Pilot Training Next: Breaking Institutional Paradigms Using Student-Centered Multimodal Learning

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ABSTRACT

The United States Air Force (USAF) Air Education and Training Command (AETC) is responsible for training and educating Airmen across the Air Force enterprise. AETC seeks to revolutionize the pilot training experience, from student selection through content delivery and course completion, by leveraging insights from recent academic studies and experiments, with an orienting objective of reducing the USAF Undergraduate Pilot Training (UPT) course from 12 to six months. Known as Pilot Training Next (PTN), this initiative will serve as a testbed for evaluation of technologies, such as Virtual Reality (VR), Artificial Intelligence (AI), physiological data collection and cognitive mapping, on commercially available hardware while simultaneously conducting pilot training for an initial class of 20 students under accelerated training timelines. PTN will also provide data-backed insights into return on investment, training effectiveness, and desired characteristics for use in recruiting future candidate pools. Based in Austin, Texas, PTN seeks to immerse itself in an entrepreneurial, innovation-centric environment that will challenge current thinking on how pilots are trained. AETC will apply PTN's lessons learned to many other pressure points across the AETC areas of responsibility, by continuing to maintain a close connection to industry partnerships. This paper discusses the execution of the first PTN course from inception to insights, with a specific focus on exploring the use of commodity Commercial Off the Shelf (COTS) technology to build affordable, portable simulation systems. This paper describes in detail the technical solution in place for training and data collection, including the VR-based flight simulation, AI-enabled virtual flight instructors, biometric sensors, and learning management system. Finally, this paper provides PTN's initial insights into training modernization and a path forward for the use of emerging technologies in training.

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INTRODUCTION

New and emerging technologies continue to shape and improve the way we deliver training material, execute practical exercises, and captivate and incentivize learners through immersive training. The US Air Force (USAF) Air Education and Training Command (AETC) seeks to revolutionize the pilot training experience, from student selection through content delivery and course completion, by leveraging insights from recent academic studies and experiments, with an orienting objective of reducing the USAF Undergraduate Pilot Training (UPT) course from 12 to six months. AETC postulates the challenge may not be met through recruiting, retention, accelerated learning or improved instructional methods individually. Instead, the USAF must employ lessons learned and improvements in all of these domains in order to positively affect the desired change in an operationally realistic timeline.

Pilot Training Next (PTN) is an initiative sponsored by AETC and executed by the Human Dimensions Team within the Trainers Division of Systems Simulation Software and Integration (S3I), Aviation and Missile Research Development and Engineering Center (AMRDEC). Its mission is to explore and apply insights and conclusions from previous studies and experiments to redefine how we train and educate future Airmen. The result is a holistic simulation-centric training environment with industry-leading virtual reality (VR) Commercial Off the Shelf (COTS) equipment, immersive scene generation, three-dimensional (3D) aircraft models with realistic flight dynamics and sub-system models, physiological data generation, student-centric Learning Records Stores (LRS), cognitive enhancement techniques, and multi-modal content delivery. Each technology, employed on its own, improves training. PTN seeks to realize non-linear improvements by employing these technologies collectively.

The first PTN course consisted of a class of 20 students and 13 instructor pilots (IPs), specifically selected for the experimental UPT program, hosted at the Armed Forces Reserve Center in Austin, Texas, beginning in February and running through August 2018. This paper discusses the execution of the first PTN course from inception to insights, with a focus on exploring the use of commodity COTS technology to build affordable, portable simulation systems. The first section of the paper describes academic research and studies that spawned the concept of PTN. The second section describes the conduct of the first PTN course including a detailed description of the technical solution for the immersive synthetic training environment (STE) and associated data collection and analysis processes. The third section highlights non-simulation aspects of the first PTN course, such as student selection, academic content and delivery, and cognitive enhancement training. The fourth section highlights insights and lessons learned from this first course, including initial data-driven findings. The final section focuses on the long-term path forward for PTN and the team's initial thoughts on promising concepts for a truly revolutionized and transferable training program, meeting the needs of the US Air Force, Army, Navy, and other services and agencies.

