



PEGASAS Project 33

Augmented Weather Interfaces Project

AWIP Presented by
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2025 PEGASAS Annual Meeting

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Although the FAA has sponsored this project, it neither endorses nor rejects the findings of this research. The presentation of this information is in the interest of invoking technical community comment on the results and the conclusions of the research.

- 2024 summative evaluation of **XR authoring framework**
- Area 1: **Deployability** XR of authoring and distributing XR-enhanced Educational Content
- Area 2: Assess effectiveness of **MR training device**
- Area 3: Assess **decision-making models** to train to adaptive behavior by pilots in weather.
- Area 4: Assess the approaches to enable an **AI-based pilot training** and education

- **2024 Summative Evaluation of XR Authoring framework**
 - **Motivation:** Instructors motivated to create their own lessons in XR due but widespread use limited by instructors' digital proficiency
 - **Aim:** XR-training authoring framework to enable instructors to create customized XR weather training
 - **Methods/Results:** Summative evaluation of XR Authoring with instructors, experts, and students
- **Area 1: Deployability of authoring and distributing XR-enhanced Educational Content**
 - **Motivation:** Instructors need a simple way to deployability of XR modules to students
 - **Aim:** Focus on key challenges in deploying the XR software system for use by instructors and students.
 - **Methods/Results:** Scalable system architecture to managing instructor XR creation student use on their mobile or tablet platforms
 - **Next Steps:** implement instructor platform to access and share created XR learning models
- **Area 2: Assess effectiveness of MR training device**
 - **Motivation:** Determine if combination of XR and flight simulation can provide pilots with valuable flight experiences to enhance weather-related decision making.
 - **Aim:** In collaboration with FlightSafety International (FSI), gather an increased understanding of use cases, limitations, challenges and best practices.
 - **Methods/Results:** Partnering with FSI assessing Mixed Reality (MR) for enhancing VFR into IMC decision making and avoidance.
 - **Next Steps:** Initial formative evaluation of VMC into IMC weather avoidance XR training benefits

- **Area 3: Assess decision-making models to train to adaptive behavior by pilots in weather.**
 - **Motivation:** Experience pilots tend to search for a match to a feasible solution; if none available, they will utilize analytical methods
 - **Aim:** Assess use of human cognition models to train adaptive pilot behavior in weather
 - **Method/Results:** Literature review of cognition models plus interviews with experienced pilots
 - **Next Steps:** Validate cognition models ability to represent adaptive pilot decision making
- **Area 4: Assess the approaches to enable an AI-based pilot training and education**
 - **Motivation:** Large Language Models use large amounts of data to train/test AI, but customizing for aviation weather training requires complex validation.
 - **Aim:** Assess the approaches to enable an AI-based pilot training and education
 - **Methods/Results:** Acquired weather-related training aids and processing them for input to AI. Identified and acquired base open-source AI models
 - **Next Steps:** Complete training of base AI models. Establish evaluation criteria. Input specific weather-related training data into model

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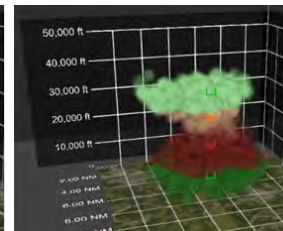
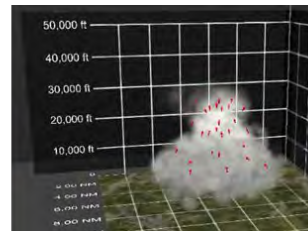
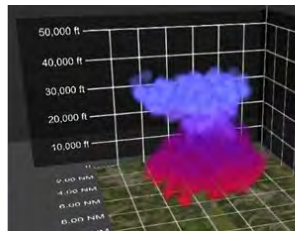
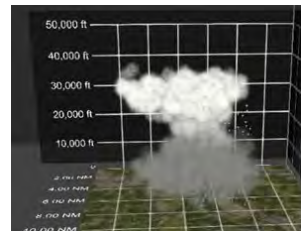
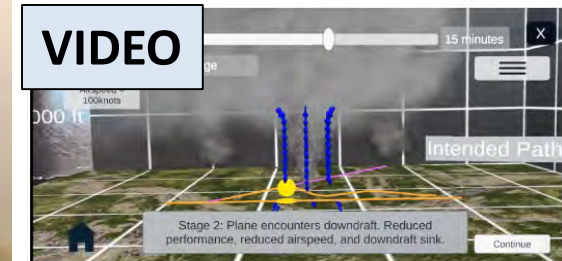
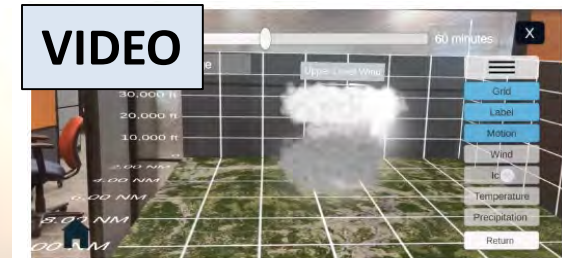
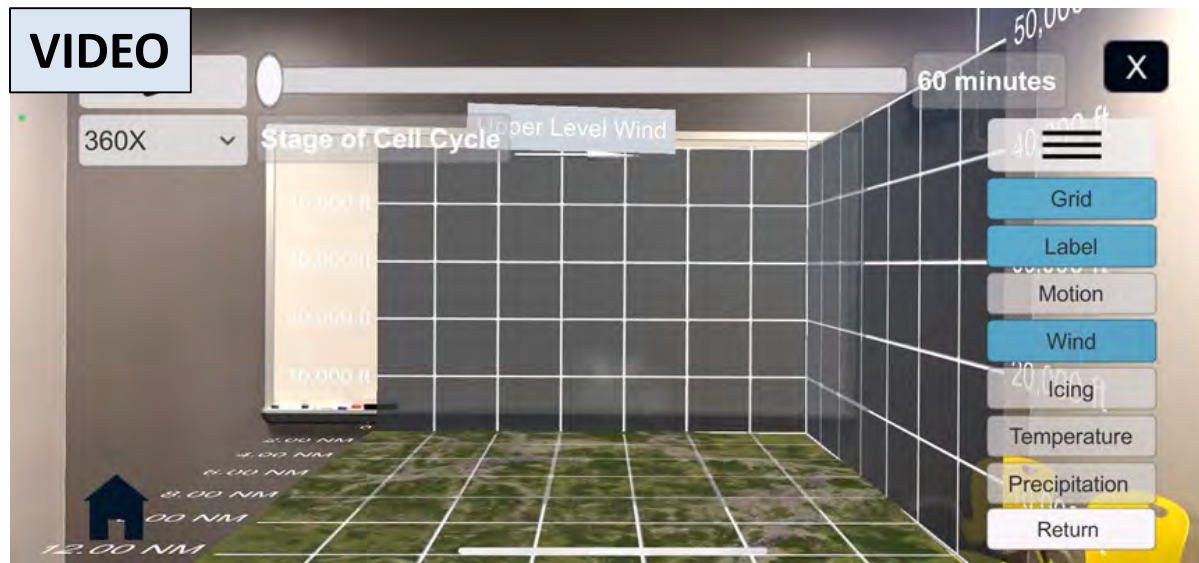
2024 Summative Evaluation of XR Authoring Tool for Aviation Weather Training

