of the replacement aircrew syllabus is to train aviators to safely operate the FA-18 in all mission sets. After completing replacement aircrew training, FA-18 aicrew must progress through similar wingman training in ACTC level II combat wingman, which provides aviators with additional training and experience before learning flight leadership in ACTC level III combat section lead. Due to changes in deployment cycles and aircrew rotations, replacement aircrew may quickly deploy or join their operation squadrons while on deployment. Therefore, significant reductions in the FA-18 replacement aircrew syllabus educational objectives may limit operational capability. However, the duplication of efforts in FA-18 replacement aircrew training and the ACTC level II syllabus divides available resources across the FRS and operational squadrons, and prolonged training delays aviators' entry to operational squadrons. As a result, a proposed alternative to balance operational capability and duplicated efforts is to maintain the same educational objectives and increase the use of learning strategies and immersive training tools to produce aviators ready for operational deployment. In effect, replacement aircrew training would focus on the fundamental skillsets, and the ACTC level II syllabus would focus on proficiency and advanced skillsets.

As opposed to advanced jet training, FA-18 replacement aircrew training continually incorporates updated tactical employment concepts into the syllabus. The FRSs frequently revise the syllabus to ensure the skills taught meet operational requirements. With respect to educational objectives, FA-18 replacement aircrew training focuses on analyzing (the cognitive process of analyze) aircraft and sensor information to build situational awareness (metacognitive knowledge). No changes are proposed to the educational objectives.

Design

The current replacement aircrew syllabus includes relevant training on applicable missions, but the design may benefit from sequencing changes to take advantage of learning strategies. The strike phase of the syllabus is sequenced with generally four simulator events of different yet complimentary educational objectives followed by four flight events of the same instructional objectives. This blocked practice sequence is repeated four times with increasingly encompassing objectives until all strike phase objectives are complete. This sequence includes limited interleaving and spacing between simulator and flight events and requires the execution of each instructional objective in live flight, which extends training time and resources. Additionally, these same skills are instructed and evaluated during ACTC level II events in operational squadrons. Instruction of skills such as weapons integration, sensor operation, and close air support procedures can leverage the capabilities of high-fidelity TOFT simulation. The syllabus should be modified to instruct more systems operation and procedural training in TOFTs and use fewer flight events to incorporate varied and interleaved practice. For example, the current syllabus includes three simulator events focused on air-to-surface dive deliveries and gunnery, followed by three flights on the same skills. A revised syllabus may include the same three simulator events using blocked practice to build proficiency, one additional simulator event incorporating interleaved practice of the three previous instructional objectives to build retention, followed by two flight events that also include interleaved practice. While this sequence would not reduce the number of required events, it would include the known benefits of interleaved and spaced practice, reduce the likelihood of aircraft and weather-related cancellations, and reduce the overhead associated with instructor lead flights.

Whereas much of strike training depends on weapon systems integration, sensor operation, and procedures, fighter weapons training occurs in a dynamic maneuvering environment with increased decision-making based upon adversary actions. Due to the increased complexity, eight events may instruct only one or two instructional objectives. The fighter weapons phase of replacement aircrew training includes a sequence of approximately four simulator events followed by four flight events, similar to the strike phase. Simulators provide an environment to learn concepts and fundamentals but cannot replicate physical dynamic maneuvering. However, LVC environments can provide training scenarios for fighter weapons training and allow pilots to experience the physical aspects of live flight. The current syllabus includes the use of LVC environments but still requires some live adversary aircraft. Most events require two adversary aircraft and one flight instructor lead per student event. Modifying the syllabus to increase the use of constructive adversaries reduces resource requirements and the potential for cancellation based on adversary aircraft availability. For example, the syllabus could include four simulator events on two educational objectives, three live flights against constructive adversaries, and one live flight against live and constructive adversaries. This proposal reduces live flight resource requirements by 37.5 percent and provides an environment for replacement aircrew to learn the fundamentals of air-to-air employment prior to entering ACTC level II training in an operational squadron.

Develop

Replacement aircrew training could benefit from the strategies used by Naval Aviation Training Next. Small class sizes are already used but the class advisor often fulfills an administrative role in replacement aircrew training rather than the mentorship role in Naval Aviation Training Next. Immersive training devices in Naval Aviation Training Next provide students additional training opportunities to prepare for syllabus events. While a lower-cost immersive training device could be developed for FA-18 training, FA-18 employment heavily depends upon interpreting sensor information on displays and extensive use of push buttons in which extended reality (XR) and VR systems interface would be cumbersome. FA-18 low-cost trainers with touchscreens to provide visual references and display interface likely provide better training compared to integrated XR or VR. Greater availability of low-cost trainers would afford students additional practice opportunities prior to syllabus events.

CONCLUSION

Undergraduate jet and FA-18 replacement aircrew training display a multitude of innovations yet remain orthodox in other areas. Naval Aviation Training Next's Project Corsair leverages student-centered learning, low-cost immersive training devices, and live constructive environments; however, it should be modified to develop higher-level cognitive processing and situational awareness skills and incorporate interleaved and spaced practice. In essence, undergraduate jet training is a model for innovative training methods, but the skills and sequence should be further refined. Conversely, FA-18 replacement aircrew training focuses on the appropriate learning objectives and is regularly revised to incorporate the skills needed in operational squadrons; however, much of the training is duplicated in operational squadrons, and immersive technologies could be further integrated to provide fundamental training efficiently. The framework discussed applies the science of learning, instructional systems development, and learning experience design to align educational and instructional objectives, incorporate effective learning strategies, include student-centered learning, and integrate immersive training technologies to create environments that teach aviators the skills required to employ tactical aircraft to their maximum potential. Ongoing research on Naval Aviation Training Next initial students' performance in follow-on training will soon provide empirical data on the actual effectiveness of undergraduate training and should be used to address training deficiencies and further develop training curricula. This framework can be applied across platforms and services to refine military aviator training to integrate emerging immersive technologies to produce effective results.

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