BACKGROUND

The idea for PTN emerged from a study conducted at Air University to evaluate the Targeted Learning System Theory (TLST) as it applies to adaptive flight training. TLST is an immersive, student-centered, multi-modal learning structure that empowers the learner and leverages emerging technology to provide high fidelity assessments and feedback (Sheets & Elmore, 2018). Rather than focusing on individual technologies used in the system, the study looked at the technologies' combined ability to increase students' contextual understanding and indicated that biometric sensing is a key component to understanding the impacts and relevance of the multi-modal approach.

As described in the following section, PTN uses two sensors to allow collection of physiological data, to include electrocardiogram (ECG), heart rate variability (HRV) and measurements of iris muscle movements. Literature indicates the ECG waveform is by far the best biometric signal for workload assessment. ECG signals respond strongly to changes in the limbic system affected by a person's attention and cognitive engagement (Hoke et al, 2017). HRV also provides a highly sensitive measurement of the overall demands of sustained attention (Luque-Casado et al, 2016). In addition, early studies by Daniel Kahneman showed compelling links between event related changes in pupil diameter and mental load (Beatty & Kahneman, 1966; Kahneman et al., 1969; Laeng et al., 2012). In fact, Kahneman is quoted as saying, "Much like the electricity meter outside your house, the pupils offer an index of the current rate at which mental energy is used". Tasks related increases in pupil diameter have also been linked to various functions such as emotional arousal, memory, fatigue and attention (Bradley, Miccoli, Escrig, & Lang, 2008; Hannula & Ranganath, 2009; Heishman, Duric, & Wechsler, 2004; Holmes & Cohen, 2005).

While PTN seeks to analyze the impacts of multiple technologies and concepts on overall pilot training, the most significant aspect of the first PTN course is the immersive STE. Studies focused on pilots who are still developing the necessary motor skills to control an aircraft, such as UPT students, show a significant decrease in the minimum number of live flight hours required to reach first solo and to receive a private pilot's license when they use simulator-based training (McLean et al, 2016). In addition to traditional simulator training, PTN also introduces a VR simulator environment with the expectation that an immersive environment aids with transference of skills from the training environment. By eliminating distracting visual and audio cues from the real world, students are more fully present during training. Anecdotally, higher presence is associated with higher transfer, and studies empirically demonstrated a positive association between presence and transfer (Winn et al, 2002; Mikropoulos, 2006).

IMMERSIVE SYNTHETIC TRAINING ENVIRONMENT

The ideas and research described above spurred AETC to initiate an experimental UPT course separate and unique from traditional USAF UPT courses, with an initial focus on the impacts of an immersive STE. By partnering with AMRDEC's Human Dimensions Team for cognitive enhancement expertise, PTN can leverage the VR, simulation and gaming capabilities from Army Game Studio. This section describes how the execution of PTN using these capabilities compares to traditional UPT and discusses the technical solution for PTN's STE as well as PTN's processes for data collection and analysis.

Shown in Figure 1, traditional UPT uses chair flying, a visualization technique in which a student imagines executing a series of tasks from a desk chair, to introduce initial flight concepts. PTN introduces similar concepts using commercially available software and hardware to create a VR simulator station, also shown in Figure 1.

Figure 1: Chair flying versus PTN simulator stations

In addition to chair flying, classroom lectures and live flights, traditional UPT students use high fidelity, high haptic feedback simulators which are formally validated for training on the T-6A training platform. However, students have limited access to these simulators because of their high cost. By integrating commodity and commercially available products, PTN can produce realistic training stations that cost less than $15,000 each, making the stations highly available to the student. During the first cohort, PTN assigned each student his own station in the classroom as well as a separate station that is shared with his roommate for training outside of normal class hours, giving students almost unlimited access to simulation-based training.

Technical Solution

The PTN student simulator station is the crucial element of training for the first PTN course. Student stations include a VR-enabled flight simulator with vibrating cockpit-style seats, hands-on throttle and stick (HOTAS), rudder pedals, an electronic virtual kneeboard, accurate Austin, Texas, area scenery, and a T-6A 3D visual, auditory and flight model that is realistic, according to expert opinion, but not validated. Each student station maintains an identical image of configured hardware and software. The hardware is mounted on a Volair simulation chair and includes an Origin Intel Core i7 6-core processor with NVIDIA GeForce GTX 1080 8GB graphics card, a Thrustmaster HOTAS with an attached stick extender, Thrustmaster pedals, a Guitammer Buttkicker 2, and a HTC Vive Pro headset with an embedded Pupil Labs camera. The entire system is mounted on a wooden platform with locking casters for easy mobility. Classroom simulation stations have a more powerful personal computer than stations located at the student housing but are otherwise identical. In addition, students each have an iPad Mini that is used as a virtual kneeboard for flight planning and use a Zephyr chest strap for monitoring physiological data such as heart rate, HRV and breath rate.