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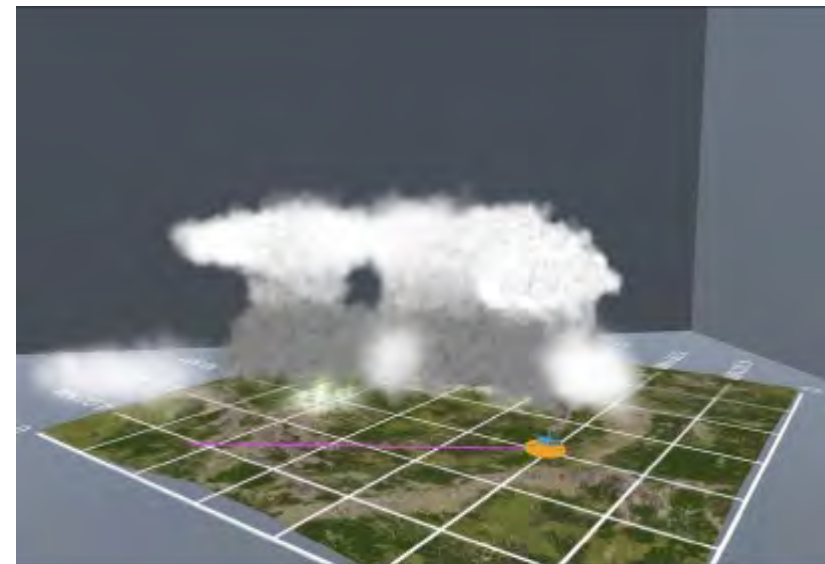
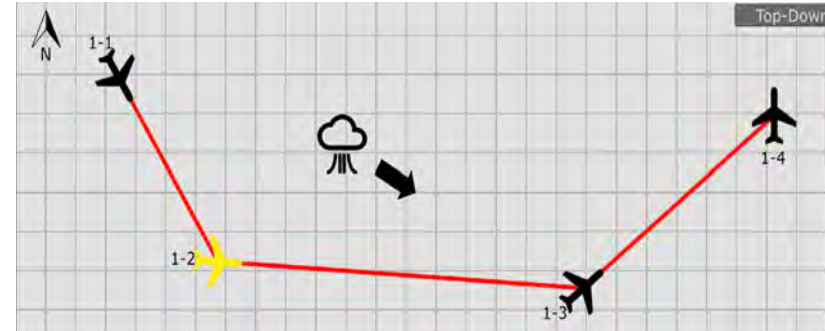
- Previous work demonstrated educational benefit of XR weather training



- Instructors motivated to **create their own lesson** modules in XR to leverage benefits
 - **Engagement**, making abstract ideas **tangible**, **scenario-based** training
 - XR can **capture students' attention** and foster a deeper connection with the subject matter
- Challenges for XR adoption
 - Instructor's limited digital proficiency
(Sánchez et al., 2021; Tzima et al., 2019; Akçayır & Akçayır, 2017; Ashtari et al., 2020)
 - Technical complexity of XR authoring toolkits
(Gaspar et al., 2020; Yang et al., 2020; Ashtari et al., 2020; Nebeling & Speicher, 2018)
 - Time-consuming nature of XR authoring (Kim et al., 2024; Alalwan et al., 2020)

