Enabling Extended Reality Enhanced Aviation Weather Training

Michael Dorneich, PhD
Morrill Professor and Joseph Walkup Professor

Research Team

Dr. Michael Dorneich

Dr. Eliot Winer

Iowa State University

Dr. Geoff Whitehurst

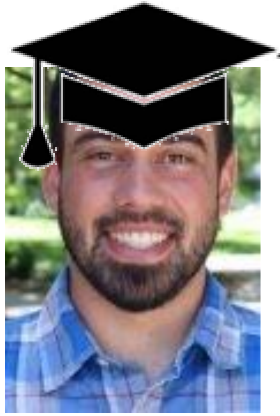
Dr. Lori Brown

Western Michigan University

Jiwon Kim

Kexin (Kate) Wang

Dr. Alex Renner



Dr. Philippe Meister

Dr. Jack Miller

…and many undergraduate research assistants

Acknowledgements

This work was supported by the Partnership to Enhance General Aviation Safety, Accessibility, and Sustainability (PEGASAS), a Federal Aviation Administration (FAA) Center of Excellence for General Aviation, Cooperative Grant 12-C-GA-ISU

Gary Pokodner

Ian Johnson

FAA Technical Point of Contact (POC)

Outline

Introduction and Motivation

For Students: Augmented Reality Weather Training

For Instructors: XR Authoring Tools

Summary and Impact

Introduction

Challenges to enhancing weather education

Requires training and assessment

- Classroom training with printed materials, sometimes with videos

Students think in 2D and think the atmosphere is stable

- Trouble translating 2D images into 3D mental imagery (Ortiz et al. 2017)

Accessibility for advanced technologies

- Desktop flight simulation lacks components for weather training (Berendschot et al., 2017)
- Flight simulators are not always accessible to all of GA (Berendschot et al., 2017)

Challenges with current weather education

Reviews of weather training curricula identified gaps (Carney et al, 2015)

- Lack opportunity to experience weather patterns and associated visual cues
- Lack of retention of weather knowledge
- Lack of situational awareness related to VMC into IMC
- Perceived lack of skills related to VMC into IMC decision-making
- Lack of ability to correlate, interpret and apply weather information

Training prepared pilots poorly to deal with “real life” weather (Major et al, 2017)

Weather often considered a boring subject (Major et al, 2017)

Augmented Reality Weather Training

Wang, W., Miller, J., Meister, P., Dorneich, M., Brown, L., Whitehurst, G., & Winer, E. (2023). "Development and Implementation of an Augmented Reality Thunderstorm Simulation for General Aviation Weather Theory Training," Journal of Imaging Science and Technology. 67(6), 1-14. http://dx.doi.org/10.2352/J.ImagingSci.Technol.2023.67.6.060402

Approach

Draw on **weather training**, **augmented reality**, and **instructional design** to develop visually enhanced learning experiences

Weather training (Air Safety Institute, 2021)

- Focus on thunderstorms because they are a consistent cause of accidents

Augmented reality (Arribas et al., 2014; Billinghurst & Kato, 2002)

- Apply immersion, animation, interactivity, and real-world registration

Instructional design (Jones et al., 2011)

- Design a learning goal, learning experiences, scaffolding, and feedback

Benefits of AR experiences for weather training

Immersion allows students to experience the 3D AR weather models in their learning environment (Rusiñol et al., 2018; Dede, 1995)

Animation helps students learn the movements of dynamic processes (Schwan & Riempp, 2004)

Interactivity helps students seek out the information they need when they need it for learning (Arribas et al., 2014)

Real-world registration places the models into weather training materials to provide meaningful context (Billinghurst & Kato, 2002)

