Immersive Space Operations Training in Extended Reality

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ABSTRACT

The training of next-generation space operators for both commercial and military capabilities relies largely on analog physical models and PowerPoint lectures. Consequently, new operators do not often fully grasp the fundamentals and complexities of the space domain, including astrodynamics, threats, hazards, opportunities, and routing maneuvers–leading to longer training times, poor retention, and costly errors. New training methods involving augmented and virtual reality (AR/VR), collectively extended reality (XR), have proven effective to educate and train students in many fields, and also has strong applicability for space education. We summarize the emerging state of the art in operational training techniques for space operations using XR, proven to reduce cognitive load, help new operators quickly understand complex scenarios, and make better, more informed decisions. These techniques include immersive, interactive, and collaborative engagement with representative space scenarios, considering maneuver tradeoffs, relative resident space object (RSO) positioning, and mission task deconfliction. 3D Volumetric XR Visualizations provide enhanced spatiotemporal understanding for proximity-based hazard assessments, tactics, techniques, and procedures (TTP) planning, and course of action (COA) evaluations within a configurable virtual environment. Synchronized AR overlays provide immersive shared access to user-level information and 3D satellite models, while variable timescales enable forward orbital propagation and backward forensic analysis to more completely understand complex orbital scenarios. Dynamic scenario creation tools enable challenging interactive student exercises, instructor-student synchronization accelerates learning through parallel hands-on training, and artificial intelligence (AI)-based skill tracking mechanisms intelligently track student proficiency. These advanced XR environments, combined effectively with well-formed training curricula and automatic skill tracking, will help train professional space operators to better manage complex spacecraft in the dynamic, contested environment beyond the Earth's atmosphere. We report the outcome of multiple quantitative and qualitative XR space operation training evaluations that demonstrate the merit of the immersive approach.

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INTRODUCTION

The US Space Force is envisioned as a digital service to accelerate innovation, yet many of the foundational training and education tools for space professionals are analog physical models and static 2D PowerPoint lessons. These tools present acute limitations to effective space education despite pressure to increase training throughput to meet global demands for space operators. Training cadre require effective digital innovations, such as capabilities that are emerging from commercial technology investments in augmented reality (AR) and virtual reality (VR), collectively extended reality (XR), to meet and exceed training throughput demands and empower next-generation Guardians, analysts, and commercial operators for the complexities of multidomain operations.

Training and education in the space domain is extraordinarily challenging. Preparing students to conduct safe and effective space missions demands that they master complex and counterintuitive orbital dynamics, understand the maneuverability of the physical space assets they are operating, and learn how to integrate uncertain data to make decisions and analyze multidomain threats and hazards (McCaffrey et al., 2019). Effectively encoding such complex concepts requires training to be as realistic as possible, but existing education tools are antiquated, requiring instructor groups to rely on analog aids such as beach balls, hula hoops, and celestial sphere models (Figure 1, left) to convey the complex 3D relationships of orbital dynamics. These techniques are cumbersome and fail to support training concepts beyond basic orbitology. In contrast to traditional orbital trainer models, classical orbital element editors in XR (Figure 1, right) provide intuitive and dynamic visualizations from multiple reference frames to help students learn space fundamentals.

Figure 1. Traditional orbital trainer model (left) vs. XR orbital element editor (right).

Complex and expensive computer programs such as the Systems Toolkit (STK) exist, but using 2D desktop screen displays to represent orbital physics requires significant mental spatial transformations to perceive the 3D context, imposing additional perceptual and cognitive burden. This results in weakly learned foundational space domain concepts, which is costly. For example, space operations instructors at Vandenberg Space Force Base have witnessed \$10M–\$100M of payload damage from errors due to operators' lack of foundational knowledge, such as when they lost control of an asset and inadvertently pointed its sensors toward the sun. Because of this, it is imperative that space instructors have insight into each student's learning progress and concept mastery.