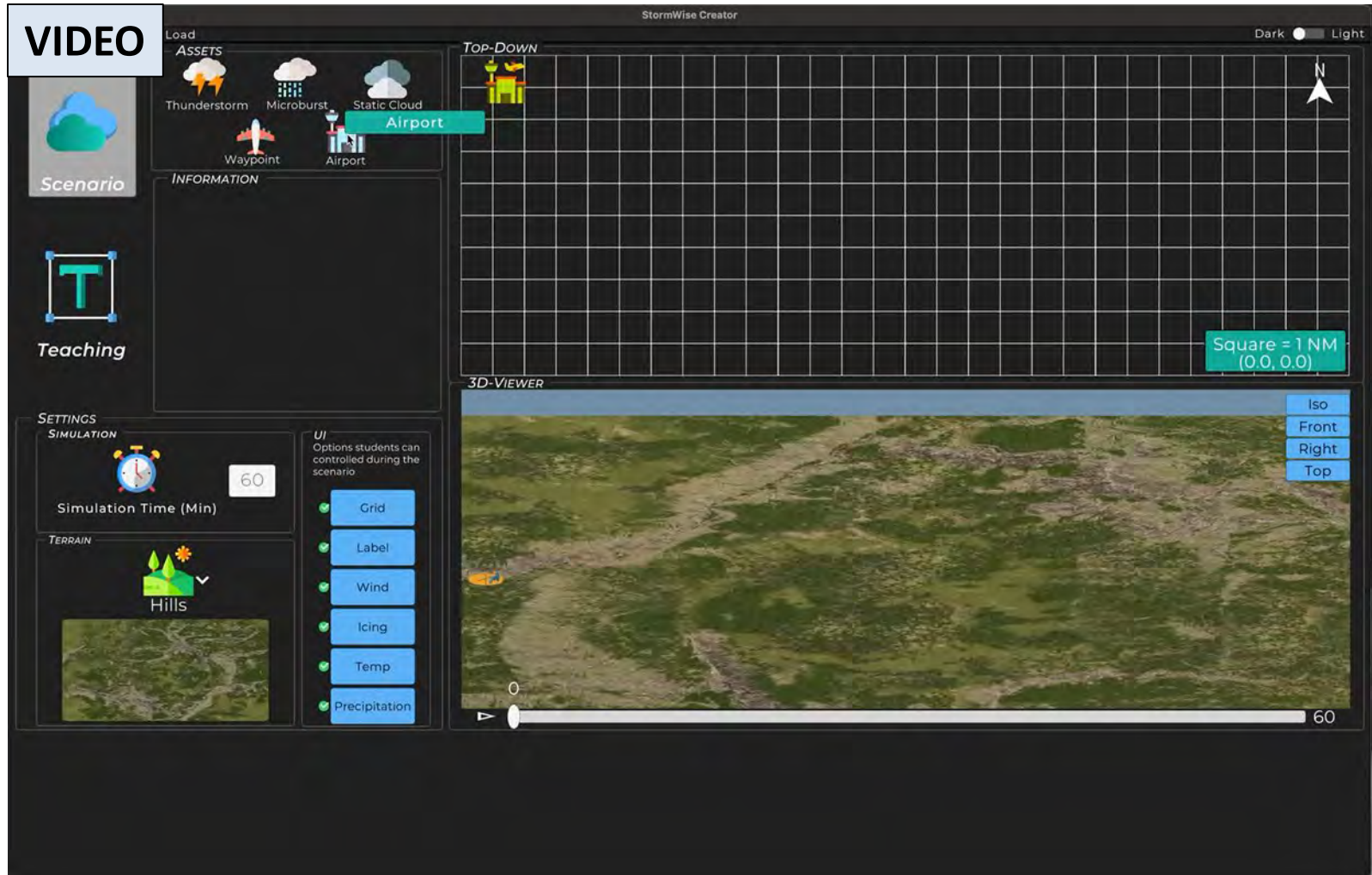
Research Objective

- **Empower instructors** with limited digital proficiency to interact with **weather objects** and scenario elements in aviation weather education using XR
- Shift the focus from technology-centric toolkits to a **content-centered approach**
- Incorporates an **instructor-centered approach**, utilizing evidence-based research and iterative improvement process





XR-Authoring Tool Demonstration



VIDEO



XR Application Availability

- **StormWise** available on Apple App Store and Google Play Store
- **StormWise Creator** available on the Mac App Store (to be published on Microsoft Store)
- **User guides:**

<https://stormwise.net>





Flight Instructors

- **Phase 1:** Evaluate the effectiveness of XR authoring tool from the **flight instructors'** perspectives



Expert Panel

- **Phase 2:** **Expert panel** assesses educational quality of XR learning modules produced by flight instructors using XR authoring tool



Students

- **Phase 3:** Access **student** learning outcomes and engagement using produced XR learning modules



Phase 1: Evaluate XR Authoring Tool with flight instructors

Objective

- Evaluate effectiveness of XR authoring tool from flight instructors' perspectives

Participants

- 30 flight instructors (23 M, 7 F)
- Age: 50.8 (SD=16.4)
- 8.9 (SD=10.7) years teaching aviation weather
- 4,858 (SD=7,083) Flight hours

10-15 min	10 min	20 min	5-10 min	10 min	5 min
Tutorial Session - 5-min Video - Have time to get familiar with tool	Pre-Exp Survey	XR Lesson Creation 1 (Sample Scenario)	XR Lesson Creation 2 (Self-Chosen Topics)	Post-Exp Survey	Debrief

Task: Develop two XR lessons

- 1) Thunderstorm avoidance (with prebuilt lecture notes)
- 2) XR lesson creation based **on own choice of topics**

Dependent Measures

- Confidence in XR Authoring
- Perceived Challenges in XR Authoring
- Perception of XR's Educational Value
- NASA Task Load Index
- System Usability Scale
- Time to Completion
- Use cases of XR



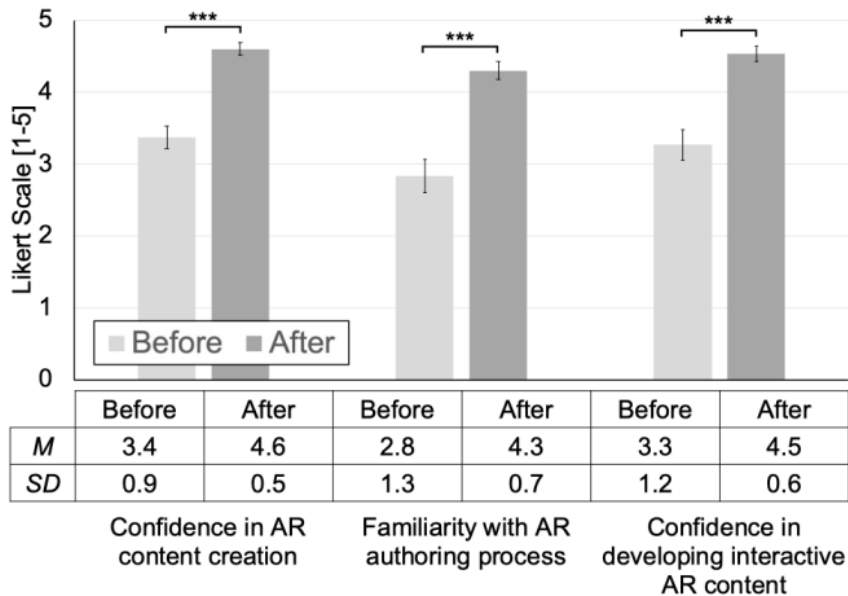
Phase 1: Evaluation with Instructors

Summative Evaluation Results

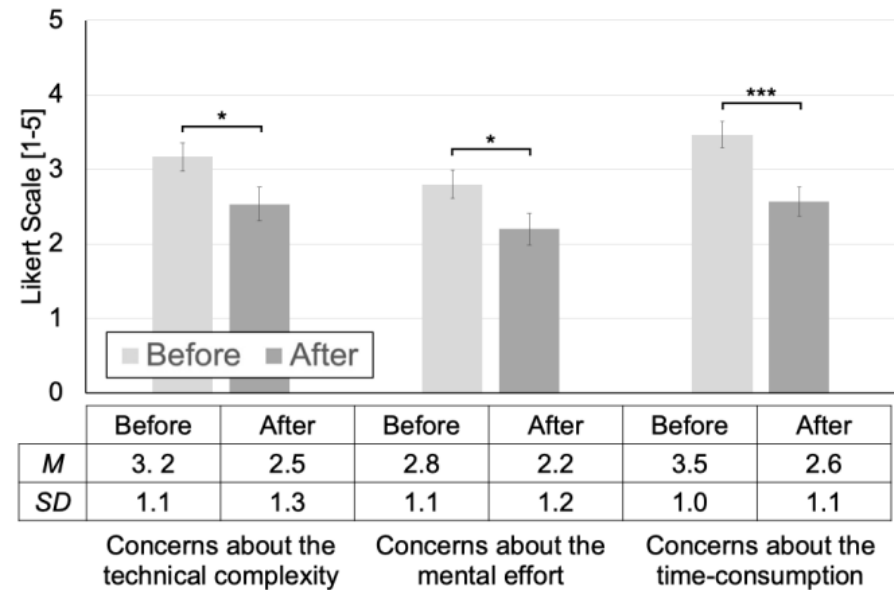
Seven Aviation weather topics covered

#	Topics	Frequency
1	En-Route Aeronautical Decision Making	10
2	Approach Aeronautical Decision Making	4
3	Risk Management	4
4	Thunderstorm Education	4
5	Preflight Planning	3
6	Microburst Education	3
7	Other Topics (Structural Icing & Cold Front)	2
	Total	30