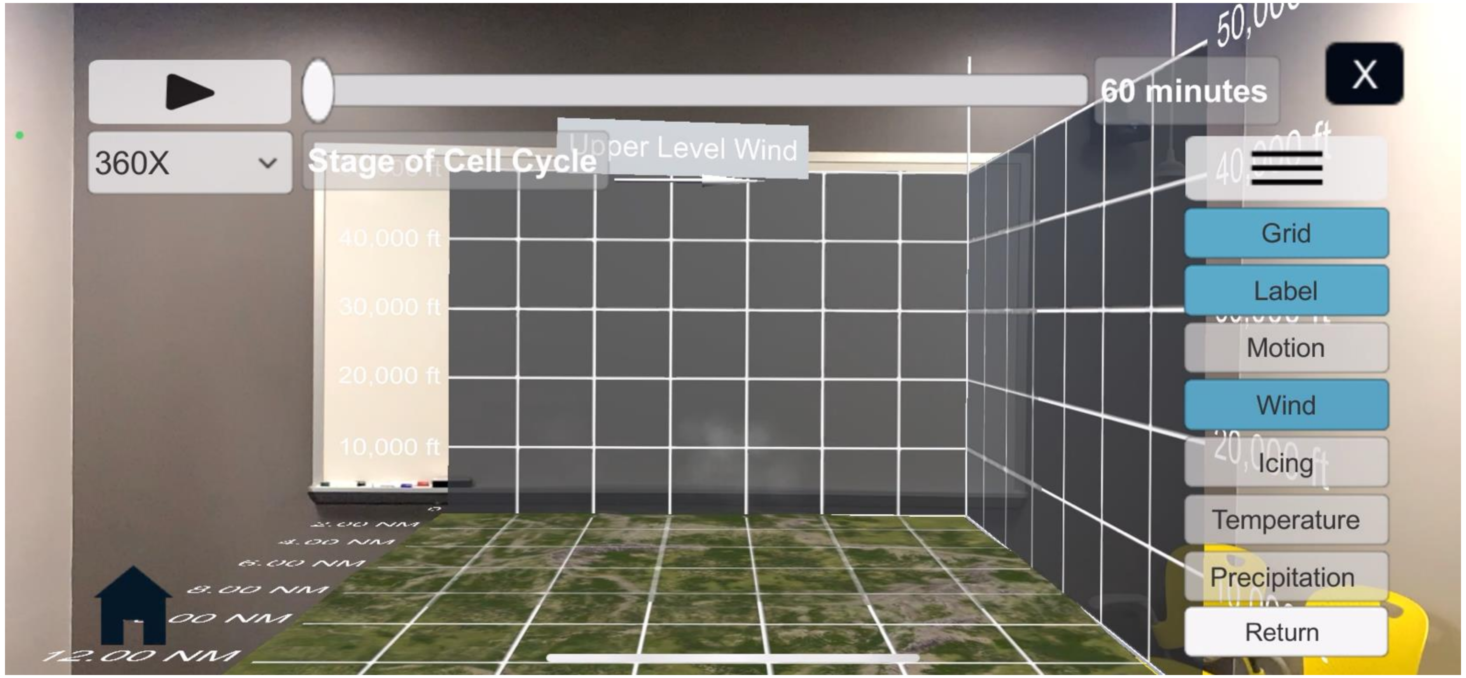
Thunderstorm cell lifecycle

Visualization

- Weather pattern
- Stages
- Hazards
- Visual cues

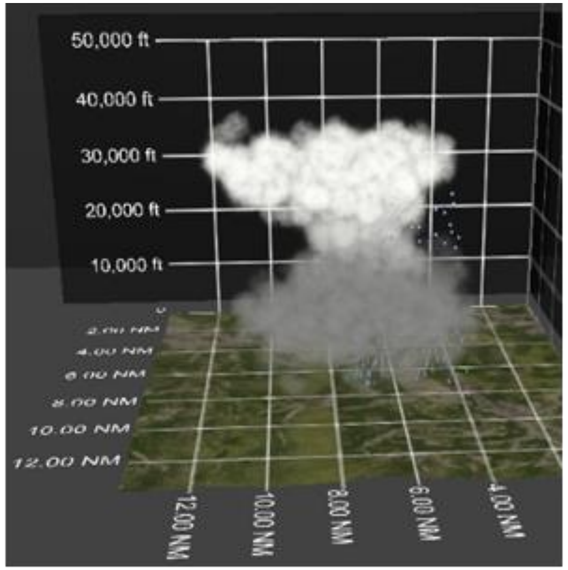
Learning experience

- View and identify characteristics

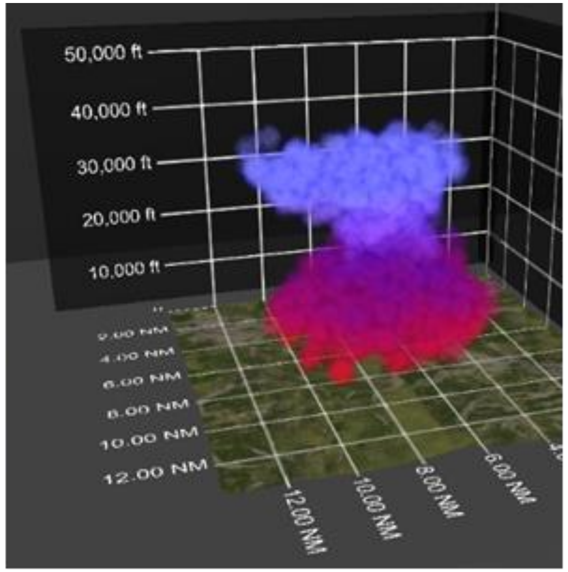


Thunderstorm cell lifecycle

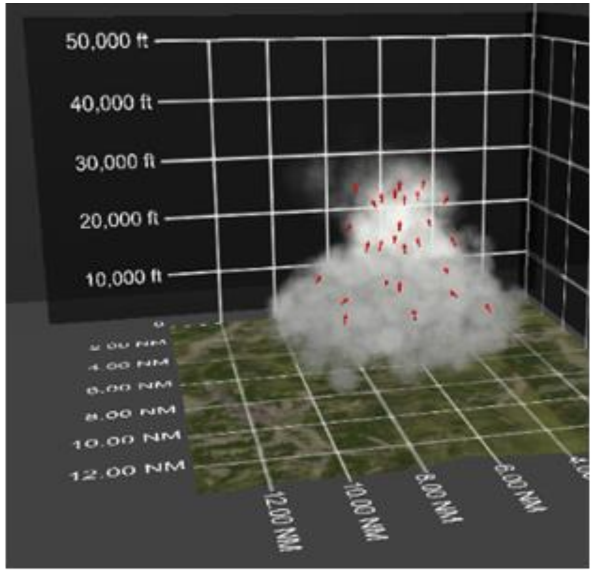
Thunderstorm model layers



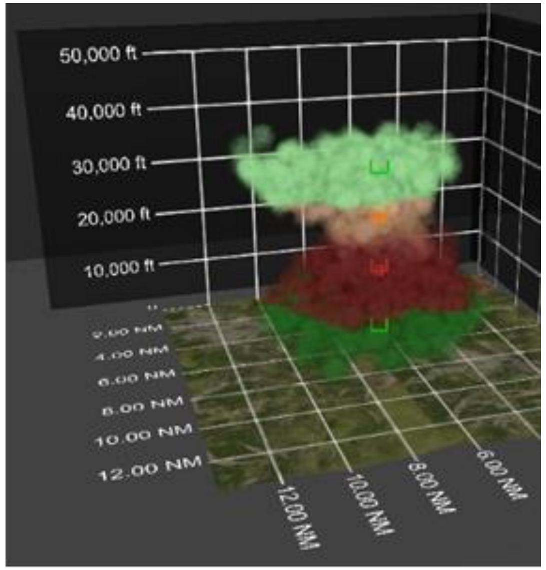
Precipitation



Temperature



Winds

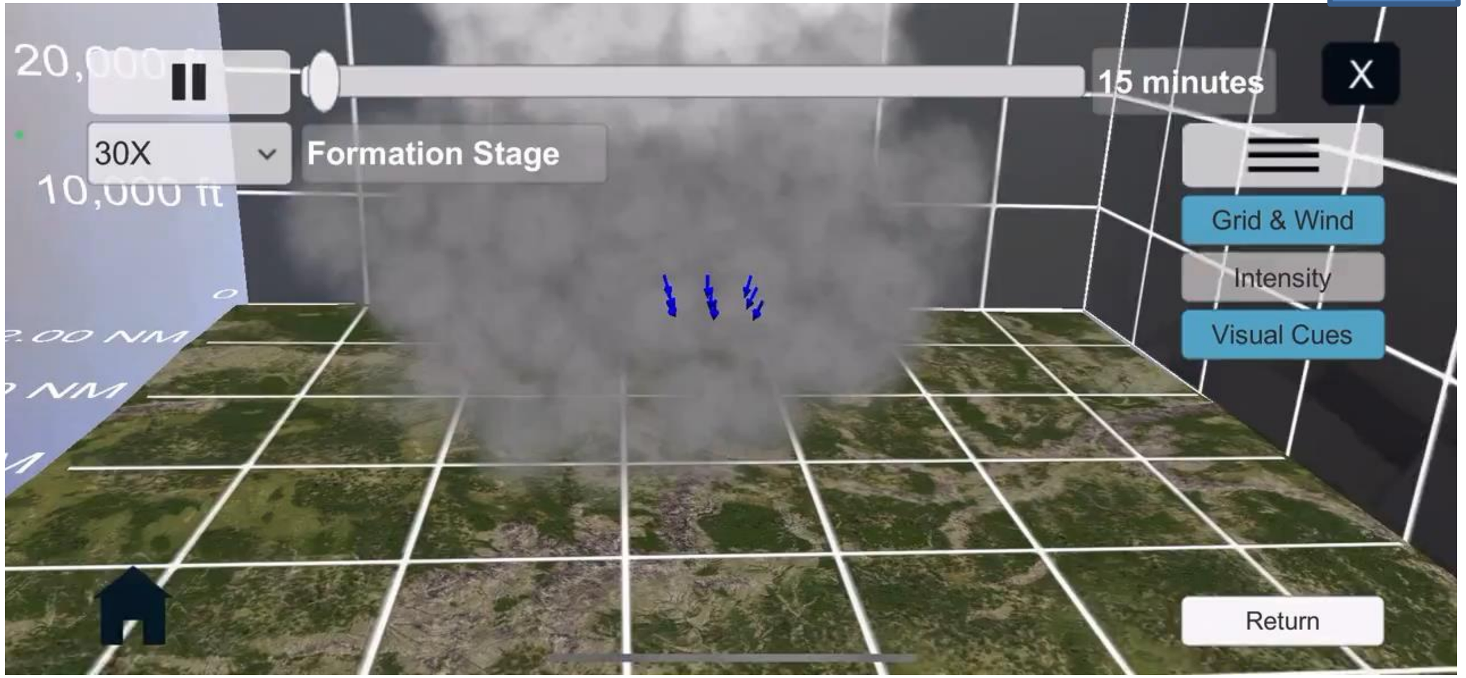


Icing

Microburst characteristics

Visualization

- Weather pattern
- Stages
- Size
- Intensity
- Visual cues



Learning experience

- View and identify characteristics

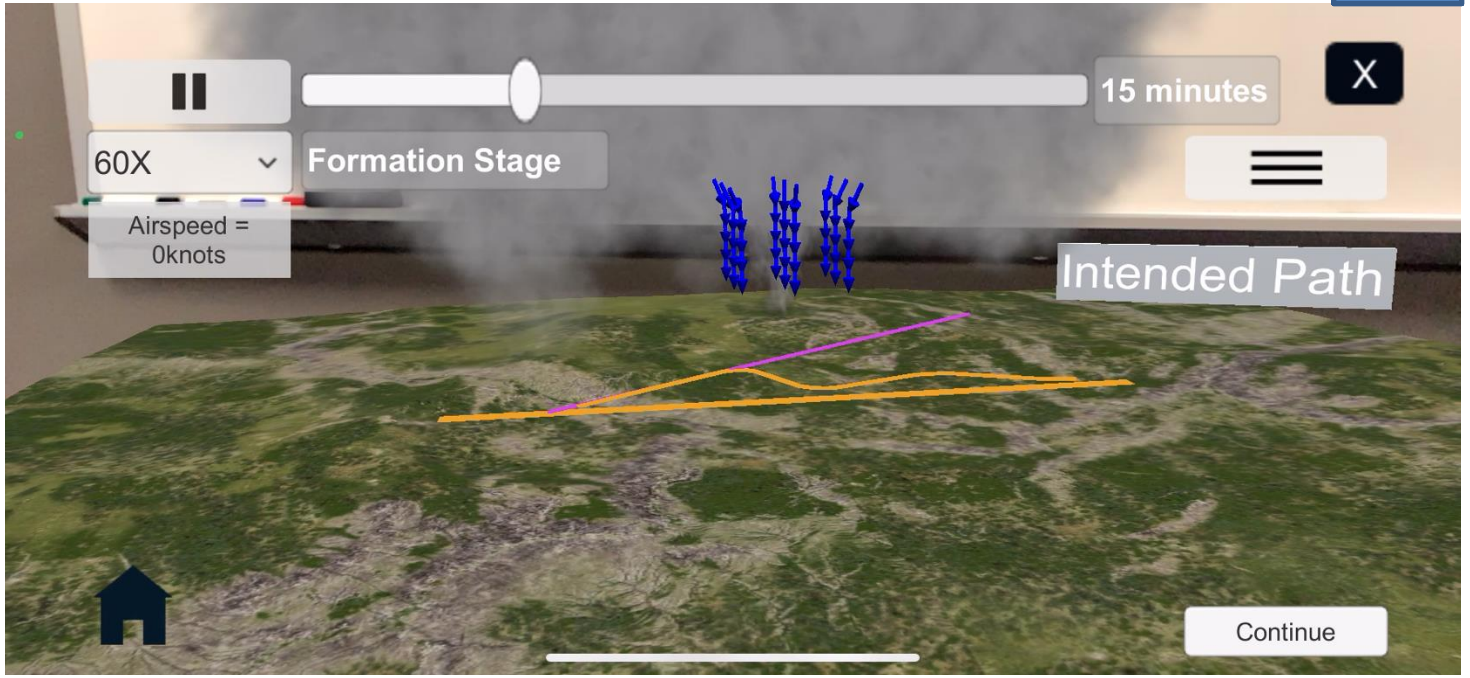
Effects of a microburst on an aircraft flightpath

Visualize four stages

- Headwinds
- Downdrafts
- Tailwinds
- Dangerously low airspeed

Learning experience

- View and read about impact of weather on flight



Effect of microburst on flight

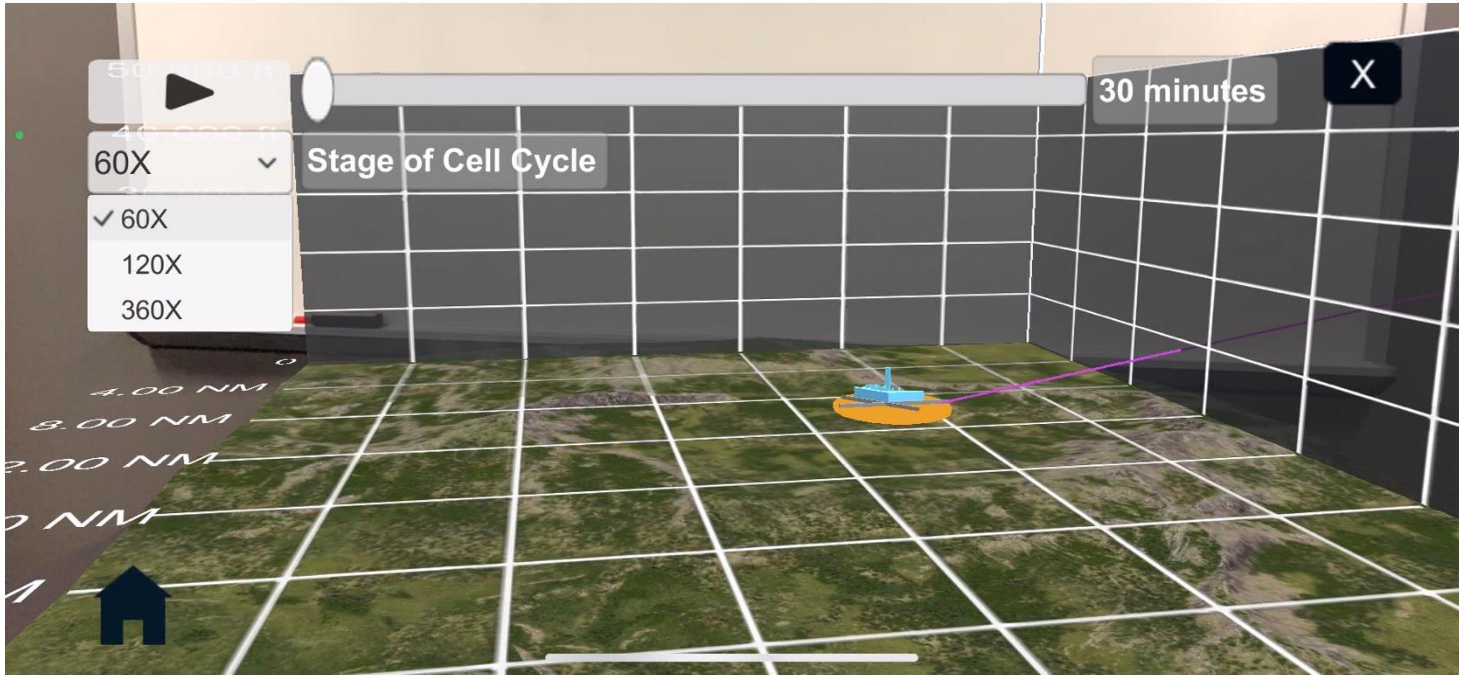
Thunderstorm avoidance protocols

Visualization

- Weather-related situation
- Flight decision

Learning experience

- Apply avoidance procedures to the weather-related situation



Weather-related situation

Scenario-based Learning Experience

Read flight and weather information

View a flight situation

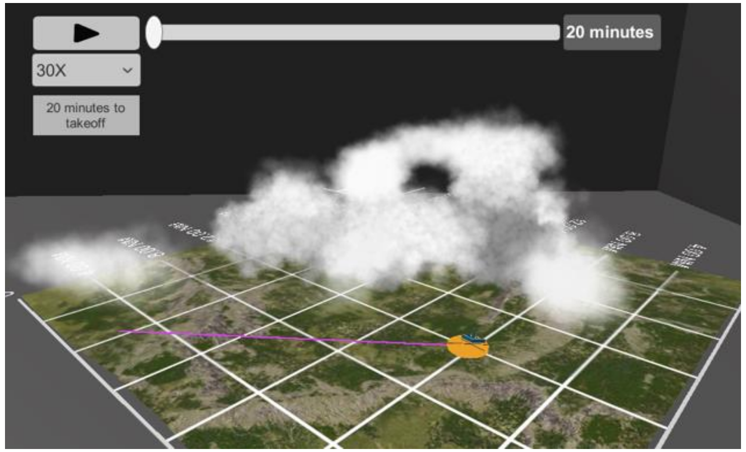
Correlate information with the situation

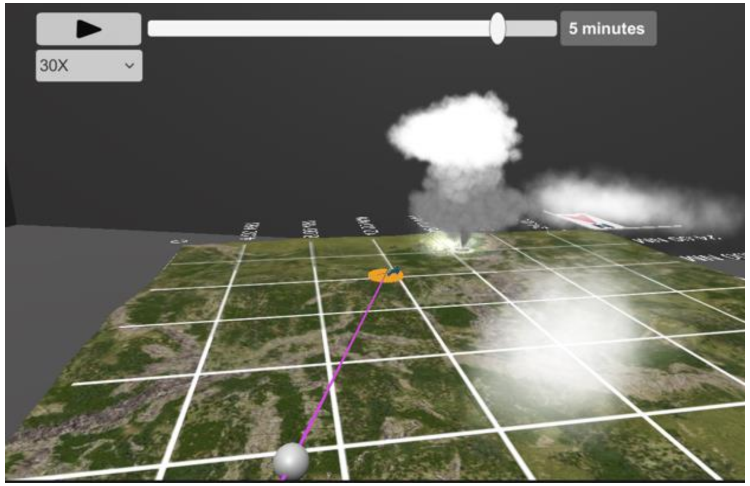
Make a flight decision

Read results of their decision

Read response of an experience pilot

Compare responses





Video: Interactive Print

Study 1*: Impact of AR activities on weather knowledge

18 participants (17 male, 1 female)

- Age M = 25.3 (SD = 10.3) years
- Total flight hours M = 96.6 (SD = 83)
- Instrument flight hours M = 14.8 (SD = 21.1)

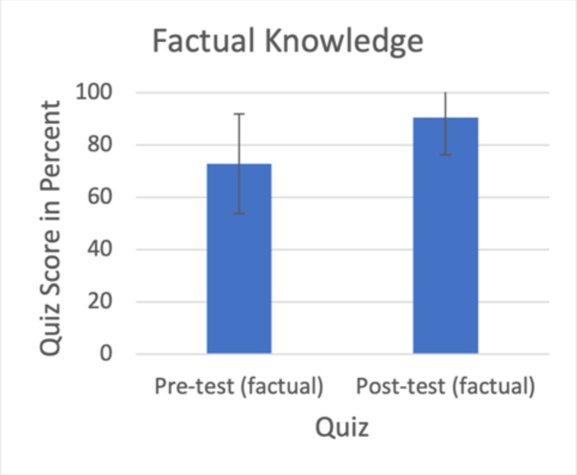
Metrics (pre and post)

- 10-question **factual knowledge** quiz from FAA commercial pilot written exam and team
- 8-question **visual knowledge** quiz about visible thunderstorm features.