The baseline simulation software consists of Prepar3D v4.2 working with FlyInside, SteamVR and FSUIPC to improve VR performance and stability. Lonely Screen provides AirPlay mirroring to Windows, which allows FlyInside to bring a virtualization of the iPad into the VR environment. Students periodically use additional software to address temporary capability gaps or to evaluate emerging technologies for inclusion into the baseline.

The student station also includes Senseye software to measure muscle movements in the eye and uses this information to show a student's real-time cognitive load, a measure of the mental effort a student is exerting (Zakariaie, 2017). The team anticipates Senseye software will allow automated changes to the training scenario in real time based on the student's cognitive load. Although studies indicate HRV can also show real-time cognitive load changes, the Zephyr chest straps require 300 heartbeats, or approximately three to five minutes, before it can accurately report changes to HRV. Senseye software can report changes to cognitive load after two seconds, the threshold for ensuring pupil movements do not indicate shock, surprise or a response to light, rather than mental effort.

One of the biggest benefits of the PTN technical solution is system and application availability. In this context, two variables primarily impact availability: basis of issue, ie. how many systems per user exist, and system reliability and maintainability, ie. how often do they break and how long do they take to fix. As mentioned earlier in this section, PTN provided a high basis of issue for the first cohort with three stations for every two students. In addition, each component of the student stations is a line replaceable unit (LRU), meaning the team can easily replace broken parts since they are not customized or specialized. Increasing the fidelity or resolution of the system, such as adding motion or other means of haptic feedback, only serves to create a more complex system – both to purchase and maintain. Therefore, the operating theory behind PTN is that availability of the system far outweighs additional capability additions. Until any given component or capability-enhancing feature matures in both stability and affordability such that it may be treated as an LRU, the team will likely delay including the capability in favor of ensuring the availability of a less complex system.

All simulation components of the PTN system use the IEEE 1278/Distributed Interactive Simulation (DIS) standard for interoperability. Each student station interacts with server-side capabilities, hosted on a locally resident server at the Reserve Center. The server hosts Discovery Machine Inc's Reflex Agent Manager (RAM), a synthetic tutor which monitors simulated flight data to provide real-time feedback on the student's progress and proficiency of maneuver execution. The synthetic tutor prevents negative training by preventing students from repeatedly executing a maneuver poorly during times when a human IP is not available to mentor the student. The synthetic tutor may eventually provide a significant cost reduction to UPT by allowing a higher student to IP ratio throughout all courses.

The server hosts all data collection and analysis systems as well as the learning management system (LMS), which are discussed in more detail in the following section.

Data Collection and Analysis

The PTN environment provides multiple types of data analysis, specifically real-time feedback, conducted during simulated flight; after action review (AAR), conducted within one hour of simulated or live flight; and post processing, provided days, weeks or months after the fact and entails more computation intensive analysis. Currently, the synthetic tutor and human IPs provide real-time feedback to the students. Zephyr and Senseye also provide a real-time display of physiological data for the IPs. However, students do not normally view their own physiological data in real time.

The Joint After Action Review (JAAR) and Cloud Ahoy software solutions currently provide AAR solutions. JAAR focuses on simulated flight and gauge data through the DIS interface while Cloud Ahoy imports data from the student's mission planning tool, ForeFlight. Both tools can synchronize multiple pieces of the PTN environment, to include biometrics and recorded video, into a synchronous playback for AAR.