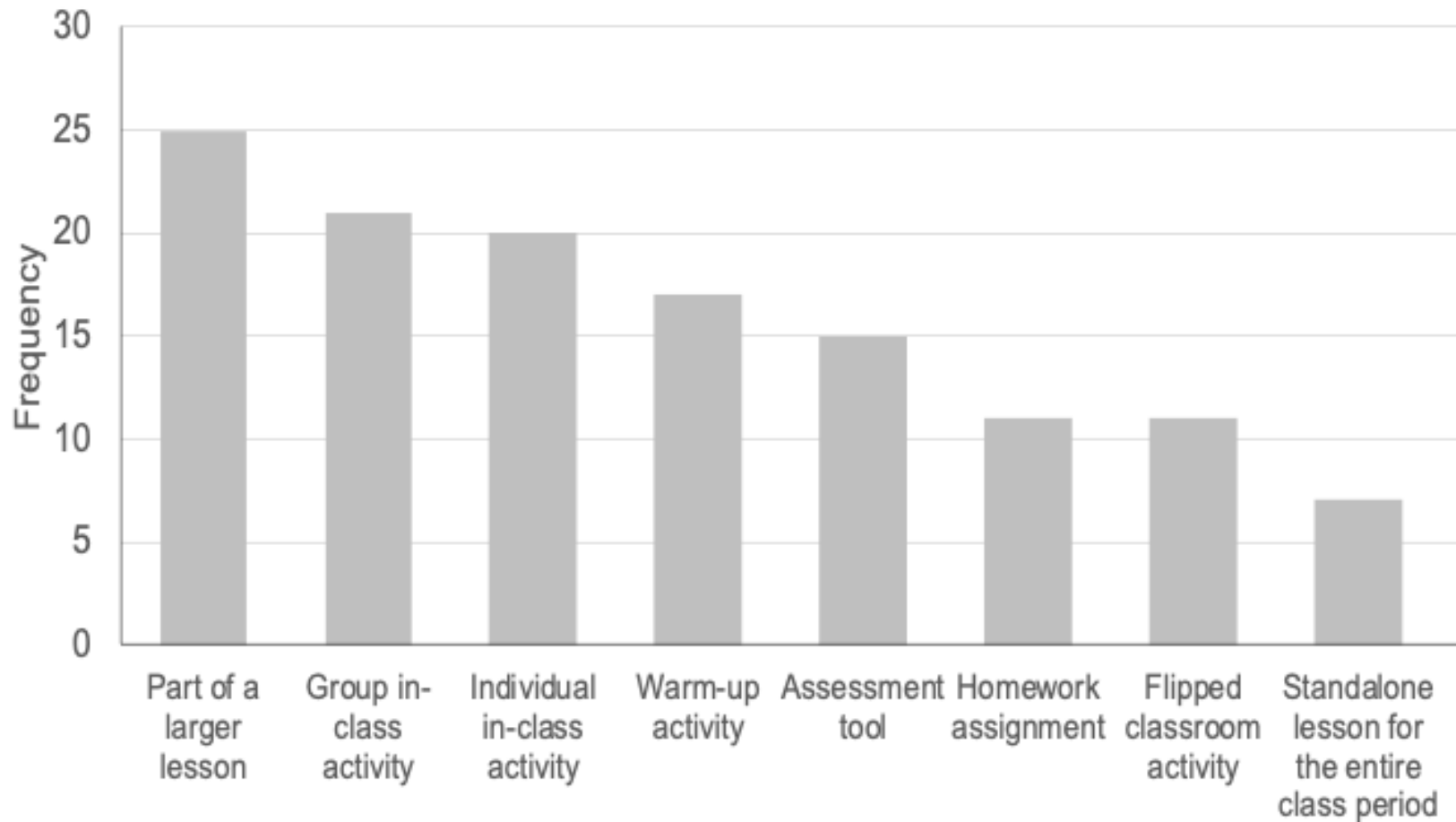
Increased confidence



Reduced concerns

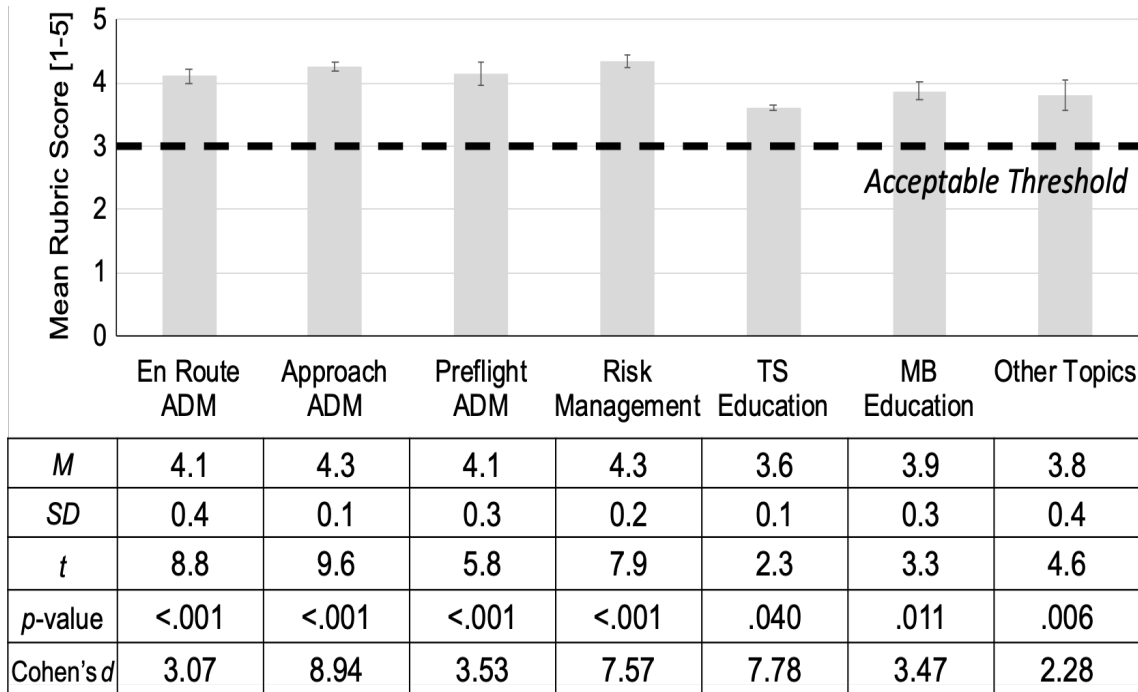


- High usability and requires low workload
 - High usability, as indicated by SUS
 - Low NASA TLX scores indicated a manageable workload for creating XR lessons
- Time Efficiency
 - Approx. 17 min to create XR modules with the tool



- Objective
 - Expert panel assesses educational quality of XR learning modules
- Participants
 - 3 SMEs (1 M, 2 F)
 - 19.0 years ($SD=13.5$) experience with AR/VR usage in aviation training
 - 2 taught aviation weather-related lessons
 - 3 were pilots, 2,730 flight hours ($SD=2,973$)
- Evaluation Rubrics [1-5 Likert Scale]
 - Learning objectives
 - Clarity
 - Correctness
 - Assessment alignment
 - Effective feedback
 - User engagement

Phase 2 Results: Quality of XR Lessons



Out of 30 modules, 29 scored greater than or equal to the acceptable threshold of 3 in all six rubric criteria.