$t(17) = -4.26$

$\boldsymbol{p < .001}$

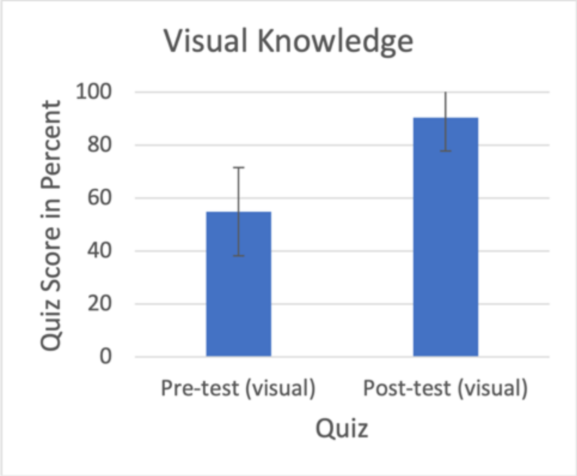
$d = 1.08$



$t(17) = -10.0$

$\boldsymbol{p < .001}$

$d = 2.41$



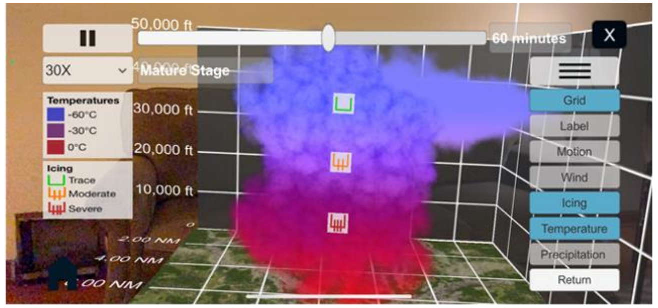
*Meister, P., Wang, K., Dorneich, M.C., Winer, E., Brown, L., & Whitehurst, G. (2022). "Augmented Reality Enhanced Thunderstorm Learning Experiences for General Aviation," AIAA *Journal of Air Transportation*. 30(4), 113-124. http://dx.doi.org/10.2514/1.D0308

Study 2*: Effectiveness of AR-based experiential training

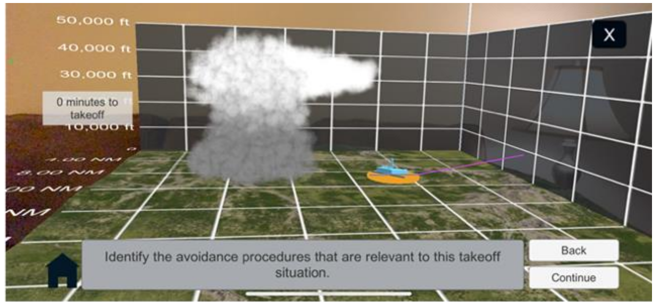
Aim: evaluate comparative impacts of interactive print (IP) and print (P)

Participants:

- 52 (38 male, 14 female)
- 23.6 (SD = 8.6) years
- 50.3 (SD = 29.6) flight hours

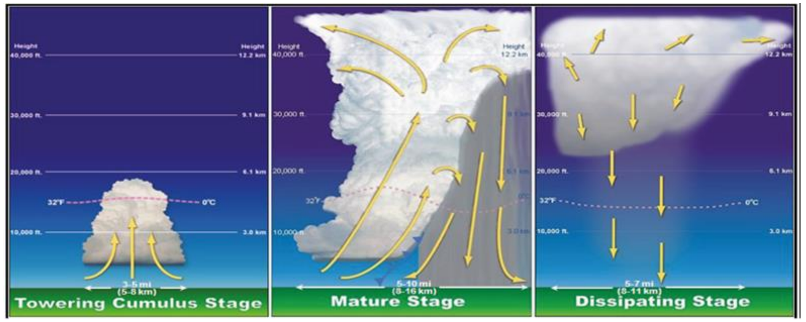


(a) Knowledge-based activity: Hazards

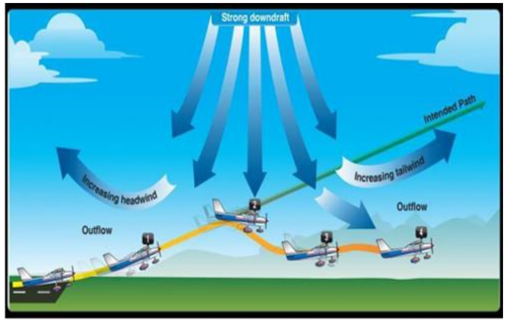


(b) Knowledge-based activity: Thunderstorm

Interactive Print



(a) Knowledge-based activity: Thunderstorm Life Cycle



(b) Knowledge-based activity: Microburst

Print

*Meister, P., Miller, J.,*Wang, K., **Dorneich, M.C.**, Winer, E., Brown, L., & Whitehurst, G. (2023). "Evaluation of Augmented Reality Interactive Print for General Aviation Weather Training," *AIAA Journal of Air Transportation*. 32(1), 12-21. http://dx.doi.org/10.2514/1.D0364

Design of the interactive print learning module

Print	Interactive print
Learning objectives (text)	Learning objectives (text)
Thunderstorm formation (text)	Thunderstorm formation (text)
Thunderstorm cell life cycle (text) Cell lifecycle characteristics (2D)	Thunderstorm cell lifecycle (text) Cell lifecycle characteristics (AR)
Thunderstorm types (text)	Thunderstorm types (text)
Thunderstorm hazards (text) Icing activity (text)	Thunderstorm hazards (text) Icing activity (AR)
Microburst characteristics (text) Microburst characteristics (2D)	Microburst characteristics (text) Microburst characteristics (AR)
Effects of microburst on flight (text) Effects of microburst on flight (2D)	Effects of microburst on flight (text) Effects of microburst on flight (AR)
Post-task survey (text)	Post-task survey (text)
Thunderstorm avoidance (text) Avoidance procedures (2D)	Thunderstorm avoidance (text) Avoidance procedures (AR)
Scenario-based takeoff (text/2D)	Scenario-based takeoff (text/AR)
Scenario-based approach (text/2D)	Scenario-based approach (text/AR)

Results / Important Findings

Participants in the interactive print training group had significantly **higher motivation levels** than those in the print training group

- *"I prefer [the AR] because it held my attention really well when I probably would've gotten bored with a presentation or reading a textbook."*

Learning effectiveness of interactive print training group marginally significantly higher than the print training group

Both groups significantly increased **factual knowledge**, but no difference between groups

- Pre-test scores high (M = 56.4%, SD = 20.2%), therefore providing less room for improvement, let alone a difference in improvement

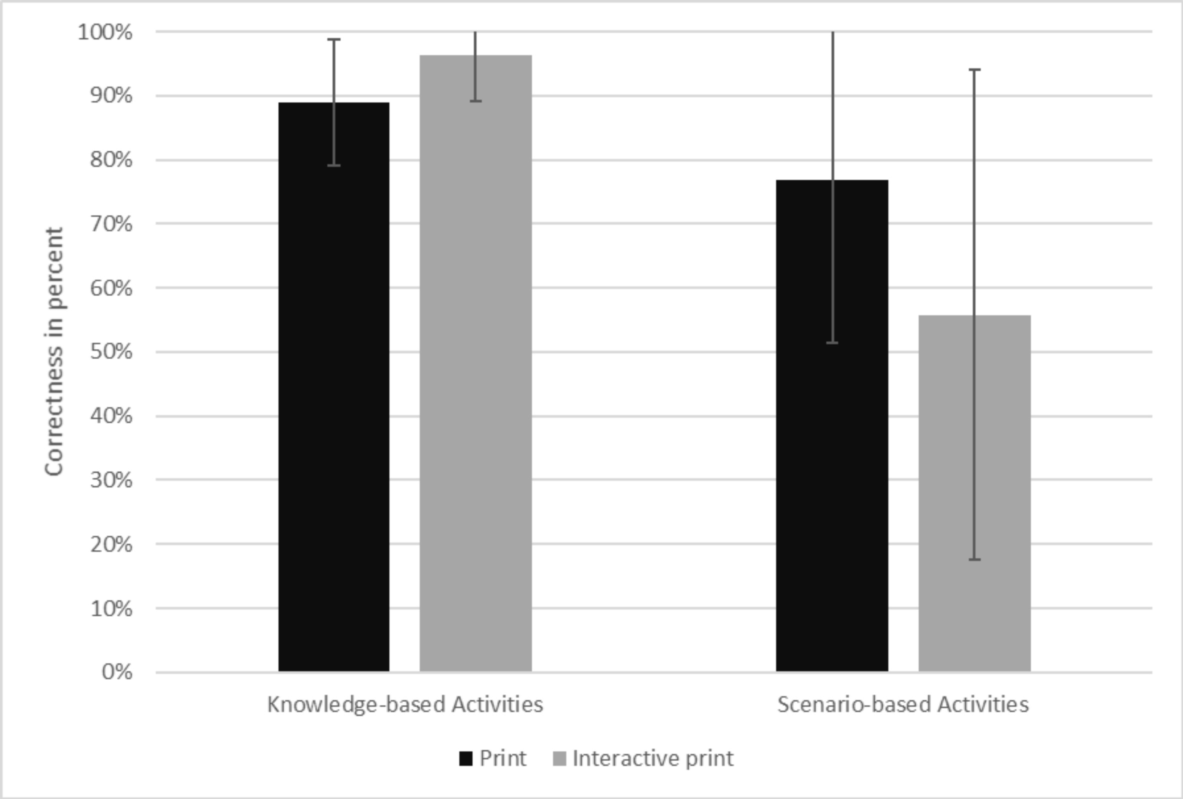
Task completion correctness

Five knowledge-based activities:

- IP group completed tasks with significantly **higher** rates of correctness, *t*(50) = 77.6, ***p* = .003**

Two scenario-based activities:

- IP group completed tasks with significantly **lower** correctness rates, *t*(50) = 14.7, *p* = .023.



Results / Important Findings

Participants made more mistakes in **scenario-based** AR activities, potentially a learning opportunity

- Students may have relied on visual cues rather than knowledge from text

Novice pilots are less skilled in estimation (Volz et al., 2020)

- Text-only print group may have assessed risk using value-based judgments on numbers from text
- AR-based interactive print group may have reverted to heuristic-based decision-making based on perception of visual characteristics, which novice pilots are known to do (Knecht & Frazier, 2015)

"After reviewing my answer, I relied too heavily on the visualization of the storm in AR and not enough on the reported [weather]."

"When looking at the METAR, I looked at the current wind direction and gust. Visually I saw that the storm was heading slightly east of my takeoff. I could have read the METAR a little more carefully to make a more informed decision."

Summary

AR content helps students visualize and comprehend weather phenomena

Align AR learning activities with target learning outcomes

Provide interactive AR content for exploratory and activity-based learning

AR provide experiential learning opportunities to let novice pilots make judgement errors in a safe environment

AR weather content on smartphones and tablets make it accessible

Limitation: who will create these AR modules?

