An XR Authoring Tool for Customizing Aviation Weather Educational Content

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ABSTRACT

In 2020, there were 212 fatalities in civil aviation activities, with 205 of them under the category of General Aviation (GA). Additionally, 17 out of 23 GA accidents were weather- related. To mitigate this issue, researchers have employed Extended Reality (XR) technologies to improve GA weather education and training for pilots. However, since the created XR content only contains limited pre-defined scenarios, it was unable to address the wide range of weather-related conditions a GA pilot will encounter. Thus, a gap exists between what instructors need and the tools available to them. Flight instructors with expertise in aviation weather could create more, and varied scenarios, but they most likely do not have the XR development knowledge required (i.e., computer graphics and coding). Alternatively, developers who routinely create XR content often have little knowledge about aviation weather. A simple to use XR authoring tool is needed to allow customized educational content to be created. Under IRB supervision, formal interviews of flight instructors were conducted to understand a range of issues such as desired educational outcomes and technical competency before software development began. Through the result of the interviews, an authoring tool was developed whereby customizable weather-related flight scenarios (i.e., clouds, precipitation, winds) to practice pilots' decision-making. Based on interview results, a modular thunderstorm cloud model (i.e., particle systems with customized graphics shaders) was provided with features to control duration, elevation, and size. In addition, the tool enables authoring in 2D with a 3D visual preview that non-graphics experts can readily understand. To enhance usability, the authoring tool provides customizable layers of mesh models, textual overlays, and adjustments for position and orientation to create clear visual time-based scenarios of weather- related flying activities. Finally, a second user study was conducted to assess the usability of the tool with overall positive results.

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INTRODUCTION

According to the International Civil Aviation Organization (ICAO), all civil aviation operations except for commercial air transport or aerial work are classified as General Aviation (GA) (2009). In 2021, GA accumulated a total of 21,965,783 flight hours, accounting for 51.35% of the overall civil aviation flight hours (NTSB, 2022) which is 27.47% more than regular air carriers (15,931,746 flight hours). However, during the same year, GA also had 1,157 accidents with 210 of them being fatal. Weather is repeatedly cited as one of the mitigating factors in an unusually high number of these accidents. Reports from the Aircraft Owners and Pilots Association (AOPA) indicate that in 2020, 23 GA accidents were related to weather, out of which 17 were fatal, which is almost 74%. Research has also shown that many pilots have deficiencies in their weather theory knowledge, and the training programs available to them are often inconsistent and incomplete in the coverage of important topics (Blickensderfer et al., 2019; Boyd, 2017; Guinn & Rader, 2012; Wiegmann et al., 2008). These research projects, along with previous work from the authors described below, suggest that focused training on weather theory, with better technological tools, could reduce the number of weather-related accidents, particularly fatal ones.

Weather theory includes a broad range of fundamental knowledge related to weather hazards and their impact on aviation safety. Weather theory covers the science behind weather patterns, identification of weather hazards, such as turbulence, icing, and thunderstorms, as well as guidelines from the FAA on how pilots should react when they encounter these hazards (Federal Aviation Administration & U.S. Department of Transportation, 2016).

XR technologies has the potential to enhance current training methods for aviation weather theory. XR is a term that summarizes various technologies that immerse a user into virtual worlds on different levels. This encompasses virtual reality (VR), augmented reality (AR), and mixed reality (MR) to create seamless and interactive experiences for users (Doolani et al., 2020). VR creates a completely artificial environment presented through a Head Mounted Display (HMDs) or projections screens surrounding a user. The user is immersed in a virtual environment and can interact with the surroundings through controllers or other input devices. AR overlays virtual content in the real world through a smartphone camera or see-through HMD. In this work, MR is defined as an immersive technology where the virtual content is mapped with a user's physical surroundings through headsets or other devices. The user can interact with real objects while completely immersed in a virtual environment. XR is already widely used in other domains for training and education often with dramatically improved outcomes and metrics such as skills acquisition and learning retention (Fidan & Tuncel, 2019; Küçük et al., 2016; Kuhail et al., 2022; Kumar et al., 2022; Thees et al., 2020). Research into the use of XR in aviation training has also been performed with promising results (Gabriella Severe-Valsaint et al., 2022; Pennington et al., 2019).