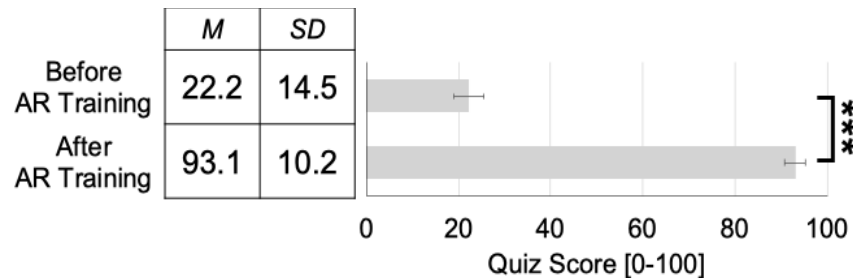
- Objective: Access student learning outcomes and engagement
- Participants
 - 21 (9 M, 12 F)
 - 18 of 21 had experience with AR in general
 - 1 out of 21 had experience using AR for learning
- Task: Learn from 5 instructor-developed XR
 - 2 preflight planning
 - 2 microburst education
 - 1 en-route ADM



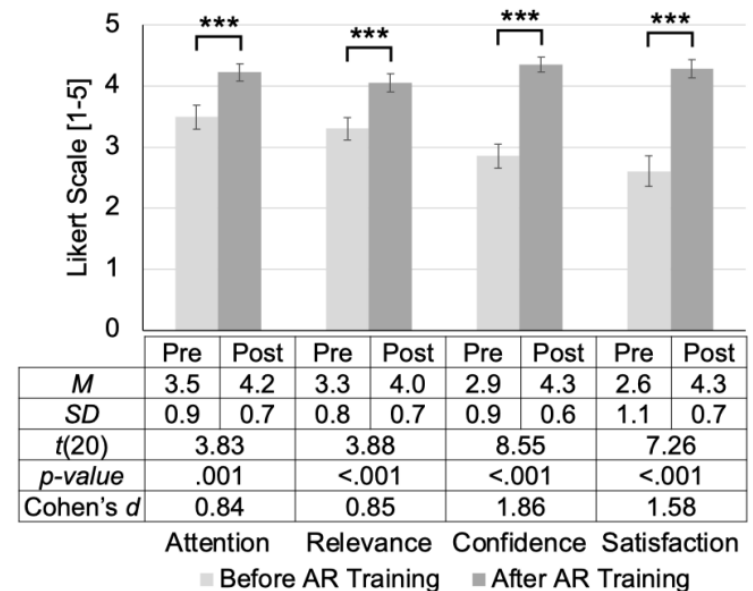
- Dependent Measures
 - Aviation weather knowledge
 - NASA task load index
 - System usability scale
 - Net promoter score
 - Time to completion

Phase 3 Results: Increased weather knowledge and motivation

Aviation weather knowledge



Motivation survey





Impact of XR-Training Authoring Approach for Aviation Weather

- Enhance student weather training
 - Provide **early access** to exploratory and activity-based learning
 - Provide **experiential learning opportunities** to let novice pilots make judgement errors in a safe environment
- Enhance instructor teaching options
 - Reduced technical barriers, **empowering instructors** to focus on educational content
 - Potential for **broad application** in fields requiring 3D visual cues for decision-making
- Lower barriers to adopting advanced educational technologies
 - Students can access experiential learning modules on **consumer devices**
 - Instructors can **easily create or modify** XR learning modules
 - Broaden **access** to high-quality XR in aviation training



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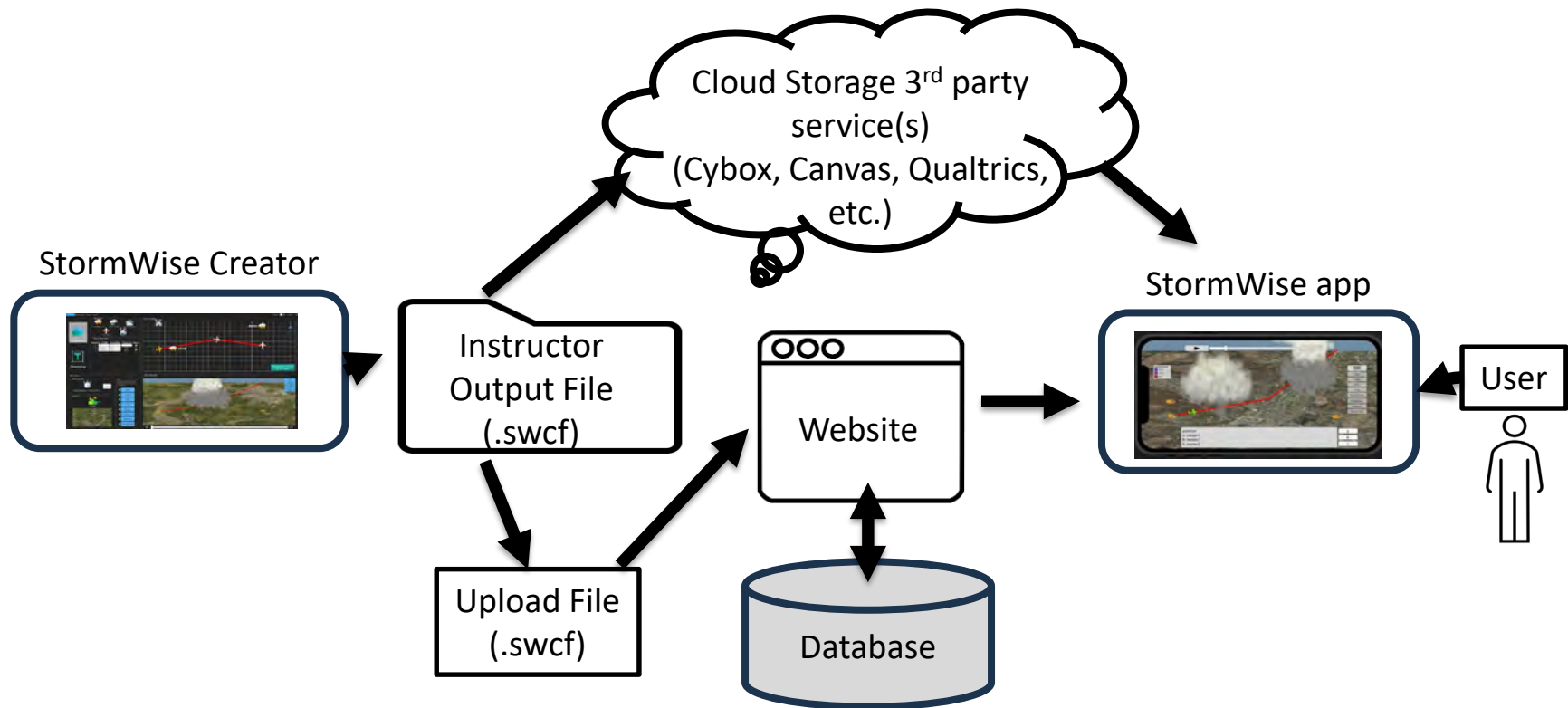
Task 1: Feasibility and Benefits Assessment of XR GA Weather Training