Authoring Toolkit for Aviation Instructors to Develop AR Learning Modules

Kim, J., Miller, J., Wang, K., Dorneich, M.C., Winer, L., & Brown, L.J. (Accepted). "Empowering Instructors: Augmented Reality Authoring Toolkit for Aviation Weather Education," *IEEE Transactions on Learning Technologies*. http://dx.doi.org/10.1109/TLT.2024.3486630

Motivation and Challenges

Instructors motivated to create lessons in XR to leverage benefits (Kim et al., 2024)

- Engagement, making abstract ideas tangible, scenario-based training
- Capture students' attention and foster a deeper connection with subject
- Personalized learning tailor content to individual student needs (Ley et al., 2020)

Challenges for XR adoption

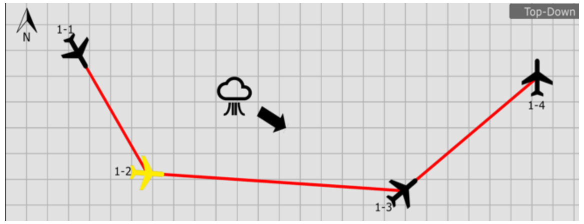
- Instructor's limited digital proficiency (Tzima et al., 2019; Akçayır & Akçayır, 2017; Ashtari et al., 2020)
- Technical complexity of XR authoring toolkits (Gaspar et al., 2020; Nebeling & Speicher, 2018)
- Time-consuming nature of XR authoring (Kim et al., 2024; Alalwan et al., 2020)

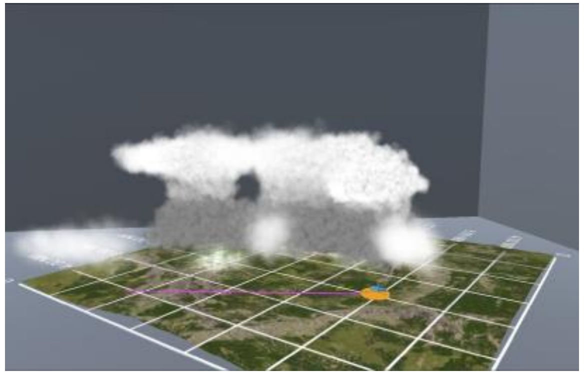
Research Objective

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 **content-centered approach**

Incorporates an **instructor-centered** design process, utilizing evidence-based research and iterative improvement process





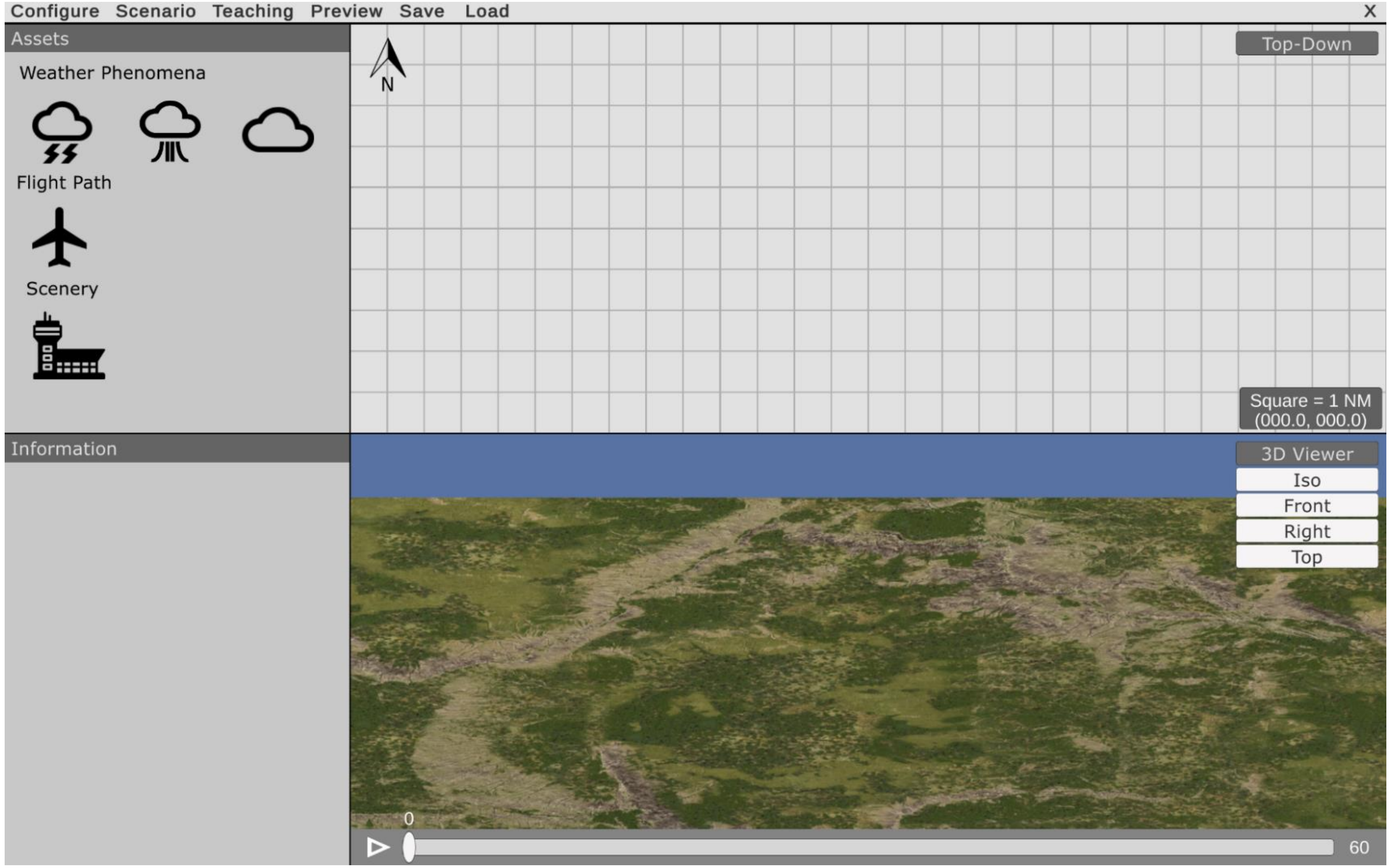
Software Structure

Gathered XR-training requirements*

- Semi-structured interviews with 17 aviation instructors

Software Structure

- Configure
- Scenario editing
- Teaching elements
- Preview
- Save/load



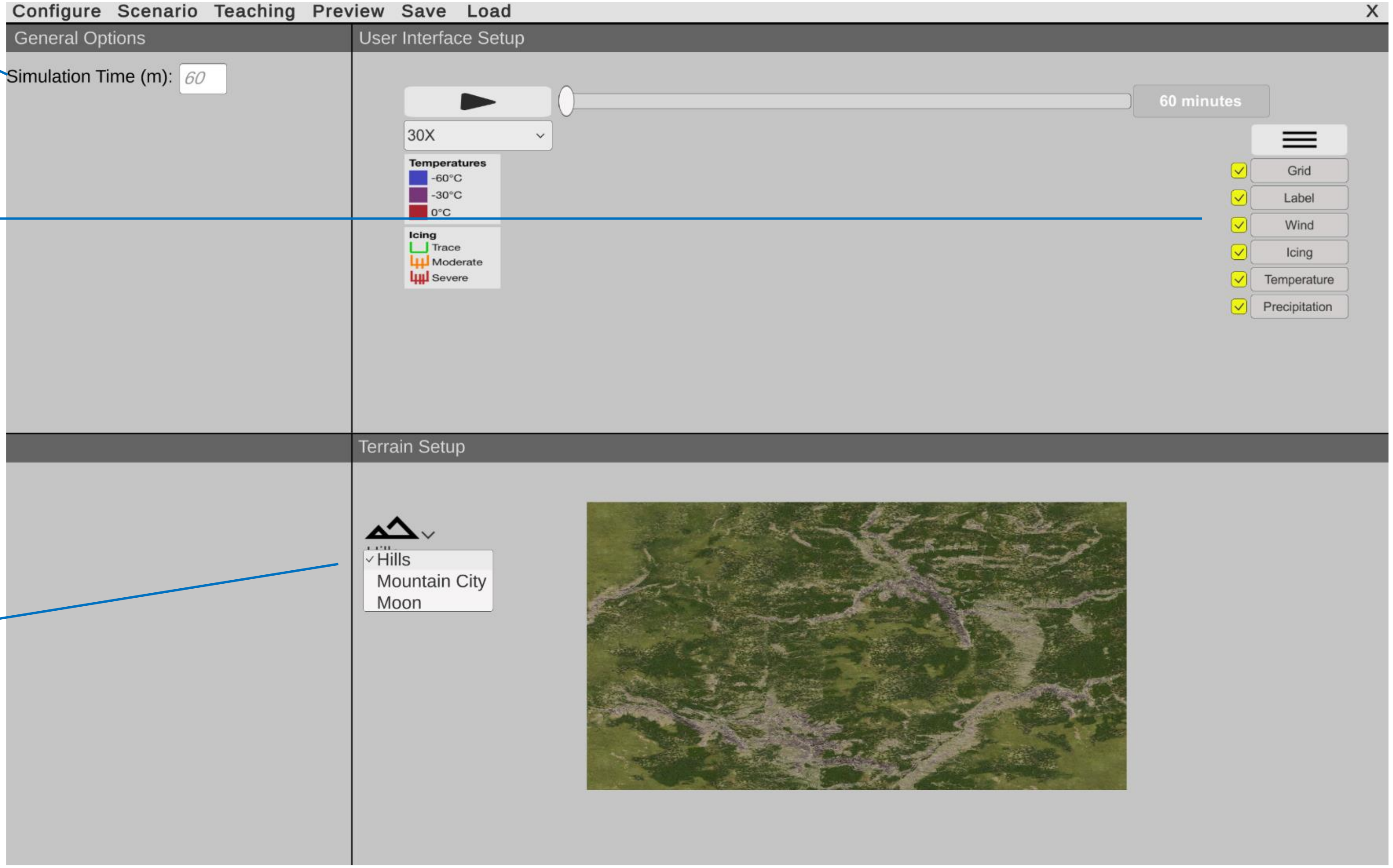
*Kim, J., Wang, W., Miller, J., Dorneich, M.C., Winer, E., Brown, L., & Caldwell, B. (2024). "Creating Augmented Reality-Based Experiences for Aviation Weather Training: Challenges, Opportunities, and Design Implications for 3D Authoring," Ergonomics. 68(3), 374-390. http://dx.doi.org/10.1080/00140139.2024.2329696

Configure

Control to adjust time

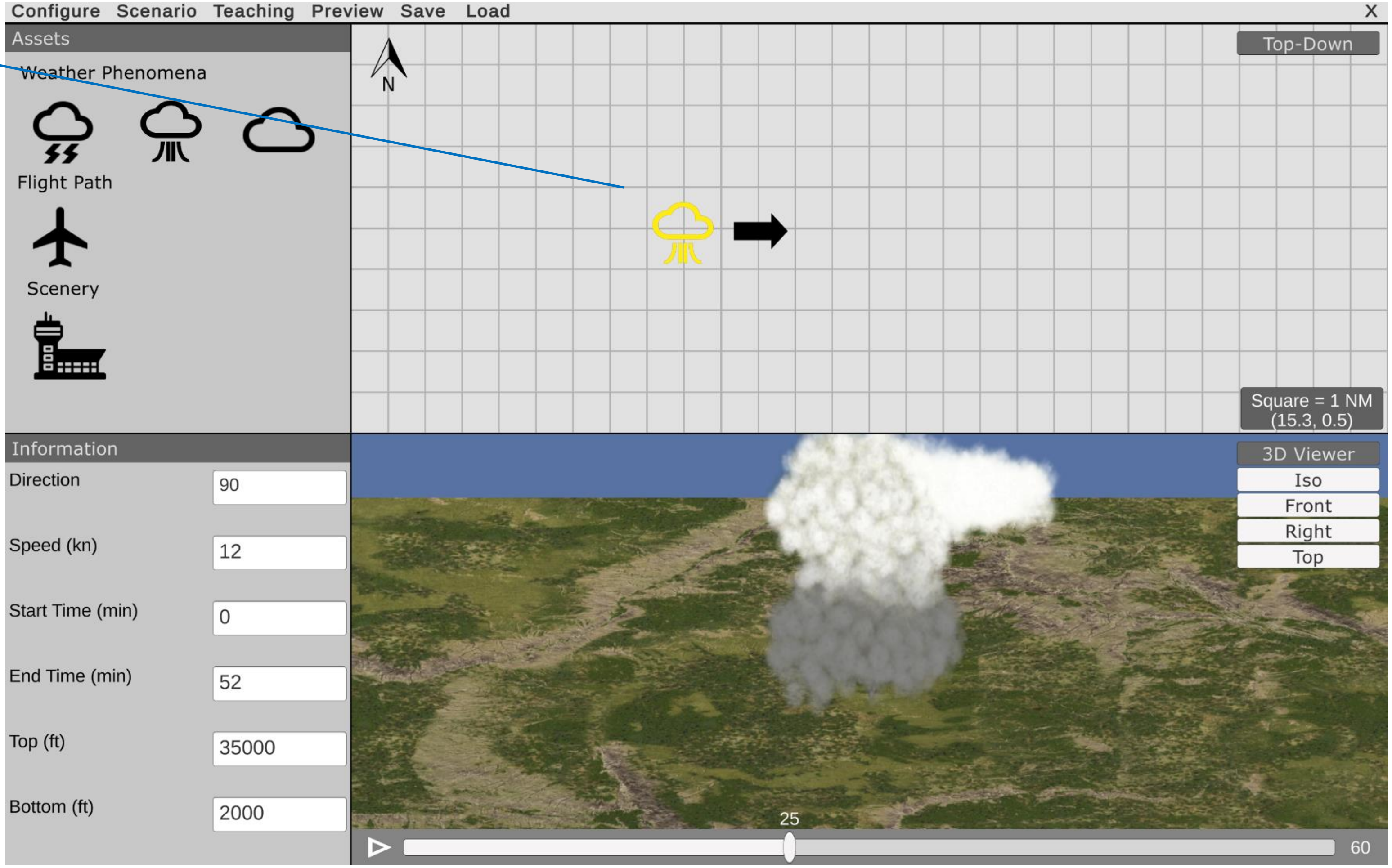
Users choose what weather filters (icing, winds, etc.) to include in scenario