In previous research, the authors addressed the technical challenges of using XR-enabled learning materials on a mobile device, specifically implementing a thunderstorm training simulation into a marker-based mobile AR application (Meister et al., 2022; Wang et al., 2021). An example of the interface and functionality is shown in Figure 1. However, a major limitation of this research was the inability to customize the learning content to meet the specific needs of individual flight instructors. This issue is a common challenge for many current XR systems when applied to education and training (Ashtari et al., 2020; Dirin & Laine, 2018; Hampshire et al., 2006; Nebeling & Speicher, 2018). XR authoring tools either require extensive programming and development skills, which most flight instructors do not have (Nusrat et al., 2021; Wang et al., 2020) or are limited to creating static viewing content without animations or interaction capabilities to take advantage of the full potential of XR training. Building off the previous research conducted, along with these new issues, two goals for a new project were established: 1) a solution allowing the

creation (i.e., authoring) of customized flight scenarios with no programming skills is required and 2) the user interface (UI) for such a solution needs to be extremely intuitive taking minutes to understand.

Figure 1. Thunderstorm training simulation (Wang et al., 2021)

This paper presents an authoring tool specifically designed for flight instructors to create interactive thunderstorm scenarios. The first step was to conduct a formal study with experienced flight instructors to identify the most important capabilities for the authoring tool. This process ensured that flight instructors could create scenarios with sufficient customization while still maintaining a simple creating experience. The developed XR content authoring tool enables instructors to incorporate weather information, add multiple thunderstorm clouds with different characteristics, draw flight paths, and include text-based teaching elements such as quizzes and hints. The tool aims to provide a tool for flight instructors to incorporate XR when teaching complex weather phenomena such as thunderstorms.

BACKGROUND

Benefits of XR Training in Aviation

Many benefits have been identified when using XR in training and education. A survey paper from 2022 (Kuhail et al., 2022) analyzed XR training benefits from 42 different papers published in recent years. The review summarized the key benefits of XR systems into four main categories: motivation, performance, subjective satisfaction, and immersion. Because of this, XR training has gained traction as an affordable solution for aviation training. For instance, the Scalab Virtual Reality Simulator, developed in 2011, employed VR HMDs and haptic gloves to simulate helicopter cockpit operations (Yavrucuk, Kubali, & Tarimci, 2011). This system significantly reduced costs compared to high-fidelity flight simulators by providing realistic feedback through haptic gloves. Another example of an XR simulator in aviation called Pilot Training Next (PTN), which was designed for initial military pilots (Pennington et al., 2019). Virtual Instructor Pilot Exercise Referee (VIPER®) was another XR tool developed to provide guidance to students (Gabriella Severe-Valsaint et al., 2022). VIPER® features adaptable virtual instructors capable of providing guidance and training content without the need for human trainers. The results of the follow-up evaluation, VIPER® showed a significantly improved training outcome compared to the other conditions.

Previous research developed a thunderstorm simulation tool to assist initial GA pilots in understanding abstract and complex 2D materials such as textbooks (Meister et al., 2022). The thunderstorm simulation contains a 60-minute thunderstorm cell cycle with a microburst. The thunderstorm model was incorporated into scenarios such as an aircraft taking off under a microburst or taking off or landing with a thunderstorm approaching the airport. The goal of these scenarios is to demonstrate the dangerous conditions that pilots might encounter to help teach proper decision-making. The thunderstorm simulation application was evaluated with 18 student pilots, or pilots with fewer than 250 total flight hours (17 male, 1 female). Private pilots rated for visual rules flying only, with fewer than 1000 flight hours, are more likely to be involved in VMC (Visual Meteorological Conditions) into IMC (Instrument Meteorological Conditions) accidents (Major et al., 2017). Thus, a threshold of 250 hours was chosen to focus the evaluation on the segment of pilots that would be most likely to benefit from training in aviation weather. The evaluation divided students into two groups, one using the AR thunderstorm training tool and the other group using traditional 2D training materials. Pre- and post-evaluations were conducted to compare students' knowledge both visual and factual. The result of the evaluation found that there was a statistically significant increase in factual knowledge (from 71% to 91%). Visual knowledge also increased from 55% to 90% in a statistically significant manner. To evaluate students' experience with the AR application, post-trial surveys were given on the application's usability, user motivation, and overall experience. The System Usability Scale (Brooke, 1996; Sauro & Lewis, 2016), which comprises ten items designed to measure perceived usability was used. Results showed the AR thunderstorm training tool's excellence in usability,

with a score of 82.4 out of 100. Furthermore, participants reported positive learning experiences with high motivation, a reasonable task load, and efficient completion times.