Emerging technology (Stouch et al., 2021) provides the ability to visualize space domain entities (e.g., satellites, orbits) and concepts (e.g., sensor coverage, maneuvers) in 3D XR based on ephemeris data (sets of position and velocity data that describe satellite orbits). Immersive XR space domain trainers are being developed that provide students with a dynamic, engaging, and intuitive tool to improve their understanding of space-relevant topics, such as astrodynamics, fuel usage, tactics, and space operations. Combining these visualizations with artificial intelligence (AI)–based skill tracking to automatically assess progress toward learning objectives will further improve student learning outcomes. Features such as intelligent performance tracking and adaptive course management, integrated with lesson plans that incorporate the ability to specify and pursue specific training objectives will decrease learning times, improve long term proficiency retention, and optimize refresher training time.

To meet these needs, The DARPA Hallmark program funded the prototype design of an XR capability that has evolved into KWYN-SOLAR (*Knows What You Need - Space Operation Visualizations Leveraging Augmented Reality* (Figure 2)).

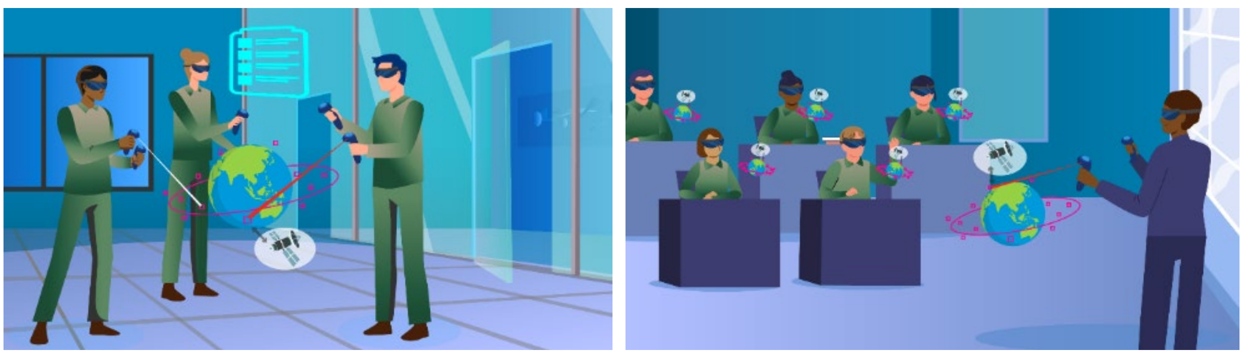

Figure 2. System concept highlighting the interactive and collaborative nature of an XR space domain educational system.

INTERACTIVE VISUALIZATIONS

To help educators, students, space professionals, scientists, and policymakers better understand the complex interactions of orbital mechanics, multiple visualization elements are required to effectively interact with the space domain in 3D using XR. The XR system environment facilitates the understanding of complex scenarios (Stouch et al., 2022), including 3D volumetric visualizations to provide enhanced spatiotemporal understanding for proximity-based hazard assessments, maneuver planning, and scenario evaluations within a configurable virtual environment.

Effective models do not just translate traditional content or design guidelines to XR, they also study the virtual work environment as a component of the overall system and use novel methods for early-stage prototyping and advanced prototype evaluation. AR is a form of virtual environment where the human interacts naturally in real time with both true reality and a synthetic overlayed reality model, such as the space environment around the Earth. Within SDA framework environments, psychophysical AR head-mounted display (HMD) limitations must be applied to inform device selection for context of use and display requirements, determining fidelity recommendations for virtual environments based on empirical experiments.

Earth-Centric Reference Frame

Figure 3 shows the Earth in two reference frames: Earth-centered, Earth-fixed (ECEF, left) and Earth-centered inertial (ECI, right). The ECEF frame (also called the geocentric coordinate system) has its origin at the center of the Earth, and rotates with the Earth. The ECI frame is a global reference frame with its origin at the center of the Earth, but does not rotate with the Earth. The ECI frame serves as an inertial reference frame for satellites orbiting the Earth. ECEF shows satellite motion from the perspective as if you are sitting on the surface of the Earth, such that satellites in geosynchronous (GEO) orbits will appear to oscillate around a specific point of latitude and longitude. ECI, in contrast, shows satellite motion from the perspective of a spacecraft floating in space beyond the Earth's gravity, such that the Earth appears to rotate, and GEO satellites will also visibly orbit around the center of the Earth.