Choose terrain from predefined asset libraries



Scenario Editing

- Specify location of TS
- Choose 3D objects from predefined asset libraries
- Specify size, speed, direction of TS
- Specify the duration of animation (e.g., TS cycle)
- Break animation or scenario down into shorter period



Scenario Editing

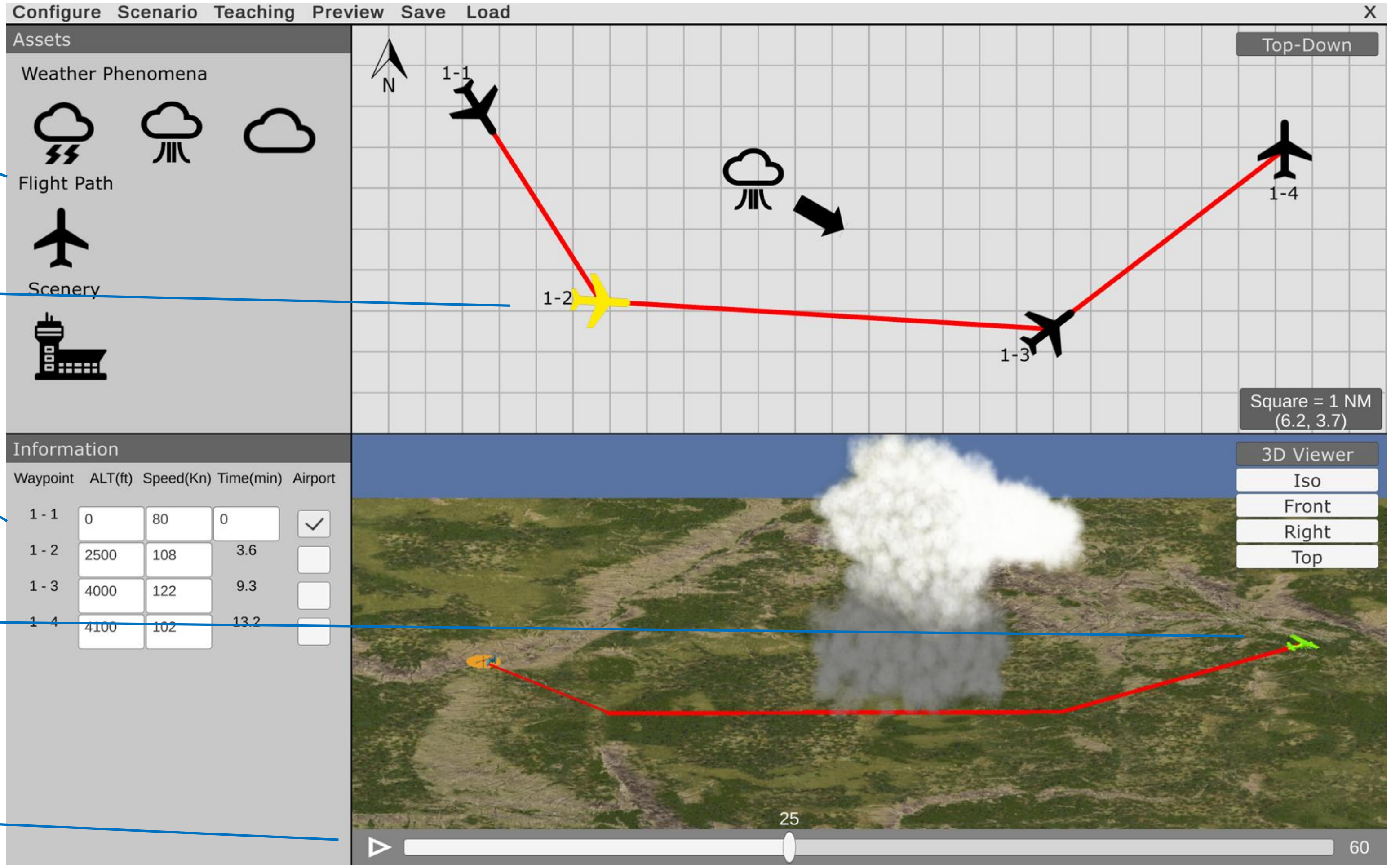
Drag and drop capability to add 3D objects into 3D scene

Specify waypoints of flight

Specify altitude of flight

Realistic-looking aircraft model

Start and stop animation

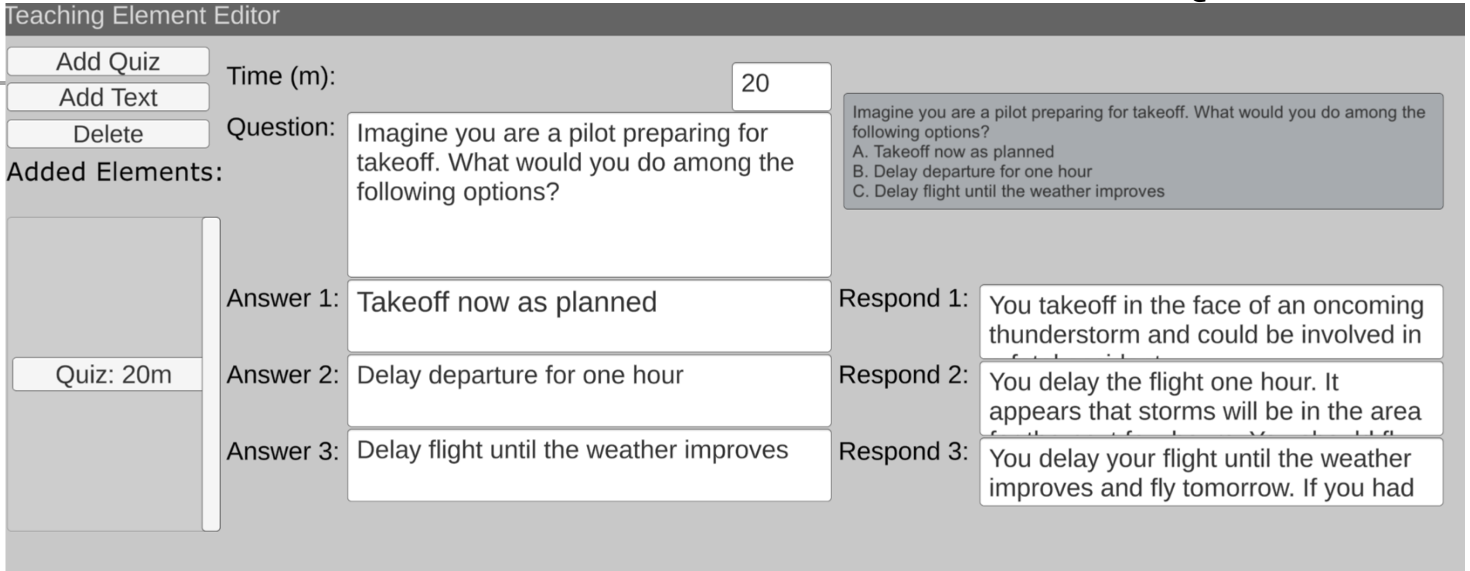


Teaching Elements

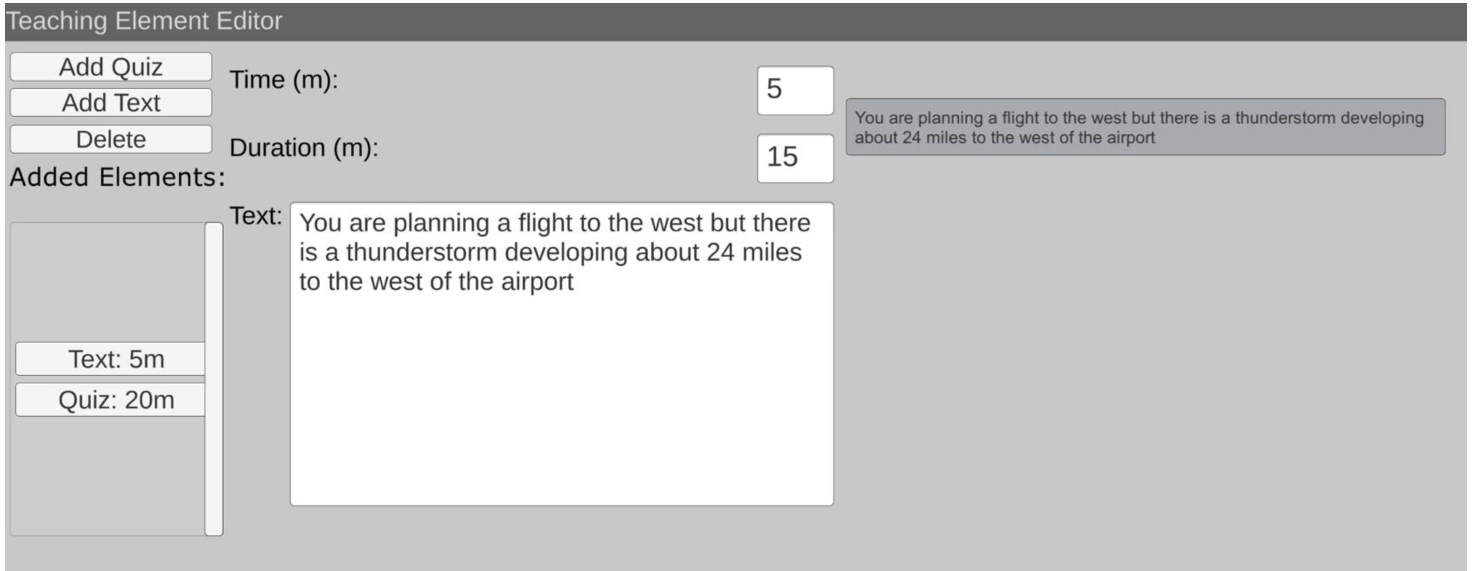
Quiz capability with multiple choice question

Instructional text box

Quiz Module



Text Module



Preview

Start and stop animation

Control to adjust time

Visualize wind direction, temperature, icing, and precipitation

Masking layers to show TS features: wind, icing, etc.

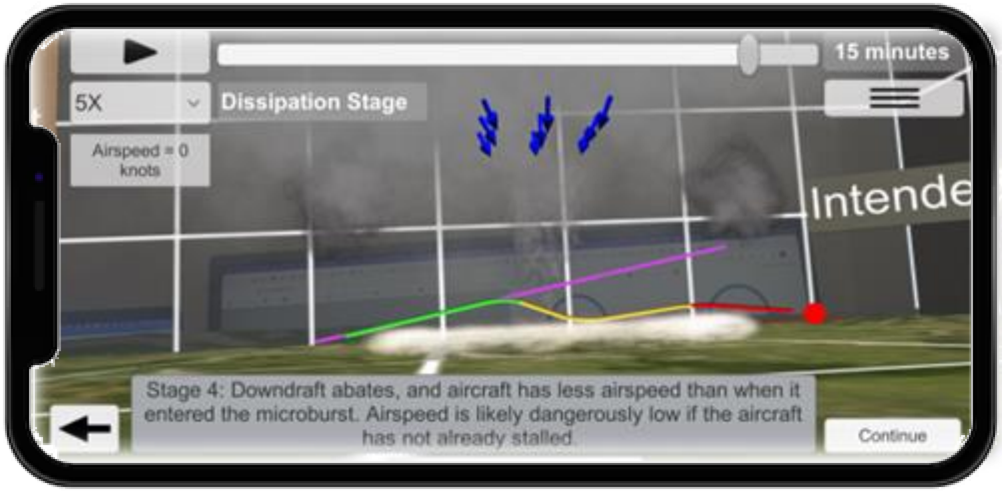
Visualize aircraft attitude (heading, bank, pitch)