Though the previous work has proved to be extremely effective in assisting pilot weather theory training, a significant challenge was identified during the development process. The scenario of the thunderstorm simulation was developed based on expertise from experienced flight instructors. However, each flight instructor had their own goal and perspective of what a scenario should contain. The final scenarios in the application were a compromise among the experts, while each would like to create their own customized scenarios to complement their exact teaching style. As a result, a new solution is to allow instructors to build their own scenario that fits their teaching purpose. However, customizing XR content is challenging for instructors who do not have any coding or developing skills.

XR Content Creation

While numerous studies have highlighted the advantages of XR training including the previous work of the authors, there are also challenges highlighted regarding content creation. Existing research primarily focused on investigating the effectiveness and impact of diverse XR content or applications in various educational domains. The content used in these research projects is mostly developed by skilled programmers using complex development platforms (Meccawy, 2022). As a result, instructors who want to use XR in their teaching face difficulties in creating content due to limitations in programming skills and overall development knowledge (Cook et al., 2019; Ziker et al., 2021). A survey paper examined 42 studies on the use of XR technology in education and highlighted the lack of end-user development tools (Kuhail et al., 2022). The authors noted that most studies in their survey relied on Unity and Vuforia, tools that require significant development expertise to use effectively. An important note is that many flight instructors do not have skills or a background in software development and that is why using tools such as Unity or Vuforia is challenging.

At the same time, currently available tools for teachers are limited in creating static or non-interactive content rather than a complete XR experience. Another survey paper reviewed 69 different AR authoring toolkits (Dengel et al., 2022). The survey revealed that among 26 open-access toolkits, only 10 (38.46%) were GUI-based and did not require any coding knowledge. Out of these 10 GUI-based toolkits, only five could create interactive experiences. However, being open-source most required expertise to download, compile and run. Of the few commercial tools available for non-developers, most are prohibitively expensive. Additionally, existing research indicates that while there are non-programming authoring tools available, they lack certain interactive features necessary to maximize the benefits of AR training, such as complex simulation controls, assessment capabilities, and personalization (Vert & Andone, 2017).

Current research on XR authoring can be divided into two different purposes: 1) for rapid visual prototyping where most of the authoring interactions happened inside the virtual environment (Kirner & Cerqueira, 2012; Seichter et al., 2008; Zhang & Oney, 2020) and 2) to allow zero- or minimum- programming skilled users to create their own XR content (Haringer & Regenbrecht, 2002; Horst et al., 2022; MacIntyre et al., 2004; Rau et al., 2022; Vert & Andone, 2017; Villanueva et al., 2020). However, for the research conducted on creating tools for non-programmers, the design criteria did not take an instructor's needs into consideration as many of the tools can only create simple 3D geometries, without complex interactions and are very generic in their model choices (e.g., cubes, blocks, and low polygonal models).

Examples of platforms designed for content creation in AR for non-programmers include basAR, ComposAR, and ARtalet. basAR is an AR authoring tool where a virtual interface is associated with a physical maker and allows users to create and modify virtual objects such as circles, squares, and triangles in an AR environment (Kirner & Cerqueira, 2012). Though there is no programming skill required, no user interactions or animations can be created. ComposAR is an AR authoring tool that allows for runtime optimization and visual coding for non-programmers (Seichter et al., 2008). However, the tool is provided for rapid AR application design and development instead of creating training content. The target user is a content designer instead of a trainer or instructor. ARtalet used a web camera and a pc to enable an authoring AR environment where users can implement, translate, and reshape pre-defined 3D objects to create customized content (Ha et al., 2010). The manipulation process in this platform is mostly on the AR environment, and only with the pre-defined shapes available.

METHODOLOGY

The objective of this research was to conduct preliminary interviews from experienced flight instructors and utilize the insights gained to develop an effective authoring tool for XR weather content. During the interviews, participants were asked, among other things, how they currently teach weather theory and how they would utilize XR in their teaching environment. The study was approved by the Institutional Review Board and the insights from these interviews guided the design and development of the authoring toolkit presented later in this paper. Therefore, the methodology section will first describe the study and interview process, then how the results directed the development of the XR weather authoring platform.