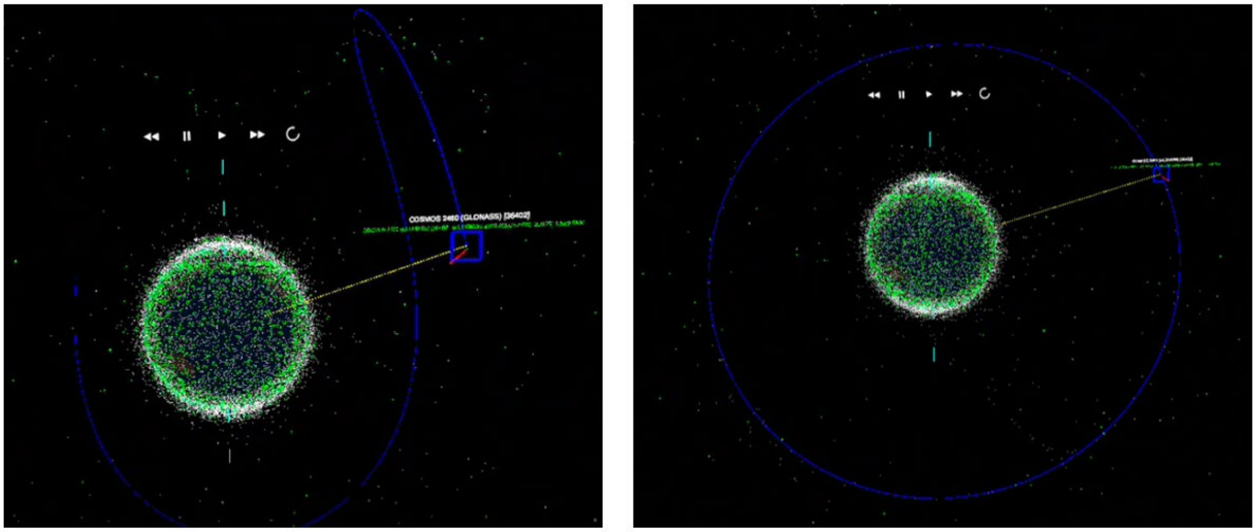

Figure 3. Earth-centered, Earth-fixed (left) and Earth-centered inertial (right) reference frames help students understand the complexities of orbital dynamics that are difficult to learn using 2D reference frames.

Spaceball Card Meta Data

Research citing feedback from students and space operators has shown that other elements, in addition to core globe and satellite visualizations, are necessary to provide informative context, understand processes, adjust orbital parameters, and assess trade offs among resident space objects (RSOs). The 'Spaceball Card' in Figure 4 provides RSO context based on the selected satellite. These data, such as the satellites NORAD identifier, launch site, orbital parameters, and operator notes, help students to better understand the various characteristics of a given satellite in the same visual field of view without losing their spatiotemporal context.

Figure 4. Spaceball Card

Workflow Management

Workflow management tools can help students manage a large volume of RSOs (more than 20,000) as they interact with the space environment. A Recent RSOs list (Figure 5, left) can help students quickly reset to specific RSOs of interest when their environment gets cluttered, and provides at-a-glance satellite data. Watch Lists (Figure 5, right) enable users to filter based on RSO type and operational details, including characteristics such as payload capability (e.g., communications, navigation (GPS), Earth observation), payload status (e.g., active satellite, orbital debris), and owner/operator (e.g., USSF, SpaceX, Canada). Filtering controls also let students toggle satellites on and off at different orbital regimes, such as low earth orbit (LEO), medium earth orbit (MEO), highly elliptical orbit (HEO), and geosynchronous orbit (GEO). Because satellites at these different orbits have very distinct orbital characteristics, quickly toggling them on and off while running scenario experiments helps students understand their different characteristics.