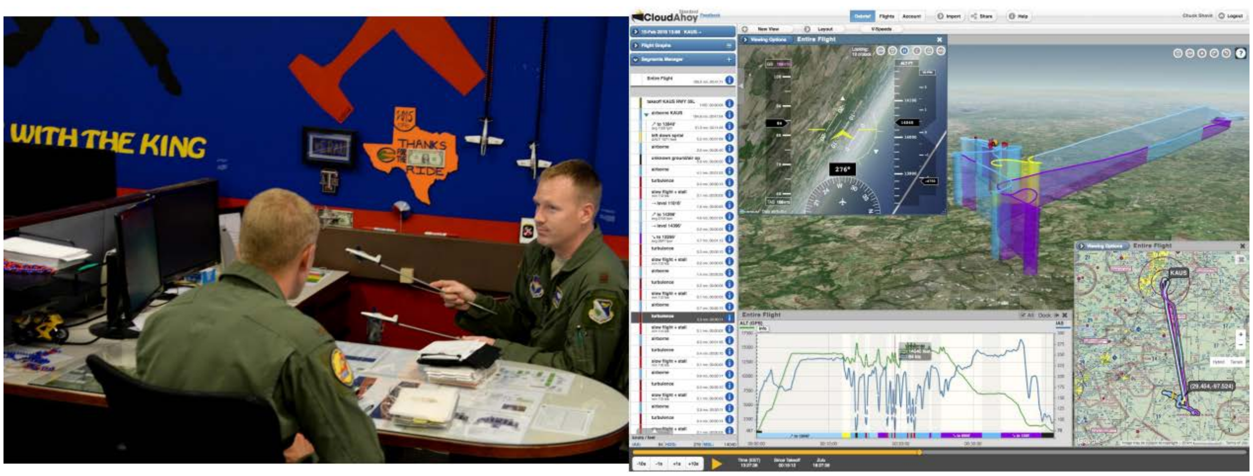

Figure 2: Traditional debrief versus PTN debrief using Cloud Ahoy

The post processing style of data analysis uses Alteryx for data modeling and Tableau for visualization. It joins all available data to look for correlations and trends in the dataset. The full PTN dataset includes simulated flight and gauge data, generated by Prepar3D and collected in DIS and video formats; live flight data collected by Foreflight in Keyhole Markup Language (KML); iris muscle measurements, cognitive load and student gaze point, generated by Senseye and collected in Comma Separated Value (CSV) and DIS format; heart rate, HRV, three-axis G-force measurements and respiratory rate, generated by Zephyr and collected in CSV format; responses to instructor and student surveys, to include subjective assessment of VR sickness and cognitive load, collected in CSV format; student flight performance data and deviation to ideal flight plan, generated by RAM and collected in JavaScript Object Notation (JSON) format; student experiential data collected in xAPI-based JSON format; student academic data, generated by the LMS and human IPs collected in CSV format; and demographic information to include prior experience and generalized student interests, collected in CSV format.

The team is making a specific effort to collect scenario difficulty parameters for both simulated and live flight. This information is critical to quantitative evaluation of student performance since a successful landing with sunny skies and no wind at an empty airport is much easier than landing in a thunderstorm at a busy hub. For simulated flight, Prepar3D provides the scenario factors that affect difficulty. However, in live flight, the team will look to Meteorological Terminal Air Report (METAR) and Terminal Air Forecast (TAF) reports, correlated to live flight times and altitudes as well as post-flight student survey reports of radio communication traffic and other factors that may impact performance.

HOLISTIC TRAINING APPROACH

Outside of the technical solution for immersive training and data analysis, PTN also addresses other facets of pilot training as whole, to include student selection, academic content and delivery, and cognitive enhancement training. This holistic approach allows PTN to include concepts behind a wide range of studies and research. This section describes how PTN is incorporating other training aspects into its overall solution.

Student Selection

Traditional UPT pilot candidates tend to come from a portion of the population with a baccalaureate background familiar with the Air Force and the possibility of becoming a pilot. AETC selects these candidates from a group of self-identified applicants using a selection interview created more than 20 years ago. PTN used this same selection interview and determined that its results provided no insight into the student's success in the program. In fact, PTN students ranking in the top third of candidates in the selection process had lower maneuver skill levels than PTN students who ranked in the bottom third in the selection process. Further analysis shows a positive correlation to graduation for factors related to maturity such as age, completion of a bachelor's degree, and a high score on the Delis Kaplan Executive Function System (D-KEFS) subtest for attention control. The team anticipates more data and maturing analytics will provide additional insights into the inherent skills, interests, and biometric parameters that serve as markers to help identify a naturally capable pilot. PTN theorizes current VR and other emerging game technologies will provide the ability to identify, interest and engage a new population of pilot candidates, without making formal education levels a sole criterion for elimination. PTN's data collection and analysis processes provide the ability to measure, inform, and assess a broad range of candidates, not just the talent that self-identifies.