Study Design and Procedure

In order to investigate the user requirements of XR authoring toolkits for flight instructors, a qualitative approach was selected. In-depth interviews were carried out with subject matter experts possessing knowledge of aviation weather training. Firstly, participants discussed their backgrounds, teaching approaches, and insights on how students acquire and apply weather knowledge. Next, they rated their likelihood of using XR-based teaching materials and discussed how to integrate XR into their aviation weather education. They also provided insights on desired features for XR authoring.

Ten participants (7 males and 3 females) with diverse aviation backgrounds were recruited. The average age of the participants was Mean=40.8 (Standard Deviation =11.0) years old. All participants completed aviation meteorology courses. A total of nine participants held FAA certificates and ratings as follows: Seven participants held Commercial and Instrument Pilot certificates, and three held Private Pilot certificates. Six participants were FAA Certified Flight Instructors, and four of them also held the Certified Flight Instructor – Instrument certification. Additionally, five participants possessed FAA ground instructor certificates, including Basic Ground Instructor, Instrument Ground Instructor, and Advanced Ground Instructor certifications. On average, participants had Mean=6.9 years (Standard Deviation=8.1) of experience teaching aviation weather.

The interview transcripts underwent analysis using inductive reasoning, which is a systematic approach where researchers derive comprehensive conclusions from the observed data (Juliet et al., 1990). This process entailed analyzing the data in a bottom-up approach to construct knowledge and put forth new theories (Walch, 2004; Govier, 2013). Inductive reasoning is especially beneficial when existing theories are insufficient or nonexistent, enabling researchers to formulate inductive generalizations regarding the phenomenon under investigation.

Study Results

Instructors felt that AR in education could enhance student's motivation by leveraging the interaction possibilities afforded by AR. Furthermore, they felt that AR could help students visualize complex concepts to bridge the gap between theory and practice. Instructors expressed a desire to be able to create personalized learning experiences that cater to individual student needs, as long as the tools were easy to use and not time consuming. Finally, instructress felt that AR could capture student attention and help them develop a deeper understanding of the material.

The interview revealed that the user needs could be grouped into two types: aviation weather training and educational XR authoring. Aviation weather training requirements encompass specific user requirements aimed at developing the XR authoring toolkits for teaching aviation weather. On the other hand, educational XR authoring requirements encompass broader user needs applicable to generic educational XR authoring toolkits.

Customizability in the XR authoring toolkit was deemed important by the participants. Specifically, they expressed the need to specify the waypoints (latitude and longitude) with corresponding altitudes for flight. In addition, they desired the ability to customize the weather, such as specifying the size, speed, and direction of thunderstorms. Furthermore, they emphasized the importance of incorporating realistic scenarios that students could relate to, as this would enhance motivation. Incorporating aircraft models and visualizing wind direction, temperature, icing, and precipitation of thunderstorms were preferred to create more authentic scenarios.

Instructors expressed a strong desire for a set of teaching elements, including text boxes and quizzes. They mentioned the importance of providing instructions directly within XR. Text boxes were deemed particularly valuable in noisy

environments where verbal instructions might be difficult to hear. Furthermore, instructors showed their intention to incorporate quizzes into XR content to assess and improve knowledge retention.

Participants also suggested functionalities such as fast-forwarding, rewinding, or jumping to specific time points in XR scenarios or animations. They expected that the time adjustment function would enable students to independently revisit lesson content, enhancing students' comprehension by enabling them to independently revisit lesson content. Additionally, participants further mentioned their desire to control the student's initial view location. This would enable them to manage the distance between the main scene they developed and the position of the student's camera.

Requirements

Information from the interviews were used to develop a set of requirements for an XR Authoring tool. Table 1 lists the specific user requirements that were determined along with the more general user needs and categories that they fit within.

Table 1. List of User Requirements

Category	User Needs	User Requirements
Aircraft & flight path	Customizability	Specify flight path, altitude, and aircraft model
Thunderstorm	Customizability	Specify TS size, speed, direction, and location
Thunderstorm	Customizability	Visualize wind direction, temperature, icing, and precipitation of TS
Teaching elements	Text boxes	Instructional text box
Teaching elements	Text boxes	Define learning objectives
Teaching elements	Text boxes	Billboard labels in 3D scene
Teaching elements	Assessment tool	Quiz with multiple choice question
Teaching elements	Time adjustment of animation	Specify the duration of animation (e.g., TS cycle)
Interaction	Customizability	Drag and drop capability to add 3D objects (e.g., terrain, airport) into 3D scene
Interaction	Customizability	Choose 3D objects from predefined asset libraries
Interaction	Time adjustment of animation	Start and stop animation (e.g., TS cycle)
Interaction	Customizability	Users choose what weather filters (icing, winds, etc.) to include in scenario
Interaction	Time adjustment of animation	Slider control to adjust time