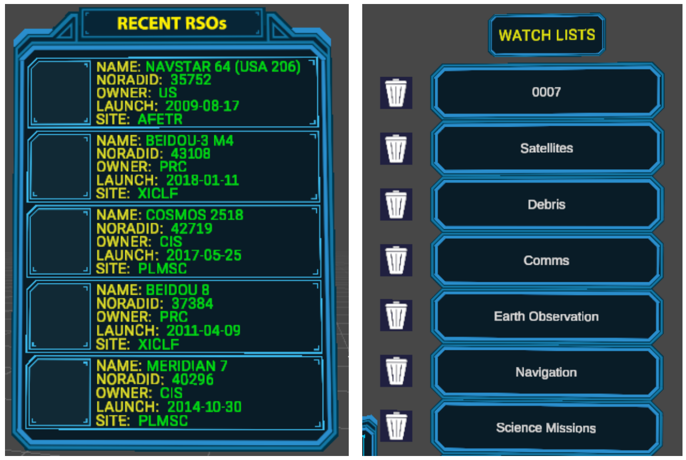

Figure 5. Recent RSOs (left); Watch Lists (right)

Dynamic Orbital Parameter Manipulation

A given satellite orbit can be succinctly represented by a set of discrete parameters that is commonly represented using two lines of plain text and is (appropriately) called the two-line element (TLE) set. The ability to view how orbits change based on these parameters significantly eases the learning process and allows these complex concepts to be much more accessible. TLE editors enable students to dynamically manipulate the orbital parameters (e.g., inclination, eccentricity, mean anomaly) as shown in Figure 6, while the actual orbit changes appropriately in real time. This shows how an integrated TLE editor that displays the classical orbital elements (COE) can both help students learn and also provide objective measurements about how well a given student is understanding a specific orbital parameter in the context of a given scenario. This in-situ parameter editing lets students experiment with orbital parameters and visualize the results in real time as the orbital tracks shift, grow, and adjust before their eyes. This has proven very effective at various USSF training units and at the USAF Academy in helping to meet the broader USSF space professional's education and training requirements.

Figure 6. Two-line element (TLE) editor shows the red orbit before and after a well-defined, measurable TLE adjustment.

Spatiotemporal Reference Frames

Satellites cannot maintain their orbital positions without constant motion, and the interaction of multiple RSOs cannot be truly understood with static snapshots alone. Temporal controls (Figure 7) adjust the speed and timeframe of the satellite data to show the position and behavior of RSOs at a particular time, and let students propagate orbital trajectories forward and backward in time to quickly achieve mastery of these dynamic spatiotemporal concepts.

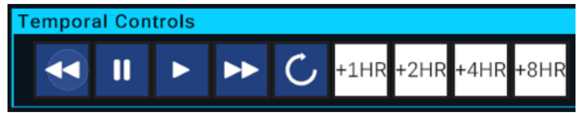

Figure 7: Temporal controls propagate RSOs forward and backward in time.

USER FEEDBACK AND ANALYSIS

We conducted multiple validation studies (Table 1) with relevant end users within the space community to elicit subject matter expertise, validate design concepts, and iteratively refine key features. Evaluation data was typically collected in the form of a survey with qualitative and quantitative response fields.

Table 1. Validation studies

Dates	Details
2017-2020	18 evaluation events were held with space professionals during the DARPA Hallmark program
2021	USSF members as part of professional education courses
2023	USAF Academy Cadets as part of the Azimuth program

DARPA Hallmark Evaluation Events

The system was first developed under the DARPA Hallmark Program as a prototype XR space domain awareness (SDA) system environment, during which it was iteratively designed, implemented, evaluated, and improved with professional space operators at evaluation events in simulated operations centers using real and synthetic data.

Formal cognitive evaluations were conducted as part of each evaluation event. Initial feedback was related to specific features and design choices, such as "the location of the information and workflow panels relative to each other is important," "orbital paths should include historical and future trajectories," and "interaction is much easier with controllers than with hand gestures."

As the capability evolved and became more useful, much of the analysis focused on improving the XR capability to help users achieve higher levels of (measurable) SDA in faster timelines when using the AR goggles than without them. This came in the form of comments such as "we care about orbital trajectory more than just RSO objects," "more intelligent filtering is needed," and "we need to know the specific mission type of each RSO."

USSF Feedback

USSF users helped to validate the system's ability to effectively educate students better than traditional book and screen-based methods, and also refine our system to meet end user needs. Overall, the system scored very well among users. Table 2 shows the rating scale used and Table 3 provides a summary of results.