Academic Content and Delivery

Traditional UPT provides academic curriculum on every aspect of flight, to include the mechanical theory behind how an aircraft works as well as standard operating procedures for planning and execution of a sortie and its related mission. The instructors for the first PTN course "fast tracked" some of traditional curriculum to put an emphasis on the gouge, the most important portions for beginning aviators. Traditionally, students receive course content using textbooks, manuals, PowerPoint slides and videos. PTN uses digital reference manuals delivered as a native iPad app. As shown in Figure 3, PTN introduced interactive 3D video and imagery allowing students to practice pre-flight checklists and other standard operating procedures using their student iPad. Additionally, PTN used the simulation stations as an extension of the classroom, allowing the students to experience what they learned in the traditional classroom environment immediately in the virtual flying environment.

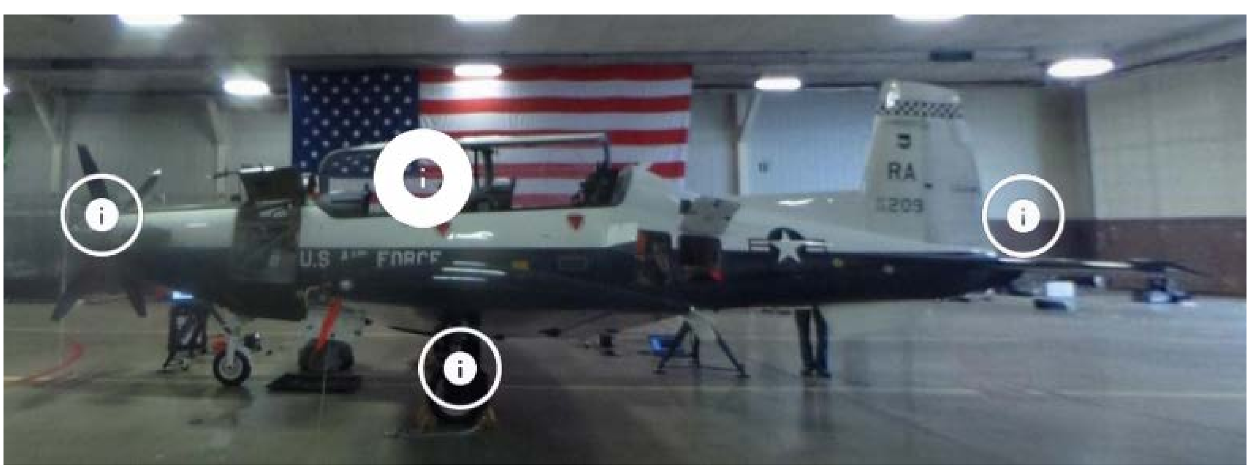

Figure 3: Interactive 3D video for aircraft familiarization

PTN also introduced a LMS called Moodle for web-based access to content, reviews and quizzes. Moodle provides data related to academic performance that goes beyond a simple quiz grade. It allows analysts to access data such as amount of time spent on particular questions, number of times the student changed this answer, and whether the student looked at reference material before answering. PTN also implements a LRS using an experience-based data collection method known as xAPI to help find correlations between academic performance, subjective evaluation of live and simulated flights, and detailed deviation data from live and simulated flight. xAPI uses a flexible Actor, Verb, Activity format. Currently, PTN's schema includes verbs such as Scored, Rested, Felt, Studied, Experienced, Answered, Flew, Achieved, Deviated and Maneuvered. The ultimate goal is to provide insights into the content and conduct of the curriculum that may speed up training for this or future cohorts and to highlight when a specific student did not completely master a required concept or skill.