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- Objective
 - Develop and test a user management system that manages users and content and facilitates transfer of StormWise Creator content from instructors to students
- Scope
 - ISU and WMU team tests and evaluates the system and a formal evaluation at ISU
- Impact
 - Provides a model that other flight instruction entities can utilize with the XR student and instructor applications

User Management System: Architecture





Task 2: Assess the Effectiveness of MR Device.

Mixed Reality Weather Decision-Making Study

Pilot Evaluation of Training Effectiveness and Safety Impacts



- 63% of fatal IMC-related GA accidents involve poor decision-making (FAA 2023).
- Continued VFR into IMC is a major risk factor for GA pilots (NTSB).
- MR can help pilots recognize deteriorating weather conditions in a safe and fully immersive environment.



Framework

Objective: Assess effectiveness of mixed reality simulation to enhance weather-related training and decision-making.

Impact: Enhance weather-related training to support improved avoidance of VFR into IMC conditions and related decision-making within GA pilots.

Task 2 Overview

- This study evaluates the effectiveness of a Mixed Reality (MR) simulator in training general aviation (GA) pilots to recognize and respond to deteriorating weather conditions.
- Nineteen GA pilots participated in a comprehensive evaluation involving structured surveys, open-ended feedback, and post-simulation interviews.
- Findings indicate high usability, increased situational awareness, moderate cognitive demand, and strong training value, especially for weather risk recognition and decision-making.
- Results support MR as a valuable supplement to traditional aviation training curricula, with potential for FAA integration to address VFR into IMC accident risks.

FSI MR Flight Training Device

The mixed reality experience, through MR Varjo XR-3 headset is integrated with FlightSafety's VITAL 1150 Visual System offering a 360° view.



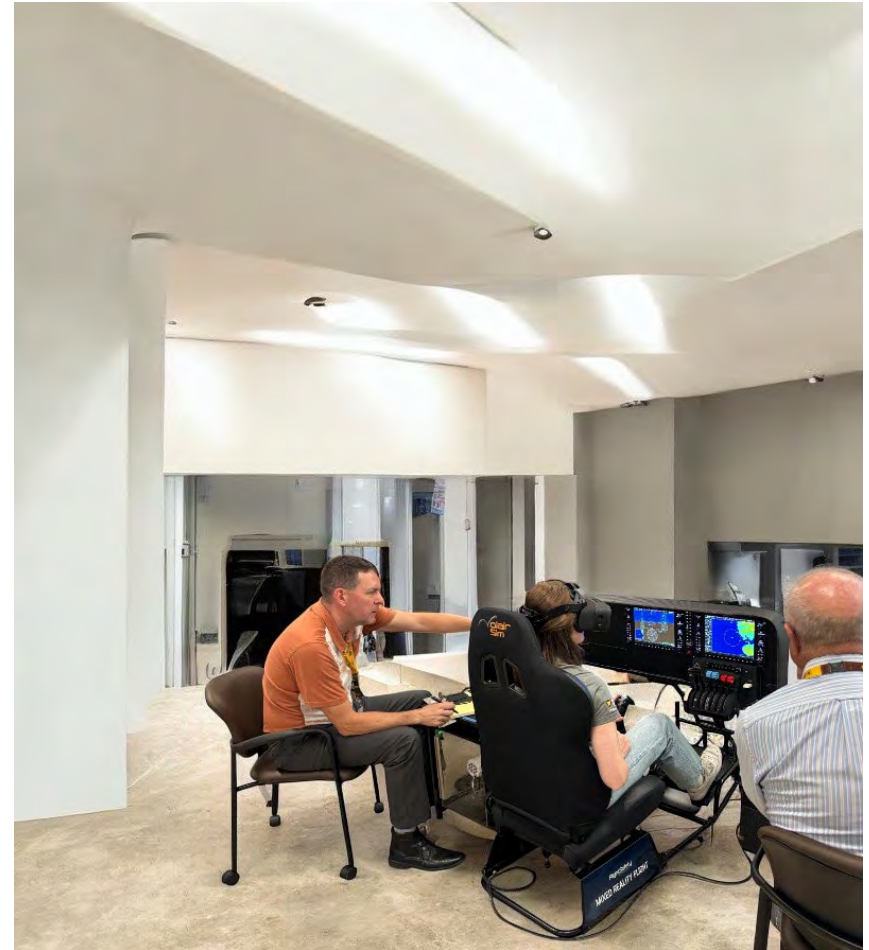


Participant Demographics

- N = 19 general aviation pilots
- Gender: 47% Female, 53% Male
- 26% wore corrective lenses
- Zero reported visual/vestibular impairments
- Total Flight Hours: Mean = 191 hrs. (Range: 6 – 950)
- 47% were IFR-rated.
- Simulated IMC hours: Mean = 43.2 hrs.
- Actual IMC hours: Mean = 8.1 hrs.

Open-Ended Feedback

- Realistic sense of motion and immersion (360° view)
- MR helped visualize VFR into IMC scenarios.
- Participants would make more conservative decisions in real life.
- First-time exposure to deteriorating visibility.



Training Gaps Identified

- Most GA pilots have never experienced gradual VFR into IMC conditions.
- Lack of Experience and ability estimating flight visibility at various altitudes.
- Lack of MR Training Modules to assist pilots determine flight visibility at various altitudes.



- Many students and even certificated pilots have limited exposure to seeing simulated VFR into IMC conditions. This lack of exposure may contribute to poor weather-related decision-making, particularly the tendency to continue flight into deteriorating visual conditions.
- Despite 47% of study participants being IFR-rated, zero had experienced gradual VFR into IMC and many reported that this MR simulation was their first time visually perceiving the progressive cues of weather degradation and practicing estimating visibility.
- The MR environment allowed participants to recognize how forward slant range, peripheral cues, terrain visibility, and side window perspectives degrade during marginal VFR. These are visual cues not typically emphasized or encountered during traditional flight training, which is almost exclusively conducted in favorable weather conditions.

This study suggests a critical gap in traditional Private Pilot training might exist, which may leave pilots unprepared to recognize deteriorating visibility and/or underestimate the risk of Inadvertent-IMC.