Table 2: USSF evaluation ratings

Highly Disagree	Disagree	Somewhat Agree	Agree	Highly Agree
1	2	3	4	5
Unsatisfactory	Needs Improvement	Satisfactory	Excellent	Outstanding

Table 3: Scores from two classes using augmented reality to help train for orbital mechanics

Item	Class 1 Scores	Class 2 Scores
OBJECTIVES		
Objective was easy to understand	4	4.5
Objective was not too easy or too difficult to achieve	3.5	3.9
UNIT MATERIALS		
Unit materials helped meet learning objectives	4.1	4.6
Overall impression of Unit materials	4.4	4.3
TRAINING AIDS		
Training aids supported lesson	4.7	4.8
Training aids were properly used	4.7	4.8
Training aids were adequate in quantity	4.8	4.5
Overall impression of training aids	4.7	4.8
EQUIPMENT		
Equipment was reliable	3.9	4.1
Equipment was readily available	4.6	4.8
Overall impression of equipment	4.3	4.7

User feedback included the following comments, many of which centered around classical orbital elements (COEs):

- "EXTREMELY helpful – very easy to see how different COEs could be affected and changed."
- "It was very helpful in visualizing orbital mechanics. The software is fairly easy to learn."
- "I'm a very visual learner so being able to actually see how I can manipulate the COEs and see how they actively change would be very beneficial if I was first trying to learn orbital mechanics."
- "It allows the user the ability to get a more visual and steerable experience with the factors that contribute an orbit's shape. Very wholistic approach to orbital mechanics. Very helpful for conceptual applications, i.e., how does COE 'X' affect the orbit?"
- "I am a visual learner and being able to see the Earth, satellites, and orbits helped very much. Being able to manipulate COEs on my own time helped me get a better understanding of orbital mechanics."

USAFA Feedback

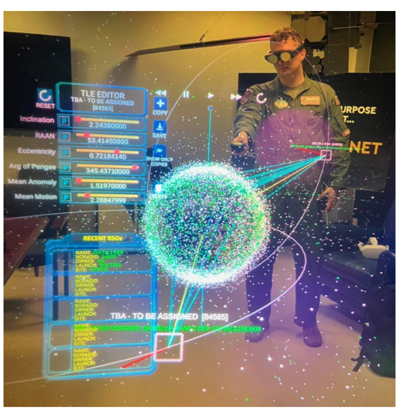

Figure 8. Live training established feasibility

Figure 8 shows a student at the USAF Academy's Azimuth program using AR to learn about orbital mechanics. After using the AR enhanced space training capability, the cadets were asked to recall the first time they encountered orbital regimes, RSO density, and TLE parameters. For each topic, they indicated the degree to which AR-based education would have influenced their learning experience, considering if it would have made their learning experience more difficult, the same, or much easier. Table 4 summarizes the results for the 46 responses.

Table 4: Summary of responses

	More Difficult	No Difference	Much Easier
Orbital Regimes	0.00%	11.63%	88.37%
RSO Density	0.00%	16.67%	83.33%
TLE Parameters	0.00%	28.57%	71.43%

The cadets were then asked "how comfortable would you be presenting space XR capabilities to a peer?" on a scale of 1=very uncomfortable, 2=uncomfortable, 3=neutral, 4=comfortable, 5=very comfortable. This was based on the premise that the ability to teach a subject to another person reflects a certain confidence in and mastery of a subject. 67% of cadets said they were now comfortable/very comfortable presenting to a peer, 20% were neutral, 12.5% were uncomfortable, and none were very uncomfortable. Another question asked "What elements of the environment did you find the most useful?" These comments are grouped by category in Figure 9. The Cadets provided feedback related to ease of use, satellite interactions, RSO density, visualization quality and effectiveness, and scaling, filtering, selecting tools, as shown in Table 5.

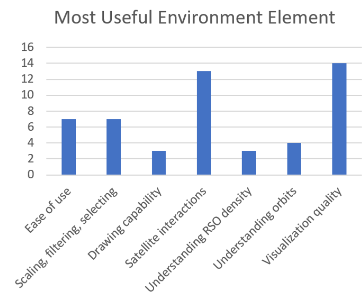

Figure 9: Useful elements for learning about the space domain.