Cognitive Enhancement Training

PTN is also evaluating the effectiveness of cognitive enhancement training as a method for accelerating skill acquisition. The AMRDEC S3I Human Dimensions Team Cognitive Enhancement for Performance Program (CEPP) trains PTN IPs and students to manage their mental energy, thoughts and attention in a manner which will provide consistent performance even in stressful environments. CEPP facilitates skill development during classroom, simulator, and live flights to help students manage cognitive overload, moderate spikes that occur from the over-activation of the sympathetic nervous system, and increase short term and active working memory. CEPP also uses baseline tests from Zephyr and Senseye to identify techniques that are successful in the program and where more training is needed. CEPP's work in the field of applied sports and performance psychology shows these cognitive enhancement techniques also allow students to develop and execute their skills at the upper range of their potential, which may provide insights into the formal training unit (FTU) student selection, as discussed in the following sections.

INSIGHTS AND LESSONS LEARNED

Of the 20 students that started PTN, 13 completed the course, graduating with wings in just half the time of traditional UPT. Given the small sample size, none of the initial findings will have statistical significance and, at the time of this writing, many findings rely on anecdotal or subjective data. However, these initial insights provide focus on guidance for future PTN work and lend credence to the value of the PTN approach. In this section, the paper provides insights and lessons learned from the first PTN course, discussing anecdotal insights from the immersive environment, the need for quantitative scoring algorithms, and the use of performance measures to enable data driven decisions.

Anecdotal Data

The immersive STE provides the greatest PTN insights to date. This environment allowed IPs to teach, coach and mentor two students simultaneously. The time IPs spent with students concentrated on more complex maneuvers where subjectivity and expert judgement play an increased role rather than less complex maneuvers which may be taught and honed using the synthetic tutor. The paired sim-flying at the student residence also allowed for buddy-checks on these less complex maneuvers, which decreases the amount of IP time needed in those areas. Instructor contact time was not reduced initially, but we can confirm the hours IPs spend in the classroom are quickly oriented on the most complex tasks of the day, while allowing the sim tools to handle the repetitive tasks and checks on learning. PTN expects to reach a student to IP ratio of 4:1 for the next class, due to increased capabilities of the synthetic tutor and the introduction of gamified simulation content to guide students through learning objectives.

Initial data indicates that early and frequent access to PTN simulators can decrease the amount of calendar time it takes to train a pilot candidate on aviation basics before he is ready to fly a live aircraft. This does not mean that the student requires less hours of practice. Instead, the low-cost simulation environment means the students can begin getting familiar with the cockpit on day one and can "fly" as much of his day as he wants. As an example, on average, PTN students completed their first successful solo flight on their seventh or eighth ride while traditional UPT students solo, on average, on their 13^{th} or 14^{th} ride. PTN IPs said this was a direct result of the student's simulator use. Because the students were using a realistic simulator from the first day of class, they were proficient with the material normally covered in the first three to four live flights before their first ride. Prior to the next PTN course, PTN plans to provide simulator systems to the USAF Academy to allow students waiting for their UPT assignment to begin the familiarization process before their course starts.

Quantitative Scoring

Quantitative scoring of student performance is a key factor to producing objective insights, as most of the desired analysis focuses on comparing student performance in PTN to historical UPT or commercial pilot training. Other key analysis focuses on identifying correlations between student performance in PTN and previous experiences and assessment scores, such as scores from the Air Force Officer Qualification Test (AFOQT), Enlisted Pilot Qualification Test (EPQT), Test of Basic Aviation Skills (TBAS) and Pilot Candidate Selection Matrix (PCSM).