Authoring Tool Development

The next step of this research was to develop the XR weather authoring tool under the goals stated earlier of: 1) a solution allowing the creation (i.e., authoring) of customized flight scenarios with no programming skills and 2) the user interface (UI) for such a solution needs to be extremely intuitive taking minutes to understand. As discussed, the user study interviews provided key insights into the needs of pilots and instructors for weather related training, using XR technologies. These insights were transformed into technical requirements in a formal development process. The following section will discuss the development of this XR authoring tool and design decisions that were influenced by the user study.

Software Implementation and Structure

The authoring tool was developed using the Unity game engine. Unity provides many tools for 2D and 3D interfaces leading to quick development iterations. This is necessary as the authoring tool includes a 2D editor as well as 3D graphics to preview the content. Further, the multiplatform capability of Unity allows for the tool to be accessible on both Windows and macOS desktops and laptops. Research into the demographics and technical competency of typical flight instructors led to the conclusion that a desktop application would be most appropriate and serve this audience well from a usability and familiarity perspective. Even though Unity is being used as the primary development tool, the flight instructors don't need to have any knowledge of it. They will receive a brand new desktop application with a simple to use interface.

In order to enable instructors to develop and customize XR weather aviation applications, the authoring tool has been designed with three main user interface (UI) windows:

- The Editor window allows instructors to create and edit 3D or teaching elements in a scenario. The Editor window consists of four panels, including the assets panel (for accessing controllable elements), information panel (for modifying object attributes), top-down perspective panel (for positioning and arranging 3D elements) and 3D viewer panel (for real-time 3D environment preview).
- The Setup window allows instructors to customize 2D user interface elements and their corresponding features in a scenario.
- The Preview window provides a comprehensive view of the entire scenario with both 2D UI elements, teaching elements, and 3D elements.

Editor Window

Many of the requirements indicated by the user study included the creation and customization of aviation related weather entities such as thunderstorms, microbursts, clouds, aircraft, and learning elements. The high degree of customization required, paired along with an intended user having no programming experience, presented an immense challenge. In order to address this challenge, an editor window was designed to provide users with the capability to intuitively drag and drop assets and customize the related attributes as necessary. However, it was key to not overwhelm a user with unnecessary features or options when adding an element to a scene. Figure 2 shows an example of the editor window. A library of high-level weather assets is provided and shown on the top left of Figure 2. The user can drag and drop from this list into the 2D grid where the bulk of the authoring process takes place. Often, it can be difficult for users to navigate, create, and modify in 3D. Therefore, the 2D grid provides a coordinate system for the user to locate assets in the horizontal plane. The location of the asset is defined by taking the 2D position of the mouse relative to the confines of that window. This position is then normalized to screen resolution and multiplied by the scale of the grid to get a final 3D position in feet. A user can set the height, and other related attributes, of the individual assets by selecting the icon. The 3D viewer under the 2D grid provides a preview in real-time so the user has a better representation of what they are authoring. This method of auto-generating the 3D positions eliminates a user from having to build a mental model from 2D elements, a challenging task for many users.

Teaching elements such as supplemental text information and quizzes were also deemed necessary by many of the interviewees from the study. To address this need, the assets library was extended to include these teaching elements as well. In order to maximize usability of the environment, these elements' function use the same drag and drop system where the user simply places the icon and then can select attributes. For quizzes this includes when in the simulation the quiz appears, the question, and the answers. Supplemental text information functions under the same principal but would only include the timing and text content. Despite seeming like a simple concept, the feedback from interviewees was critical in ensuring the proper capabilities were implemented in an intuitive manner.