Table 5: Comments by category

Ease of Use
▪ It was to control and select things precisely ▪ It was very easy to adapt to ▪ It's awesome to work with and is user friendly
Satellites Interactions
▪ Selecting different satellites, understanding orientation was helpful ▪ Separating the satellites into different space regions was helpful ▪ Understanding how particular satellite users (commercial, nation states) try to use space was helpful ▪ Isolating the individual orbits and seeing multiple satellites moving at the same times was awesome ▪ The essential central panel was easy to use to sort satellite types
RSO Density
▪ I liked the visualization of the objects in space and how dense certain objects are ▪ The resident space object density made me realize how much space junk there really is
Visualization Quality and Effectiveness
▪ Everything was highly accessible and labeled ▪ The size of everything made it easy to see and use ▪ I like how it was all visual so we could see everything that was going on ▪ I liked the visualization of the objects in space and how dense certain objects are ▪ Spatial relationship with abstract concepts is very beneficial ▪ Hands on experiences internalizes experiences
Scaling, Filtering, and Selecting Tools
▪ The shrink/zoom, being able to manipulate satellites was helpful ▪ The ability to walk around and select objects and have all the information at your fingertips made it much easier to understand than reading or watching videos on the topic

Overall, the results show that 3 dimensional representations of the space domain are very useful in helping students understand these concepts. The results were overwhelmingly positive with 88% expressing that they learned orbital regimes better, 83% RSO density, and 71% TLE parameters. We also received valuable feedback to improve the system. Table 6 summarizes the feedback about the interactive learning aspects.

Table 6: Suggested improvements

Visualizations, Size, and Scale
▪ Have pre-created items to pull into get a better sense of size and scale of things in space. ▪ It'd be neat to go to the satellite and see the world from satellite itself and follow with its orbit ▪ Show an image of the satellite you select ▪ Make control panels more organized and good to look at ▪ Make the user interface simpler ▪ Improve the ability to search for satellites.

Ease of Use and Comfort
▪ Make the orbit animation smoother ▪ Make it more accessible and easier to navigate ▪ It is kind of uncomfortable to wear with glasses
AR/VR Gloves, Gestures, Drag and Drop, Voice commands
▪ Add ability to grab and drag objects, especially the different panels ▪ Add voice for typing, as the keyboard took a bit of time
Teaching Curriculum
▪ Add more example scenarios w/ explanations and walkthroughs ▪ Have interconnected monitors so multiple people can see one display simultaneously. ▪ Add other celestial bodies, especially the moon and Mars ▪ Have someone teach you with their own headset so they can see what you see

Institutions are planning to measure ROI during their upcoming academic year. Specifically, one institution is pursing plans to evaluate how the use of AR/VR to reinforce concepts impacts overall mastery of material. To do so, they will compare students' grades from their first exam to their final grade for the course. Historically, students who have done poorly on the first exam continue to struggle during the semester and sometimes must retake the course.

INTELLIGENT ADAPTIVE TRAINING

Current Approach - Interactive Learning

User-driven scene annotations can help with the learning process and enable instructors and students to more effectively communicate about specific areas of confusion. These annotations might include free drawing in 3D space and custom 3D shape laydowns, such as sensor fields of view projected on the earth and 3D computer-aided design (CAD) models of satellites to let users zoom in to inspect their structure and makeup. This real-time 3D telestration engages students and supports the ability to annotate space objects, orbital trajectories, unusual conditions, and scenarios of particular interest.

Interactive visualizations of 3D RSOs, ground sites, and spatiotemporal relationships, as well as customizable scene annotations and mission planning capabilities can further aid in learning. Immersive AR/VR solutions enable custom experiences contextually tailored to individual needs and enhance spatiotemporal understanding for satellite visibility on Earth, proximity-based conjunction assessments, and potential maneuver options.

Proposed Enhancements - Intelligent Skill Tracking

AI-based models from intelligent tutoring systems (ITSs) built on custom student skill assessments can express and track student skill proficiency while they are learning about the space domain. Techniques such as Charles River's Methodology for Annotating Skill Trees (MAST) framework (Bauchwitz et al., 2019) construct detailed skill models that map to interactive exercise objectives, or vignettes, during the various interactive lessons. Skill-tree models (Figure 10) and computational reasoning techniques are used to define the critical communication tasks, skills, and behaviors associated with individual roles and functions during successful space operations (e.g., orbital transfers, conjunction avoidance maneuvers, Earth imaging, communications relay).