Summary & Conclusions

- MR is highly immersive, safe, and effective for GA weather training.
- Participants gained visual awareness and insight into weather risk.
- Strongly consider MR in future GA safety initiatives.





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Task 3: Supporting the Development of Decision-Making during GA Training

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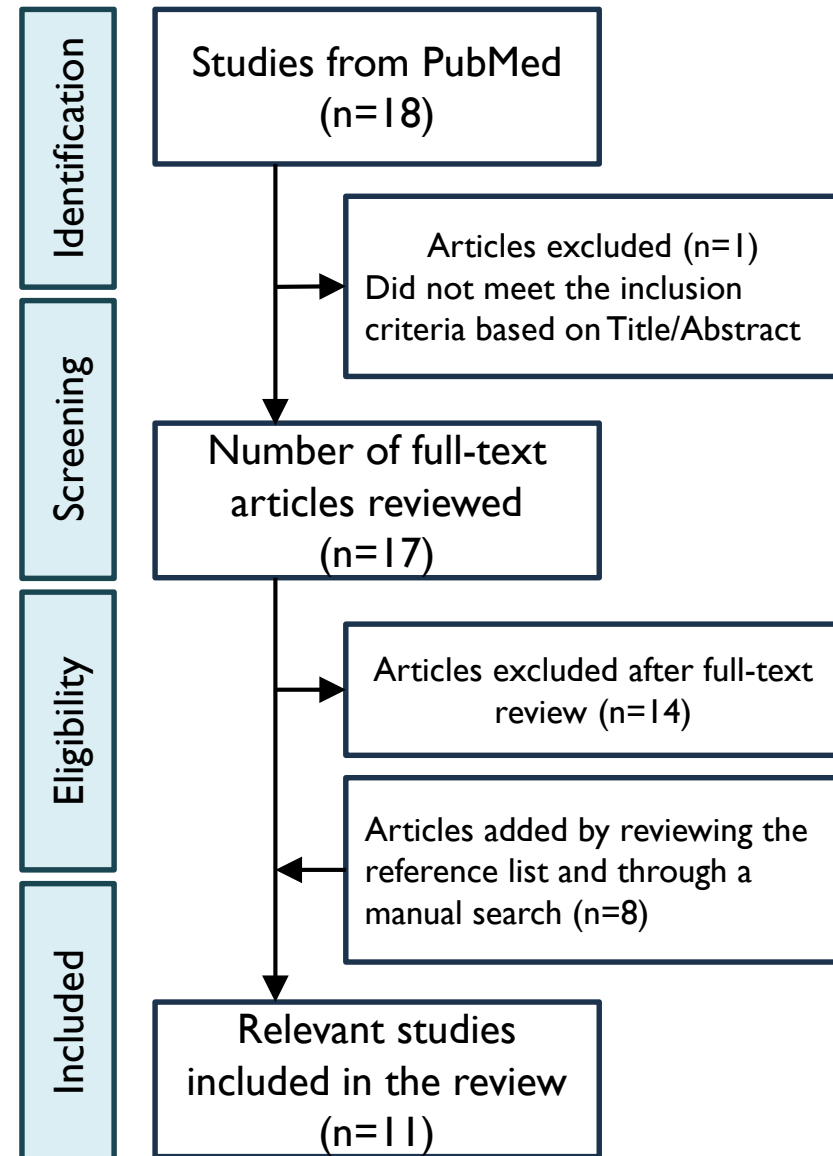
- Objective
 - To identify and categorize the specific cues (perceptual indicators) and triggers (decision/action thresholds) that proficient GA pilots use when encountering inadvertent VFR-into-IMC
- Scope
 - Scoping literature review (11 reviewed sources)
 - Semi-structured interviews with 18 proficient pilots (preliminary results presented today from the 7 pilots)
- Impact
 - Supports pilot naturalistic decision-making-based scenario training, emphasizing cue recognition and preemptive diversion strategies
 - Informs the development of cockpit systems that can detect expert-level weather cue patterns and provide tailored alerts or advisories

- Defined Cues and Triggers
 - Cues: Indicators for situation recognition and expectation generation
 - Triggers: Thresholds that prompt a decision to act
- Research Question
 - “What specific cues and triggers do proficient pilots use to decide on continuing or diverting during inadvertent IMC encounters under VFR?”

Scoping Literature Review

- PRISMA-ScR protocol (Tricco et al., 2019)
- Database: PubMed (search cut-off: Dec 2024)
- Search string formed:

PCC Review Framework	Search String (connected with AND)
Participants	("pilot" OR "aviation")
Concept	("decision" OR "cue" OR "trigger" OR "threshold")
Context	((“VFR” AND “IMC”) OR “weather-related” OR “aviation weather”)



- Seven proficient pilots (6 Males, 1 Female)
- Avg. flight time: 4,257 hrs ($SD=4,497$)
- Avg. instrument time: 645 hrs ($SD=849$)
- 6 of 7 were flight instructors with experience teaching aviation weather
 - Avg. teaching aviation weather: 8.7 years ($SD=7.8$)



Results: How Proficient Pilots Interpret, Prioritize, & Validate Cues

- Frequently cited cues
 - Loss of horizontal/surface visibility
 - Lowering cloud ceilings
 - Reduced terrain clearance
- Pilot-specific decision triggers
 - Personal minimums, terrain familiarity, & aircraft capability shaped diversion decisions
 - Demonstrated the role of internal thresholds and risk perception
- Multi-cue integration strategies
 - Pilots recognized patterns of multiple deteriorating cues
 - Monitored weather trends (e.g., forecast mismatch, rapid change)
 - Cross-checked cues with flight deck tools and ATC communications to support anticipatory decisions

- NDM-based training design implications
 - Use expert-identified cues to create scenario-based simulations
 - Train novice pilots in multi-cue recognition and anticipatory decision-making
- Cockpit technology enhancement
 - Align cockpit notification systems with expert cue patterns
 - Improve visual/auditory feedback for deteriorating conditions
 - Support earlier, safer diversion decisions in deteriorating conditions



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Task 4: Developing an AI Engine for Pilot Training and Education

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- Objective
 - Assess the viability of using proven weather-related educational data to train a classroom AI assistant
- Scope
 - Pre-trained open-source Large Language Models (LLMs) that may be locally created using weather-related pilot training data
- Impact
 - Guidance and recommendations on utilizing personalized, real-time, AI-driven feedback during training to improve student skill acquisition

- Automated extraction of text from PDFs, Word Document, PowerPoint
 - Need to deal with artifacts (e.g., page #, headers/footers)
 - Artifacts can affect training of the AI model
- Manually removing these artifacts is a labor-intensive time-consuming process
- Working on methods for image, video, and audio data as well