The final consideration regarding the editor window is how the user navigates through the timeline of the authored simulation. To address the feedback from the interviewees, a simple play/pause button was implemented with a slider timeline, as opposed to an individual timeline for each element that requires use of keyframes and other video production concepts. The content in the 3D viewer is represented temporally based on the progress slider timeline. This allows a user to visualize where one asset is located spatially relative to another at a given time, such as the position of an airplane at a specific stage of a thunderstorm cell. The user can then scrub through the timeline by dragging the slider or play/pause the simulation using the button. Allowing animation customizations directly in the editor window with a single timeline, greatly simplifies the user interface.
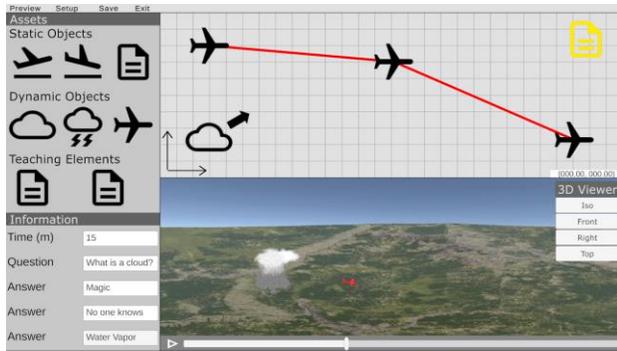
Figure 2. The Editor Window

Setup Window

To further enhance the customization capabilities of the authoring tool, a simple setup window was developed. Interviewees from the study often reported they wanted to be able to control what the student saw both in terms of content and the UI itself. Therefore, the setup window provides the default UI with every option available, shown in Figure 3. The user can then select the yellow checkbox next to each UI element to decide what a student will see when using the developed scenario. Other customization options such as total simulation time and the terrain are included in the setup as they are general options and are not spatially located in the scene. These settings are imperative to the functionality of the platform as many of these user defined values dictate the scale and timing of the simulation. Allowing a user to customize the interface definition in the actual layout that will be used in the final application, removes confusion about what will be seen, accessible, etc.

Figure 3. The Setup Window

Preview Window

The preview window gives the user a representation of what the simulation will look like for the student as shown in Figure 4. This intermediate step allows a realistic view of the final scenario without having to build executable code and deploy to the device intended for students to use. The preview window allows the instructor to ensure all their needs are met and that the proper functionality is present. An outline of a mobile device is provided to give a visual representation of what the simulation will look like with proper resolution and aspect ratio. Further, the learning elements can be previewed in this window. Since learning elements were a critical requirement from the interviews, it is imperative that the quizzes and supplemental information is presented how and when the instructor intends in relation to all other elements in the scenario (e.g., thunderstorm, aircraft, etc.).
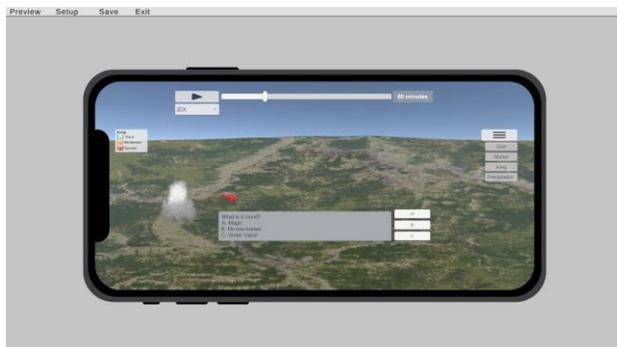

Figure 4. The Preview Window

EVALUATION

The XR weather authoring tool was evaluated in terms of meeting the user requirements determined by the flight instructor interviews as well as key technical performance metrics. This preliminary technical evaluation involved a test weather training scenario designed by expert aviation flight instructors. Then, the scenario was implemented for use in XR using the authoring tool described in this paper. The training scenario selected involves the creation of a thunderstorm cell lifestyle with custom characteristics and teaching elements.

The authoring process of this scenario included the creation of a thunderstorm model, setting the thunderstorm attributes, including an airplane and flight path, adding text elements, adding a mid-simulation quiz, and ensuring the correct visual overlays are available to the student. The specific authoring tasks are provided in **Error! Reference source not found.** and the test scenario in the authoring tool is shown in Figure 6. The authoring tool was able to meet the user requirements from the instructor interviews showing the potential of this tool to design numerous weather training scenarios.