These models can then be used to quantitatively evaluate performance from observed spatiotemporal manipulations in the context of state information made available through simulation scenario data. The skill modeling framework integrates models of domain knowledge, tasks, and skills of multiple types (e.g., perceptual, procedural, decision-making), with metrics (Perez et al., 2013). This supports identifying critical skills and ensuring performance of those skills can be assessed in simulation. These techniques have been used successfully to model skills such as aircraft maintenance surface sonar operation.

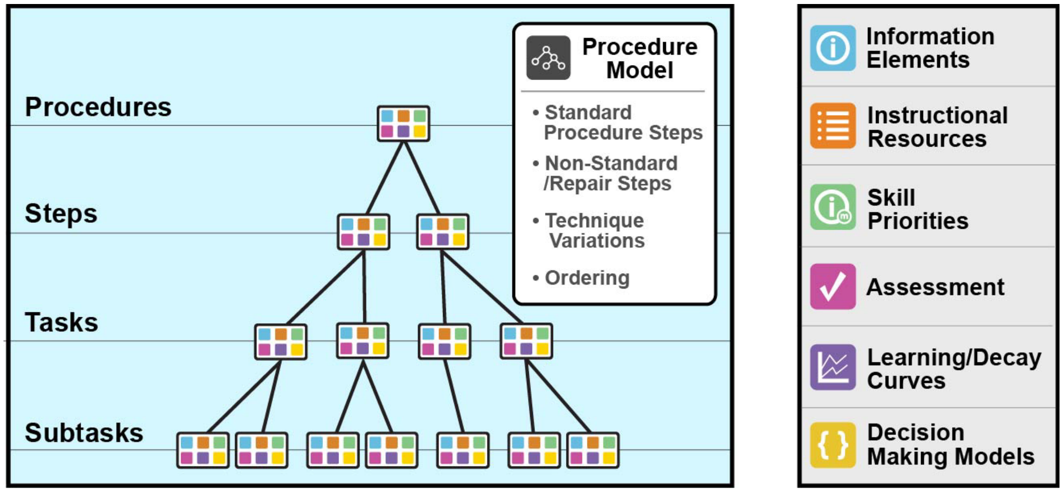

Figure 10. Representative skill tree (left) and annotations (right) for hazard assessment.

The example in Figure 10 shows a visual representation of a skill tree. The "skeleton" of the skill tree is the procedure or task model that breaks down the entire task into constituent steps, tasks, and subtasks. Layered on top of this skeleton are the annotations (shown as colored boxes in the tree.) Consider an example task of '*avoid a co-orbital conjunction*': a domain awareness and response planning skill that requires certain data to be collected, modeled, and understood, and a COA to be planned and executed in a timely manner. The skill tree represents this task by deconstructing it into elements such as what must be observed, confirmed, documented, and then decisions made and new orbits calculated, visualized, and executed. Skills and metrics are then attached to each subtask, which allow performance to be defined and measured. For example: following an initial warning notification, did the operator recognize the severity and adjust the necessary orbital parameters to quantify the likely approach distance, per established TTPs? A set of educational objectives to be modeled as scenario-based skills are shown in Table 7.

Table 7: Space education objectives that could be used to define a set of skills for learning in XR

Classical Orbital Element (COE) Definitions	Ground Tracks	Relative Motion and Proximity Operations
Define each of the six COEs and how they define a unique orbital trajectory	Calculate the semimajor axes for a set of ground tracks for satellites at LEO, MEO, HEO, and GEO orbits	Understand the motion of one satellite with respect to another using relative motion plots
Describe how inclination, right ascension of the ascending node, and eccentricity affect an orbit	Understand why satellite ground tracks look the way they do and describe mission-specific orbit types	Describe the relative motion between two satellites with different semimajor axes
Explain why COEs are preferred over position (R) and velocity (V) state vectors	Draw the ground track defined by the argument of perigee, inclination, eccentricity, and true anomaly	Identify the relative amount of fuel needed to engage proximity operations at each orbital regime
Explain when some COEs are undefined and how alternate orbital elements are measured	Identify whether a ground track is circular or elliptical	Describe a set of viable launch trajectories to approach and refuel a given satellite at GEO