In addition to subjective scoring by the human IPs, PTN scored students using the Elo Rating System, which was originally developed for rating chess players but can also be used in educational systems to dynamically estimate the skill of students and difficulty of items (Pelanek, 2016). Figure 4 shows initial attempts to track the progress of the class over time using the Elo Rating System against maneuvers performed in simulated flights. In the background, the chart shows the number and type of maneuvers students attempted on particular days with empty columns during weekends and non-simulation training dates. The X-axis represents specific training dates, and the Y-axis indicates average skill level of the cohort. Each line represents the progression of skill level across all students for all maneuvers in a particular component of the training. Although Figure 4 is a roll-up of the skill levels of all students, the Elo algorithm calculates skill level per student per maneuver. Skill level begins with a negative number due to PTN's implementation of the Elo system, which starts the student and the maneuver with a rating of zero. If the student does not complete the maneuver he is facing, his rating moves down, possibly to a negative value, and the maneuver's rating moves up. If the student successfully completes the maneuver, his rating moves up, and the maneuver's rating moves down. As the student masters a particular maneuver, the maneuver's rating will stabilize, providing a quantitative difficulty level for that maneuver with a particular student. As more students attempt the maneuver, the algorithm will provide an average difficulty level for the entire cohort. PTN can then compare a student's ranking, or the average class ranking, to maneuver rankings to evaluate progress through the course. Due to the significant skill increase over time of the basic maneuver and patterns lines, Figure 4 lends credence to the idea that basic concepts and skills, such as takeoff, departure, cross-check, overhead patterns and emergency landing patterns, are well trained on the PTN simulator.

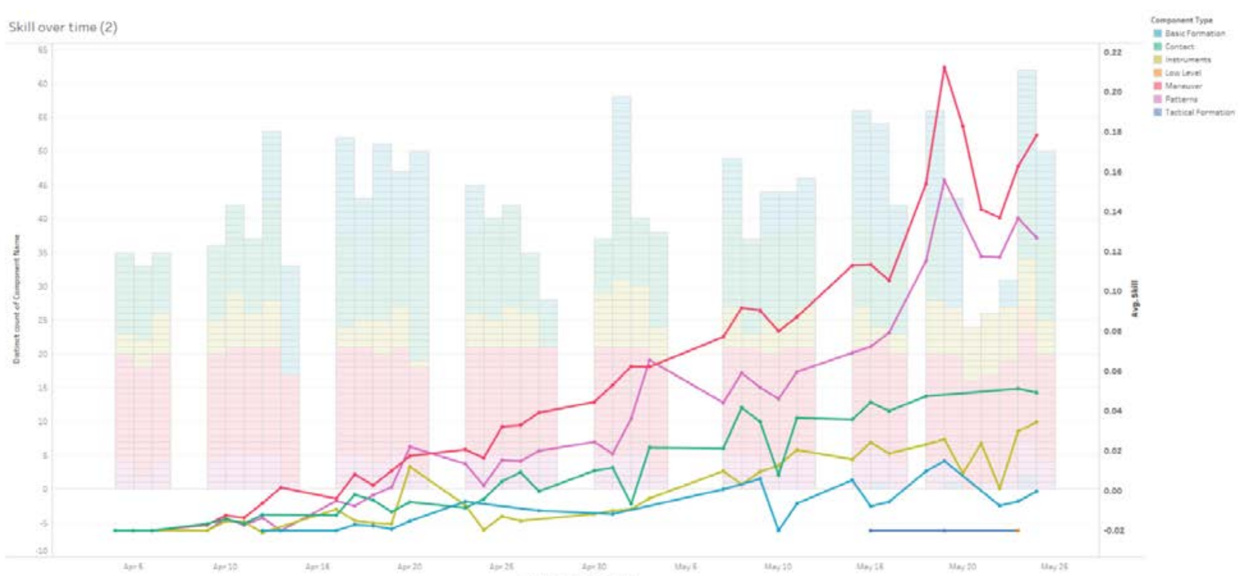

Figure 4: Elo ratings of PTN student performance on simulated flights by training component

Reducing subjectivity in student scoring is essential to identifying struggling and thriving students early, concentrating on tasks needing remediation, quantifying aptitudes for flying various airframe types in order to inform FTU placement, and iteratively informing student selection criteria. In addition to the scoring algorithm, PTN identified performance outcomes associated with each facet of the training, along with the parameters which represent mastery of the skills associated with the performance outcome. For example, students must perform a pre-flight check. The desired behavior, or performance outcome, is the ability to walk around the aircraft and ensure it meets all requirements for safe flight in less than seven minutes. Traditional training requires students to memorize the pre-flight checklist. PTN asks students to use the checklist as a tool while going through the physical motions of a pre-flight check in virtual reality. The amount of time a student requires to complete the pre-flight check as well as the number of items correctly identified as “safe” or “unsafe” are parameters for student mastery. Near term work will compare the time needed to master this skill, and to achieve other performance outcomes, for PTN students versus traditional UPT students. These comparisons will help drive changes to training content, length of training events, and sequencing of particular training elements.