Authoring Task:
1. Add a text screen to provide the following learning objective of this AR-based activity.
   a. "In this activity, you will identify the avoidance procedures that are relevant to the given takeoff situation"
2. Set a total simulation time to 50 min.
3. Specify the terrain as Mountain City.
4. Control the options regarding the thunderstorm model as follows:
   a. Turn off Grid, Motion, Wind, Icing, Temperature, Precipitation
   b. Turn on Label
5. Add and place the thunderstorm model at the center of the 3D scene.
6. Specify the timing of the thunderstorm animation, i.e. when it starts and ends.
   a. Timing: 20-50 min
7. Specify the size, movement direction, and speed of the thunderstorm as follows:
   a. Size: 15 miles (in diameter)
   b. Heading: West
   c. Speed: 10 Knots
8. Add and place an airport closer than 20 miles to the thunderstorm.
9. Specify the size of the airport as follows:
   a. Size: 2 sq miles
10. Add and specify a short flight path that departs from the airport, taking off in the opposite direction of the thunderstorm.
    a. Specify five waypoints of the flight path
11. Add the following quiz associated with thunderstorm avoidance activity.
    a. Question. Should you takeoff or should you delay your takeoff or choose an alternative plan?
    b. Answers.
       i. Take off now as planned
       ii. Delay departure for one hour
       iii. Delay fight until the weather improves

Figure 5. Test scenario authoring task

The steps in Figure 5 provide an example of how the authoring tool enables instructors to create and modify specific features for an educational module to enhance pilot competency. For example, in step 4, instructors can control whether various visual features are enabled during a scenario to help pilots understand precipitation changes occur as a thunderstorm moves through its lifecycle. In addition, steps 7 and 8 allow instructors to control a thunderstorm's speed and direction relative to an airport, showcasing the potential for teaching different takeoff and landing scenarios.
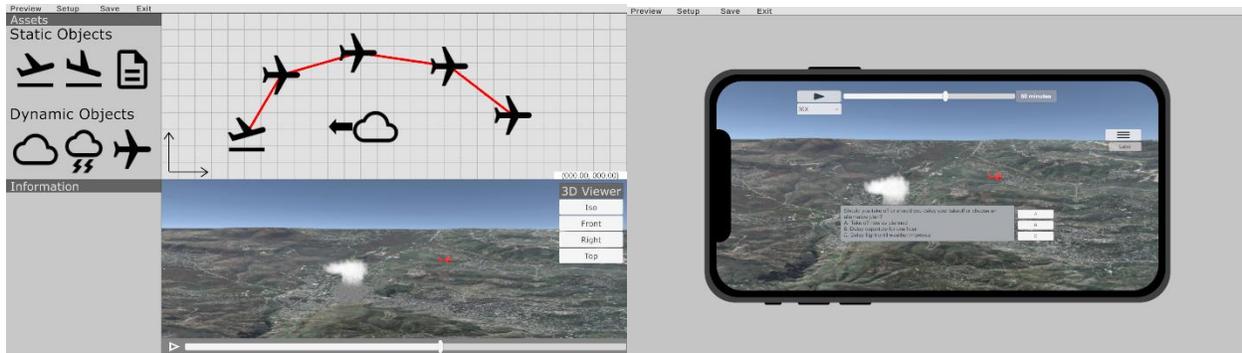
Figure 6. Test scenario created using authoring tool

For ease of use, the authoring tool was built into a self-contained executable that requires no installation process. Further, the executable only requires ~129 MB of storage and can be compressed into a zip folder for software delivery. This is advantageous from an accessibility standpoint as there is no expertise requirement for the flight instructor. In addition, the authoring tool was tested on a 2020 MacBook Pro with integrated graphics as well as a Windows PC with a dedicated NVIDIA 3080 Ti graphics card. In both cases, the framerate was limited to the display's refresh rate of 60hz using vertical sync. The authoring tool always maintained a consistent 60 frames per second during the authoring of the test scenario regardless of what window or function was being used to create the test scenario.

CONCLUSION

The utilization of XR in training and education has been extensively researched and revealed numerous benefits. Previous work successfully implemented a thunderstorm training simulation in a marker-based mobile AR application, receiving positive evaluation feedback. However, flight instructors express the need for customization options to align scenarios with their teaching objectives. The present study identified gaps between instructional needs and available tools for GA weather training. Current authoring tools either require coding skills or lack the ability to create complex and interactive content. In-depth interviews were conducted to gather insights and ensure the tool's features aligned with instructor needs. The development process involved a careful balance between incorporating insights from the interview results and maintaining an appropriate complexity level for the tool. As a result, the initial modular and user-friendly XR authoring tool prototype for GA weather training has been developed. This tool provides flight instructors with the means to create customizable weather-related flight scenarios, including clouds, thunderstorms, and flight paths, enabling pilots to practice decision-making. For future work, an evaluation of the authoring tool as a teaching aid will be performed to gather feedback to further enhance the authoring tool's capabilities and explore additional features to enhance its utility in aviation training.

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