Measures of Learning Effectiveness

Traditional interfaces for scenario monitoring and post-exercise data exploration most often present singular, drill-down data views in a serial manner that results in data overload. Typical consequences of these approaches include instructors missing new or important events, having difficulty interpreting and fusing multiple spatial and temporal perspectives of activity in complex battle environments, and poor understanding of un- or under-explored scenario information (Voshell et al., 2005). To mitigate these problems, we use design techniques with high visual momentum (e.g., longshots, status summary, side-effect views) to coordinate multiple information perspectives and support instructors in finding, extracting, and integrating relevant performance information in and across mission-specific views (Woods & Watts, 1997; Kilgore & Voshell, 2014). These display techniques leverage the natural perceptual strengths of human operators by employing simple visual mechanisms and task-centric display perspectives to rapidly convey critical communication information and meta-information resources to the instructor, while minimizing demands on higher-order cognitive processing. Figure 11 shows an example of a notional coordinated workspace.

Figure 11. Interface for user-selected query constraints and objectives, training sequences under comparison, and alternative ROI measures of performance.

This notional coordinated workspace helps instructors see and understand communications as they occurred in time, space, and mission context by providing cross-cued audio playback tools, detailed utterance logs, and performance summaries in multiple tailored displays. Instructors can easily drill down or zoom out to specific events within a timeline or geospatial context to review performance at varying levels of granularity.

Metrics used to collect and monitor student performance will be more objective when the intelligent learning system is based on a robust modeling framework that represents procedure skill models. Best practices use instructor dashboards to record instructionally relevant student behaviors, such as time spent in exclusively LEO/MEO/HEO/GEO orbits or using the TLE editor, to intelligently classify student actions as probabilistically satisfying course objectives. A summary of each students' objective fulfillment and proficiency assessment will be shown in an instructional dashboard (Figure 11), allowing instructors to see instructional trends, such as objectives that were entirely missed by students.

Tools and Data

To build an advanced XR framework for SDA, custom XR engineering tools can reduce development times and increase capability effectiveness. These include flexible interaction libraries for more ecologically valid human machine interface (HMI) experiences in virtual environments, advanced haptic development and interface customization libraries, integrated hooks for distributed XR and live training, synchronous and asynchronous networking libraries to enable co-located and distributed virtual environment collaboration in XR, and massively scalable modeling and simulation capabilities to support persistent virtual environments.

Real or realistic simulated data is necessary to drive space education and training, Data sources such as the Unified Data Library (UDL, https://unifieddatalibrary.com) can provide space catalog data (e.g., TLEs, ephemerides, VCMs), RSO metadata (e.g., type, fuel, affiliation, capabilities, launch date, orbital regime), command and control (C2) data (e.g., telemetry, tracking and control (TTC) data), and mission context (e.g., communication links, DCGS node locations, AIS tracks, terrestrial and space weather, intelligence reports) to support effective training scenarios.

DISCUSSION

New AR-based capabilities to support space domain education and operational training are having immediate and tangible benefit for Space Force instructors and students. These interactive environments begin to meet the needs of organizations such as the US Space Force and USAF Academy, who need training innovations to scale space domain learning, increase engagement, and deepen knowledge retention. Immersive XR training and education tools supplemented with AI-based training technology that organizes, customizes, and guides training content to dramatically increases learning per instruction hour is the first step toward this goal. In addition, these capabilities have the potential to excite K–12 students about STEM tools and space missions. Throughout the last 30 years, the number of students in the US pursuing STEM fields in higher education has remained stagnant, putting us at a considerably risk of falling behind other nations in developing innovative technology. To remain competitive in the global marketplace, we must recruit and inspire young students to enter these fields. This shortage of STEM educated graduates can have dire consequences, as it affects our national security (Athanasia & Corta, 2022; Herman, 2019).

Based on user feedback, future development includes refactoring the interactive control panel to more consistently manage the different interaction modes (e.g., TLE editing, ground site editing, moving and scaling informational panels, adding telestration annotations, managing watch lists), adding the ability to save and load custom scenario configurations, and increasing the fidelity of satellite trajectories to include dynamic maneuvers that are not consistent with traditional COEs.

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