PATH FORWARD

Long term, PTN expects to use its data analysis to inform the development of cognitive models which will be used to predict success of the trainee in their FTU training. Traditional UPT adheres to a strict schedule while PTN allows students to move at their own pace through the curriculum and practical exercises. The team believes this student-driven approach will reveal learning patterns that can help inform track selection, the process of determining if a student will progress from undergraduate pilot training to fighter, bomber, cargo, remotely piloted aircraft (RPA) or other training units. Figure 5 shows initial attempts to predict completion of Mobility Air Forces (MAF) and Combat Air Forces (CAF) competencies based on student progress over time. Each line represents a specific student, with the X-axis representing specific training dates and the Y-axis indicating the number of simulation components the student completed with an IP rating of adequate or higher. A single line is highlighted in this chart to serve as an exemplar path to competency completion. This student experienced extended plateaus and rapid ascensions throughout the course. Other students maintained a steady trend line for progress through the course. The team plans to track outcomes of students’ future training to help identify correlations between learning patterns and success in a specific squadron. PTN is uniquely capable of developing these competency models due to its focus on emerging technologies and data collection. Future work will continue efforts to develop competency models to inform student selection.

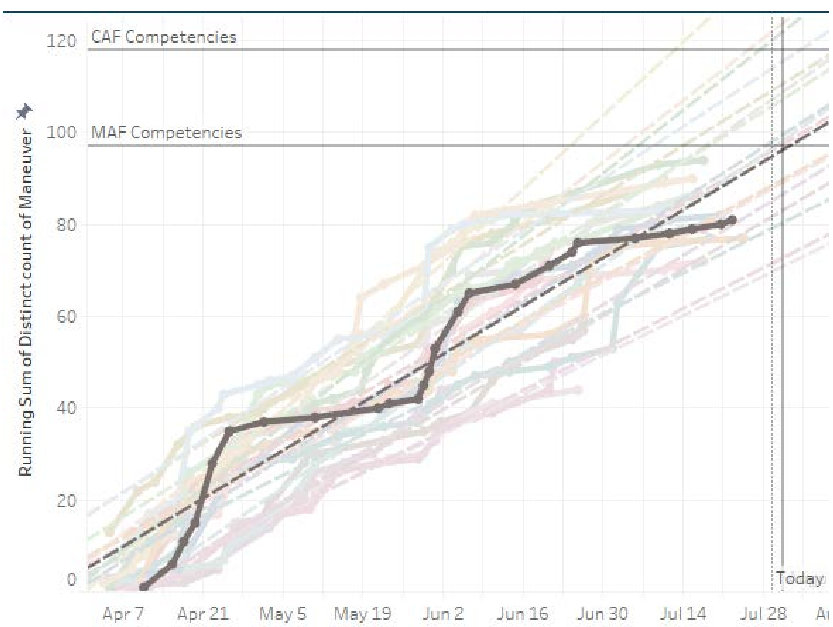

Figure 5: Cumulative tracking of student progress over time

Early identification of a candidate’s FTU will also allow for individualized training which focuses primarily on those skills he will need. For example, cargo pilots do not need to understand the effects of G-forces as well as fighter pilots. A recent study compared the USAF F-16 and RAAF F-18 training programs and determined the USAF squadrons lacked the ability to tailor training to meet student's individual needs in comparison to the RAAF program. The RAAF training course comprised one squadron and a smaller cadre of IPs, which allowed the RAAF to make internal changes quickly without needing to gain approval from higher headquarters (Smith, 2018). Because PTN is organized in a similar way, PTN may be able to achieve similar results.

In future evolutions of PTN, the team will concentrate on delivering academics, tests, and other content through multiple modes and media, enabling a student to select and progress through training material in a way which benefits him most. Additionally, those content delivery mechanisms will feed back to our student performance models via physiological data collection and performance scores, to assess how each student continues to absorb training material and the quality of learning. Eventually, PTN will be able to associate training content to in-flight performance in order to distinguish content necessary for becoming a pilot, thereby reducing the overall curriculum.

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