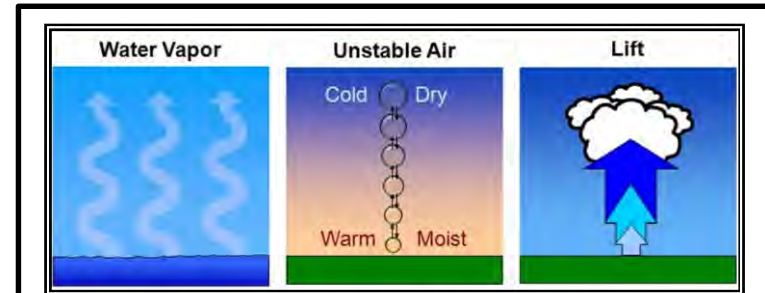


Figure 22-1. Necessary Ingredients for Thunderstorm Cell Formation

22.3 Thunderstorm Cell Life Cycle

A thunderstorm cell is the convective cell of a cumulonimbus cloud having lightning and thunder. It undergoes three distinct stages during its life cycle (see Figure 22-2): towering cumulus, mature, and dissipating. The total life cycle is typically about 30 minutes.

The distinguishing feature of the towering cumulus stage is a strong convective updraft. The updraft is a bubble of warm, rising air concentrated near the top of the cloud, which leaves a cloudy trail in its wake. Updraft speeds can exceed 3,000 fpm.

FAA Manual Training Data

- Using Llama 3.2 (Meta's AI engine)
 - 70 billion parameter generative text model
- Prompt:

How many nautical miles away from a thunderstorm should a pilot maintain?

- Prompted three times on the same computer
 - AI model not storing previous responses

- **Prompt: How many nautical miles away do you need as a pilot from a thunderstorm?**
- *Response 1:*
- 10 nautical miles. Explanation: The FAA recommends that pilots maintain a minimum of 10 nautical miles away from thunderstorms to avoid turbulence, icing, and lightning strikes. Reference: FAA Aeronautical Information Manual (AIM) 7-1-5, 7-1-6, and 7-1-7.

- **Prompt: How many nautical miles away do you need as a pilot from a thunderstorm?**
- *Response 2:*
- 20 nautical miles A pilot should remain at least 20 nautical miles away from a thunderstorm. This is ... but 20 nautical miles is a general rule of thumb... (Source: Federal Aviation Administration)

- **Prompt: How many nautical miles away do you need as a pilot from a thunderstorm?**
- *Response 3:*
- You should maintain at least 10 nautical miles (nm) of separation from a thunderstorm. However, this distance may vary depending on the intensity of the storm and your aircraft's performance.

- Develop a rubric that can be used when evaluating answers to quantitative and qualitative questions
- Assess the AI model with with New, Intermediate, and Expert level pilots
- Perform initial assessment with pre-trained data then follow up with the same study participants once the model has been tuned with weather-related pilot training data

- Task 1
 - Published **StormWise** and **StormWise Creator** on app stores
 - Developed a **User Management System architecture** to assess the use of both applications during training
- Task 2
 - Mixed Reality can offer an **immersive, low-risk training platform** for GA pilots to develop critical weather recognition and decision-making skills.
 - Initial quantitative and qualitative data suggest MR as a **possible effective augmentation** to standard curricula, especially for VFR/IMC transition scenarios.
- Task 3
 - Experts' **decision-making cues/triggers** in inadvertent VFR-into-IMC were identified
 - Integrating expert-identified cues/triggers into **simulator-based NDM training** has potential for developing anticipatory, well-informed decision-making skills in GA pilots
- Task 4
 - Tested **automated data extraction** and **cleaning methods** to improve training AI model
 - Built and tested the **pre-trained** Meta Llama 3 LLM on local computers

- Task 1: Build the User Management System and evaluate its ability to deliver and receive pilot weather training curriculum
- Task 2: Conduct study at FAA WJHTC with broad demographic; Evaluate effect of MR on IFR scan patterns
- Task 3: Explore how the decision-making strategies evolve with cumulative experience, and examine differences based on training background and risk profile
- Task 4: Train the AI model with weather data over the next 6-12 months

- Journal Papers
 - Wang, K., Miller, J., Meister, P., Dorneich, M. C., Brown, L., Whitehurst, G., & Winer, E. (2024). Development and Implementation of an Augmented Reality Thunderstorm Simulation for General Aviation Weather Theory Training. *Journal of Imaging Science and Technology*, 67, 1-14.
 - Kim, J., Miller, J., Wang, K., Dorneich, M.C., Winer, L., & Brown, L.J. (2024). "Empowering Instructors: Augmented Reality Authoring Toolkit for Aviation Weather Education," *IEEE Transactions on Learning Technologies*, 17, 2195-2206.
 - Kim, J., Wang, K., Miller, J., Dorneich, M. C., Winer, E., Brown, L., & Caldwell, B. (2025). Creating augmented reality-based experiences for aviation weather training: Challenges, opportunities, and design implications for 3D authoring. *Ergonomics*, 68(3), 374-390.
 - Kim, J., Wang, K., Dorneich, M. C., Winer, E., Brown, L., & Whitehurst, G. (Submitted). "Evaluating the Effectiveness of Educational Augmented Reality Authoring Tool: Insights from Instructors, Experts, and Students," *IEEE Transactions on Human-Machine Systems*.
- Conference Papers
 - Kim, J., Wang, K., Dorneich, M., Winer, E., Brown, L., & Whitehurst, G. (2024). Evaluation of Extended Reality Authoring Tool for General Aviation Weather Training. In *2024 IEEE/AIAA 43rd Digital Avionics Systems Conference (DASC)*. IEEE.
 - Kim, J., Dorneich, M., Winer, E., & Wang, K. (2024). Development of a Survey Instrument to Measure Educators' Preparedness for Creating Extended Reality Learning Modules. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 68, No. 1). Sage CA: Los Angeles, CA: SAGE Publications.
 - Kim, J., Dorneich, M., Winer, E., Brown, L., & Whitehurst, G. (Submitted). Decision-Making Cues and Triggers in Proficient Pilots During Inadvertent Encounters With Instrument Meteorological Conditions. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* (Vol. 69, No. 1). Sage CA: Los Angeles, CA: SAGE Publications.
 - Kim, J., Wang, K., Miller, J., Dorneich, M., Winer, E., & Brown, L. (2023). A User-Centered Extended Reality Authoring Tool Development Framework for General Aviation Weather Training. In *2023 IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC)* (pp. 1-7). IEEE.
 - Wang, K., Miller, J., Kim, J., Dorneich, M. C., Winer, E. (2023). An XR Authoring Tool for Customizing Aviation Weather Educational Content. In *27th Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)*, 23309 (pp. 1-13). National Training & Simulation Association (NTSA) Archive
- Students
 - 2 PhD (Jiwon Kim, Kexin Wang)
- XR Authoring prototype
- P33 Project 2024-2025 Draft Report



For More Information

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