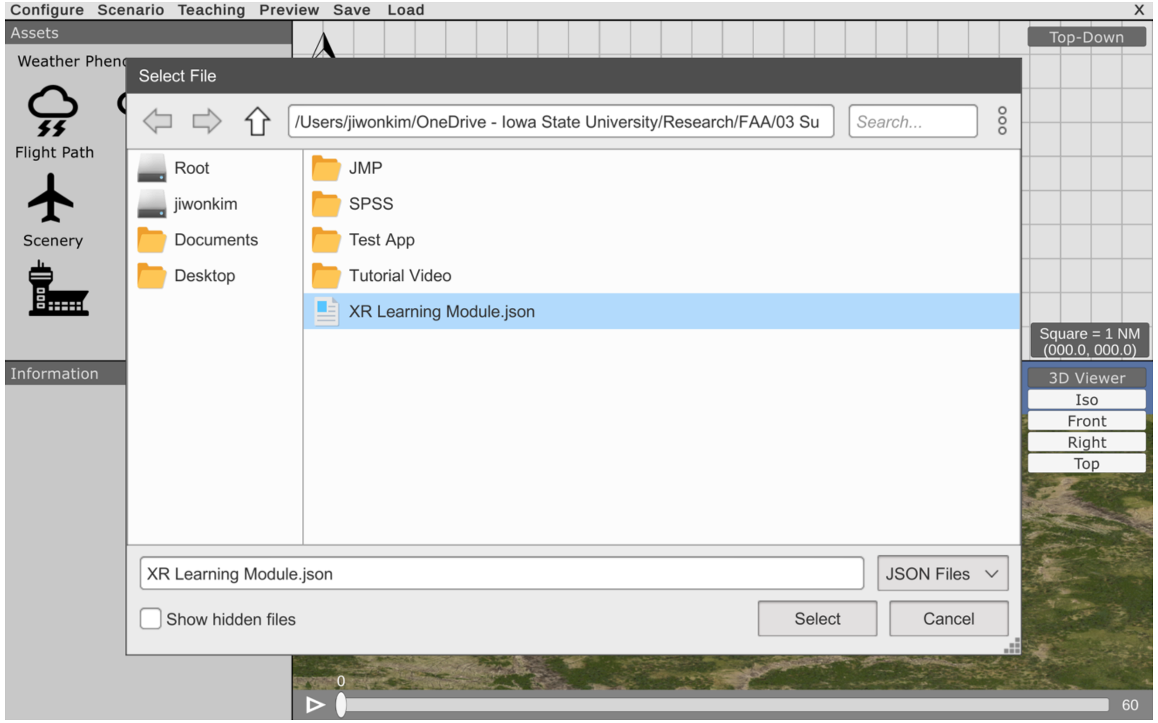
Save/Load

Load prebuilt XR module to tweak it

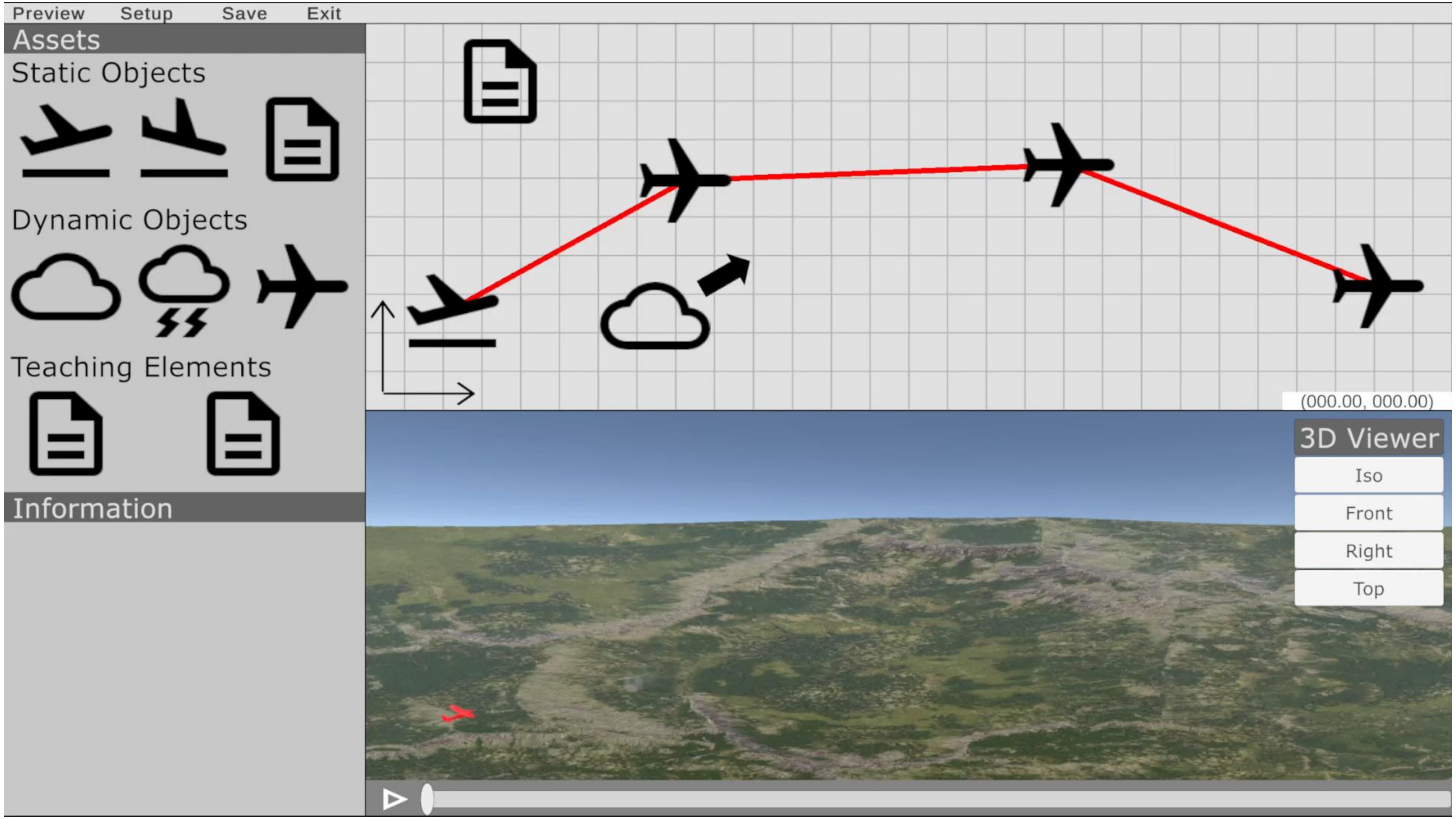
Specify local location to save

StormWise App





XR Learning Module.json


Preview
Setup
Save
Exit
Assets
Static Objects
Dynamic Objects
Teaching Elements
Information
(000.00, 000.00)
3D Viewer
Iso
Front
Right
Top

Study 3: Evaluate AR Authoring Tool with flight instructors

Objective:

- Evaluate effectiveness of XR authoring tool

Participants

- 30 flight instructors (23 Male, 7 Female)
- 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

- Thunderstorm avoidance (with prebuilt lecture notes)
- 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

Results: 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**

Addressing Barriers to Use of AR

Increased confidence and decreased concerns

- Enhanced instructors' **confidence** in XR authoring (▲37%) and **familiarity** with the process (▲52%)
- Reduced concerns about **technical complexity** (▼20%), **mental effort** (▼21%), and **time requirements** (▼26%)

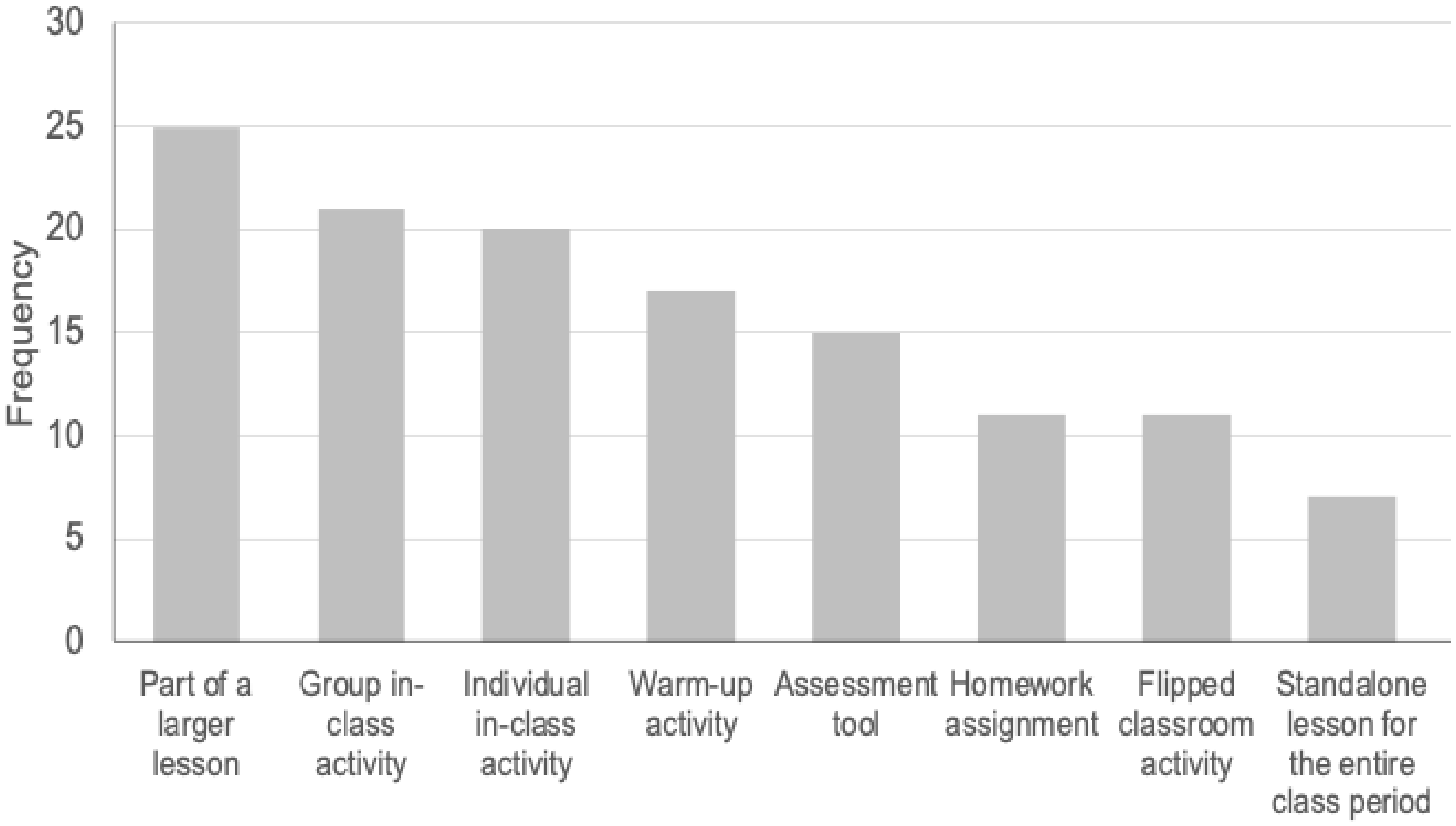
High usability and requires low workload

- 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

Potential Use Cases of AR



Study 4: Subject matter expert review of modules

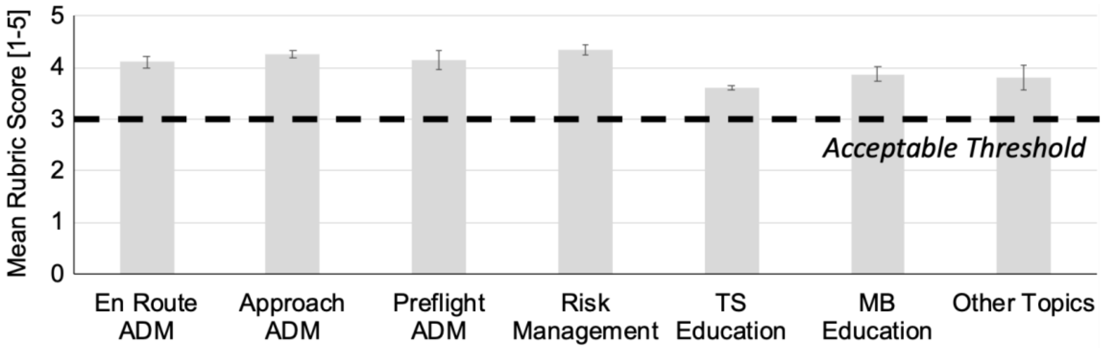
Objective: Expert assess educational quality of AR learning modules

Participants

- 3 (1 male, 2 females)
- 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)

Rubric

- Learning objectives, Clarity, Correctness, Assessment alignment, Effective feedback, User engagement



M	4.1	4.3	4.1	4.3	3.6	3.9	3.8
SD	0.4	0.1	0.3	0.2	0.1	0.3	0.4
t	8.8	9.6	5.8	7.9	2.3	3.3	4.6
p-value	<.001	<.001	<.001	<.001	.040	.011	.006
Cohen's *d*	3.07	8.94	3.53	7.57	7.78	3.47	2.28

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

Impact of AR Training for 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 early create or modify XR learning modules
- Broaden access to high-quality XR in aviation training

dorneich@iastate.edu

THANK YOU

References

Aguayo, C., & Eames, C. (2023). Using mixed reality (XR) immersive learning to enhance environmental education. The Journal of Environmental Education, 54(1), 58-71.

Air Safety Institute, “The 30th Joseph T. Nall Report,” 2021.

M. Akçayır and G. Akçayır, "Advantages and challenges associated with augmented reality for education: A systematic review of the literature," Educational research review, vol. 20, pp. 1-11, 2017.

N. Alalwan, L. Cheng, H. Al-Samarraie, R. Yousef, A. I. Alzahrani, and S. M. Sarsam, "Challenges and prospects of virtual reality and augmented reality utilization among primary school teachers: A developing country perspective," Studies in Educational Evaluation, vol. 66, p. 100876, 2020.

V. Arribas, L. Casas, E. Estop, and M. Labrador, “Interactive PDF files with embedded 3D designs as support material to study the 32 crystallographic point groups,” Comput. Geosci., vol. 62, pp. 53–61, 2014.

N. Ashtari, A. Bunt, J. McGrenere, M. Nebeling, and P. K. Chilana, "Creating augmented and virtual reality applications: Current practices, challenges, and opportunities," in Proceedings of the 2020 CHI conference on human factors in computing systems, 2020, pp. 1-13.

Berendschot, Q., Ortiz, Y., Blickensderfer, B., Simonson, R., & DeFilippis, N. (2018). How to Improve General Aviation Weather Training: Challenges and Recommendations for Designing Computer-Based Simulation Weather Training Scenarios. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 62(1), 1792–1795. https://doi.org/10.1177/1541931218621406

M. Billinghurst and H. Kato, “Collaborative augmented reality,” Commun. ACM, vol. 45, no. 7, pp. 64–70, 2002.

T. Q. Carney et al., “Weather Technology in the Cockpit (WTIC) Project B: Unexpected Transition from VFR to IMC,” 2015.

Cassola, F., Mendes, D., Pinto, M., Morgado, L., Costa, S., Anjos, L., ... & Paredes, H. (2022). Design and evaluation of a choreography-based virtual reality authoring tool for experiential learning in industrial training. IEEE Transactions on Learning Technologies, 15(5), 526-539.

C. Dede, “The evolution of constructivist learning environments: Immersion in distributed, virtual worlds,” Educ. Technol., vol. 35, no. 5, pp. 46–52, 1995.

A. Dengel, M. Iqbal, S. Grafe, and E. Mangina, "A review on augmented reality authoring toolkits for education," Frontiers in Virtual Reality, vol. 3, pp. 1-15, 2022.

H. Gaspar, L. Morgado, H. Mamede, T. Oliveira, B. Manjón, and C. Gütl, "Research priorities in immersive learning technology: the perspectives of the iLRN community," Virtual Reality, vol. 24, pp. 319-341, 2020.

M.-B. Ibáñez and C. Delgado-Kloos, "Augmented reality for STEM learning: A systematic review," Computers & Education, vol. 123, pp. 109-123, 2018.

S. K. Jones, R. K. Noyd, and K. S. Sagendorf, Building a Pathway to Student Learning : A How-To Guide to Course Design. Herndon: Stylus Publishing, 2011.

J. Kim, K. Wang, J. Miller, M. Dorneich, E. Winer, and L. Brown, "A User-Centered Extended Reality Authoring Tool Development Framework for General Aviation Weather Training," in 2023 IEEE/AIAA 42nd Digital Avionics Systems Conference (DASC), 2023: IEEE, pp. 1-7.

Kim, J., Wang, K., Dorneich, M.C., Winer, E., Brown, L., & Whitehurst, G. (2024). "Preliminary Evaluation of Extended Reality Authoring Tool for General Aviation Weather Training," IEEE/AIAA 43rd Digital Avionics Systems Conference. San Diego, CA, Sep 29-Oct 3

Kim, J., Miller, J., Wang, K., Dorneich, M.C., Winer, L., & Brown, L.J. (Accepted). "Empowering Instructors: Augmented Reality Authoring Toolkit for Aviation Weather Education," IEEE Transactions on Learning Technologies. http://dx.doi.org/10.1109/TLT.2024.3486630

References

Knecht & Frazier, E. Pilots' Risk Perception and Risk Tolerance Using Graphical Risk-Proxy Gradients. No.DOT/FAA/AM-15/9. United States. Department of Transportation. Federal Aviation Administration. Office of Aviation. Civil Aerospace Medical Institute, 2015.

T. Ley, R. Maier, S. Thalmann, L. Waizenegger, K. Pata, and A. Ruiz-Calleja, "A knowledge appropriation model to connect scaffolded learning and knowledge maturation in workplace learning settings," Vocations and Learning, vol. 13, pp. 91-112, 2020.

T. Long, "Analysis of Weather-Related Accident and Incident Data Associated with Section 14 CFR Part 91 Operations," The Collegiate Aviation Review International, vol. 40, no. 1, pp. 25-39, 2022.

W. L. Major et al., "VFR-into-IMC Accident Trends: Perceptions of Deficiencies in Training," J. Aviat. Technol. Eng., vol. 7, no. 1, pp. 50–57, 2017.

Meister, P., Wang, K., Dorneich, M.C., Winer, E., Brown, L., & Whitehurst, G. (2022). "Augmented Reality Enhanced Thunderstorm Learning Experiences for General Aviation," AIAA Journal of Air Transportation. 30(4), 113-124. http://dx.doi.org/10.2514/1.D0308

Meister, P., Miller, J.,*Wang, K., Dorneich, M.C., Winer, E., Brown, L., & Whitehurst, G. (2023). "Evaluation of Augmented Reality Interactive Print for General Aviation Weather Training," AIAA Journal of Air Transportation. 32(1), 12-21. http://dx.doi.org/10.2514/1.D0364

N. Moorhouse and T. Jung, "Augmented reality to enhance the learning experience in cultural heritage tourism: An experiential learning cycle perspective," eReview of Tourism Research, vol. 8, 2017.

M. Nebeling and M. Speicher, "The trouble with augmented reality/virtual reality authoring tools," in 2018 IEEE international symposium on mixed and augmented reality adjunct (ISMAR-Adjunct), 2018: IEEE, pp. 333-337.

Y. Ortiz, E. L. Blickensderfer, and J. King, "Assessment of general aviation cognitive weather tasks: Recommendations for autonomous learning and training in aviation weather," Proc. Hum. Factors Ergon. Soc., vol. 2017, pp. 1861–1865, 2017.

M. Rusiñol, J. Chazalon, and K. Diaz-Chito, "Augmented songbook: an augmented reality educational application for raising music awareness," Multimed. Tools Appl., vol. 77, no. 11, pp. 13773–13798, 2018.

S. Schwan and R. Riempp, "The cognitive benefits of interactive videos: Learning to tie nautical knots," Learn. Instr., vol. 14, no. 3, pp. 293–305, 2004.

S. Tzima, G. Styliaras, and A. Bassounas, "Augmented reality applications in education: Teachers point of view," Education Sciences, vol. 9, no. 2, p. 99, 2019.

Volz, K. M., and Dorneich, M. C. "Evaluation of Cognitive Skill Degradation in Flight Planning." Journal of Cognitive Engineering and Decision Making, Vol. 14, No. 4, 2020, pp. 263–287. https://doi.org/10.1177/1555343420962897.

Voukelatou, G. (2019). The contribution of experiential learning to the development of cognitive and social skills in secondary education: A case study. Education Sciences, 9(2), 127.

Wang, W., Miller, J., Meister, P., Dorneich, M., Brown, L., Whitehurst, G., & Winer, E. (2023). "Development and Implementation of an Augmented Reality Thunderstorm Simulation for General Aviation Weather Theory Training," Journal of Imaging Science and Technology. 67(6), 1-14. http://dx.doi.org/10.2352/J.ImagingSci.Technol.2023.67.6.060402

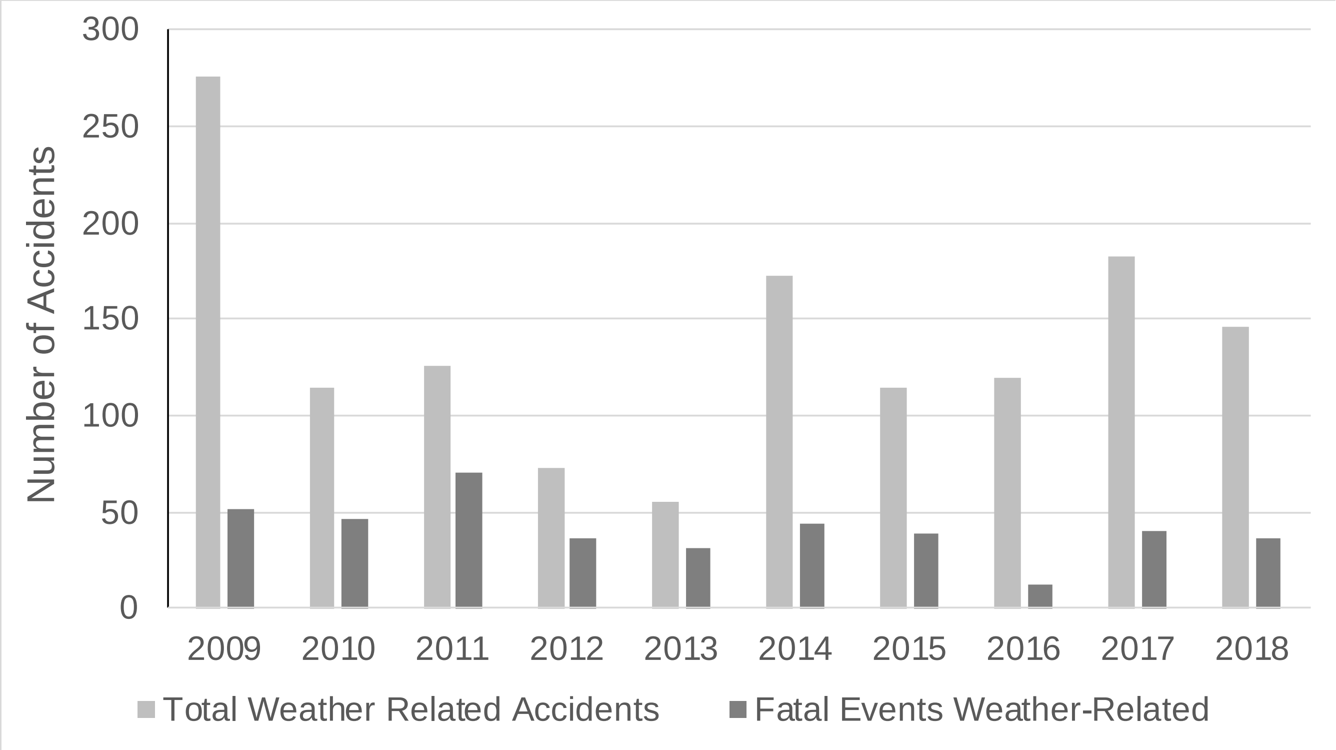
Appendix

Background

General aviation (GA) pilots have less training & fewer flight hours than commercial pilots

Weather substantial contributing factor to GA accidents

- 8% were attributed to weather conditions (2009-2018)
- Among these weather-related accidents, 30% of them led to fatality (Long, 2022)



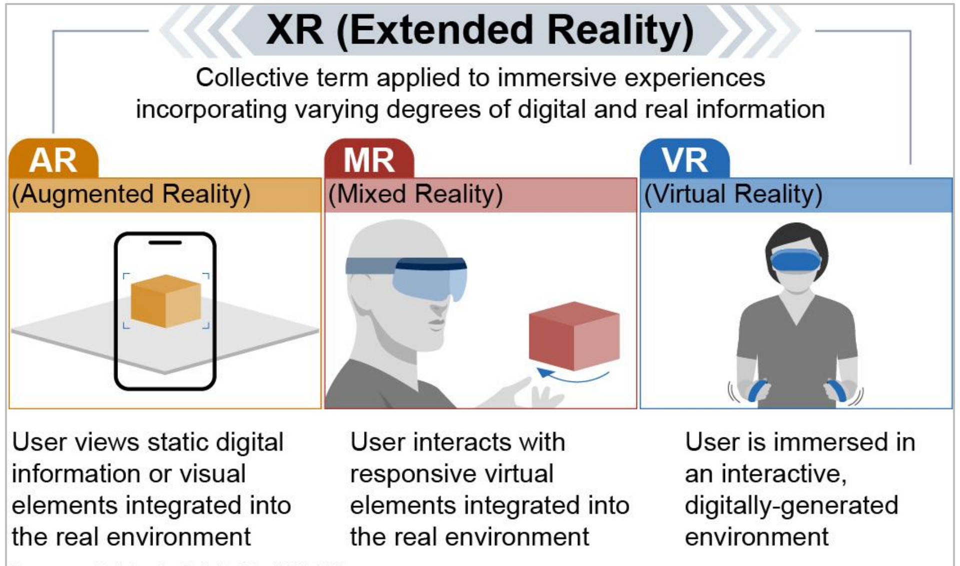
Source: National Transportation Safety Board

Usefulness of Extended Reality (XR) Technology in Training

Enhancing student engagement (Ibáñez et al., 2018; Chen et al., 2020)

Experiential learning (Moorhouse & Jung, 2017; Voukelatou, 2019)

Customize the scenario to better relate to the student (Aguayo & Eames, 2023)

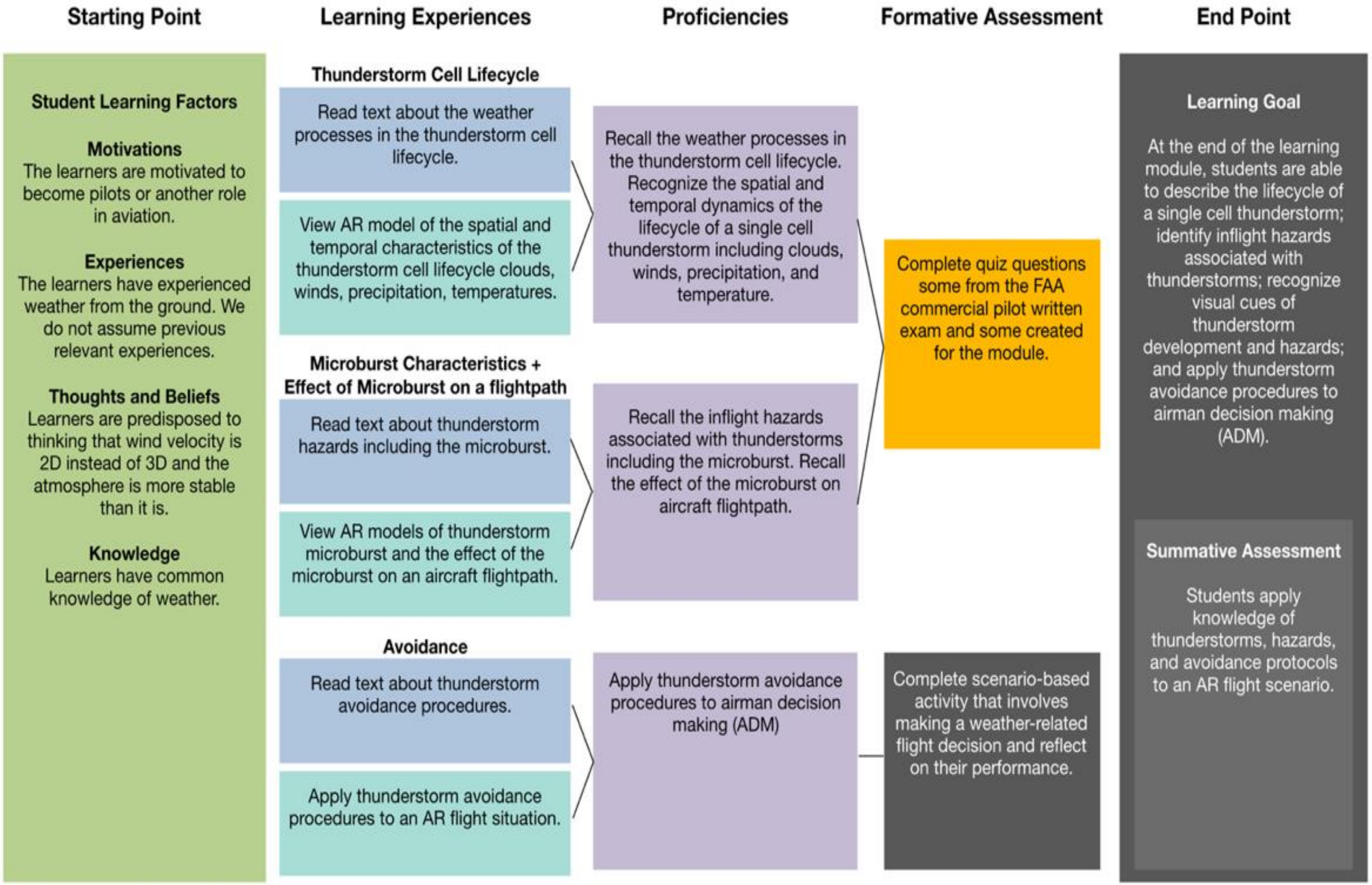


Source: GAO. | GAO-22-105541

Augmented Reality Weather Training

Wang, W., Miller, J., Meister, P., Dorneich, M., Brown, L., Whitehurst, G., & Winer, E. (2023). "Development and Implementation of an Augmented Reality Thunderstorm Simulation for General Aviation Weather Theory Training," Journal of Imaging Science and Technology. 67(6), 1-14. http://dx.doi.org/10.2352/J.ImagingSci.Technol.2023.67.6.060402

Instructional Design of AR Learning Content



Authoring Toolkit for Aviation Instructors to Develop AR Learning Modules

Kim, J., Miller, J., Wang, K., Dorneich, M.C., Winer, L., & Brown, L.J. (Accepted). "Empowering Instructors: Augmented Reality Authoring Toolkit for Aviation Weather Education," *IEEE Transactions on Learning Technologies*. http://dx.doi.org/10.1109/TLT.2024.3486630

Instructors Motivated to Create Own Scenarios in XR

Instructors motivated to create lessons in XR to leverage benefits (Kim et al., 2024)

- Engagement, making abstract ideas tangible, scenario-based training
- Capture students' attention and foster a deeper connection with subject

Research interviews confirmed XR can help students relate to scenario-based training more effectively (Kim et al., 2024; Cassola et al., 2022)

Personalized learning tailor content to individual student needs (Ley et al., 2020)

- Offer interactive activities, quizzes, and simulations
- Cater to different learning styles

Challenges

Research Problem

- XR is recognized as useful and instructors motivated to use it, but limited options available for non-programmer instructors to create XR lessons

Challenges for XR adoption

- Instructor's limited digital proficiency (Tzima et al., 2019; Akçayır & Akçayır, 2017; Ashtari et al., 2020)
- Technical complexity of XR authoring toolkits (Gaspar et al., 2020; Nebeling & Speicher, 2018)
- Time-consuming nature of XR authoring (Kim et al., 2024; Alalwan et al., 2020)

Previous studies have highlighted challenges in

- Bridging the gap between technical XR authoring tools and instructors' digital proficiency (Ashtari et al., 2020; Nebeling & Speicher, 2018)
- Necessity for user studies in the development of XR authoring tools (Dengel et al., 2022)

Development process

Gathered XR-training requirements (Kim et al., 2024)

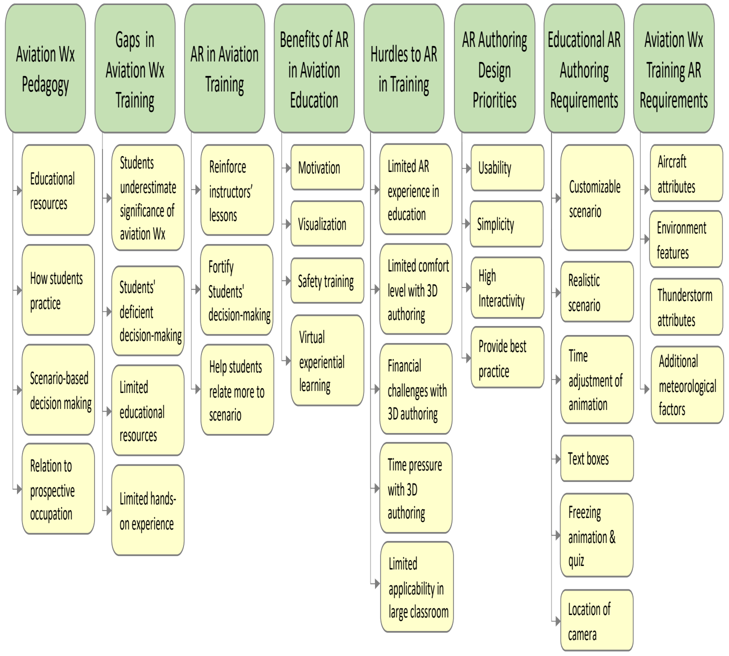
- semi-structured interviews with 17 aviation instructors

Developed XR-training test cases

- SMEs identified aviation weather use cases for training scenarios
- Test Cases: TS Lifecycle; TS Avoidance; MB Effects Flight

Implemented XR-Authoring Toolkit (Wang et al., 2023; Kim et al., 2023)

- Transform requirements into authoring functions
- Key features: UI setup; 3D editor; Teaching elements; Preview



Study 2

Developing Augmented Reality for General Aviation Student Pilots

Meister, P., Wang, K., **Dorneich, M.C.,** Winer, E., Brown, L., & Whitehurst, G. (2022). "Augmented Reality Enhanced Thunderstorm Learning Experiences for General Aviation," AIAA *Journal of Air Transportation*. 30(4), 113-124. http://dx.doi.org/10.2514/1.D0308

Meister, P., Miller, J.,*Wang, K., **Dorneich, M.C.**, Winer, E., Brown, L., & Whitehurst, G. (2023). "Evaluation of Augmented Reality Interactive Print for General Aviation Weather Training," *AIAA Journal of Air Transportation*. 32(1), 12-21. http://dx.doi.org/10.2514/1.D0364

Comparison of interactive print vs print

In an aviation weather training module, what is the impact of a module with AR activities on the learner's experiences, outcomes and motivation compared to a module with no AR content?

Create **interactive print** training by integrating AR-based learning activities and AR scenario-based activities into existing print learning materials

Evaluate interactive print training against print training with students

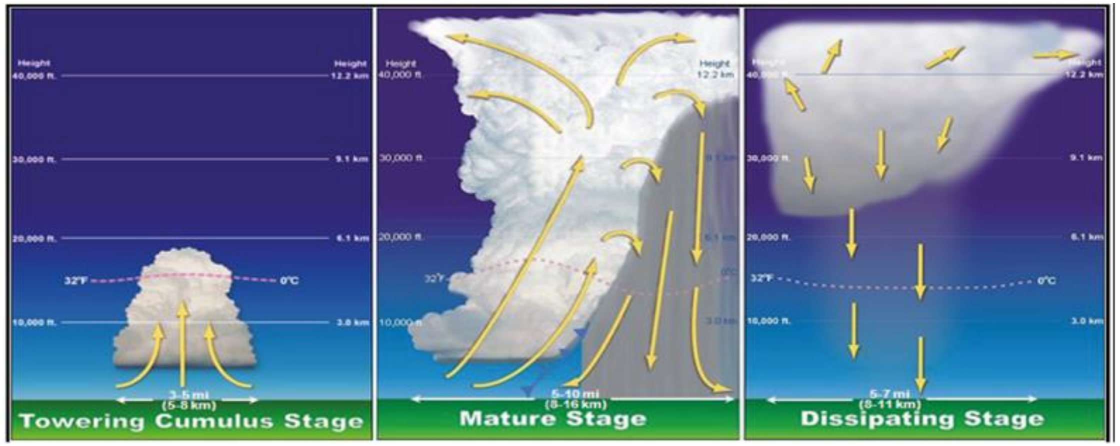
Study 1: Objective and Participants

Aim: evaluate comparative impacts of interactive print (IP) and print (P)

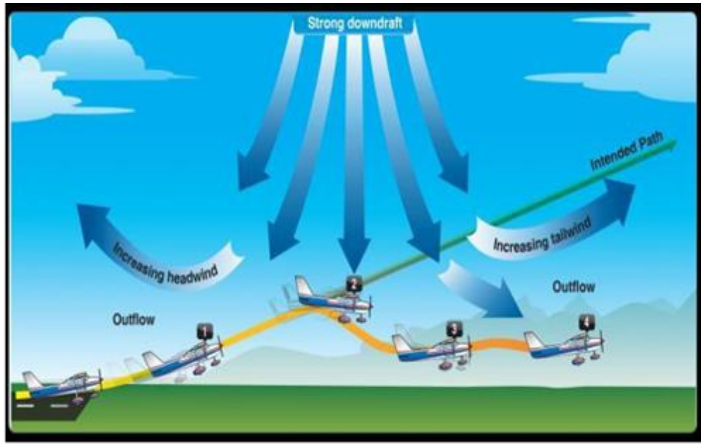
Participants:

- 52 (38 male, 14 female)
- Age M = 23.6 (SD = 8.6) years
- Total flight hours M = 50.3 (SD = 29.6)
- 27 had taken ground school, 21 had aviation meteorology course, 11 had no training

Print

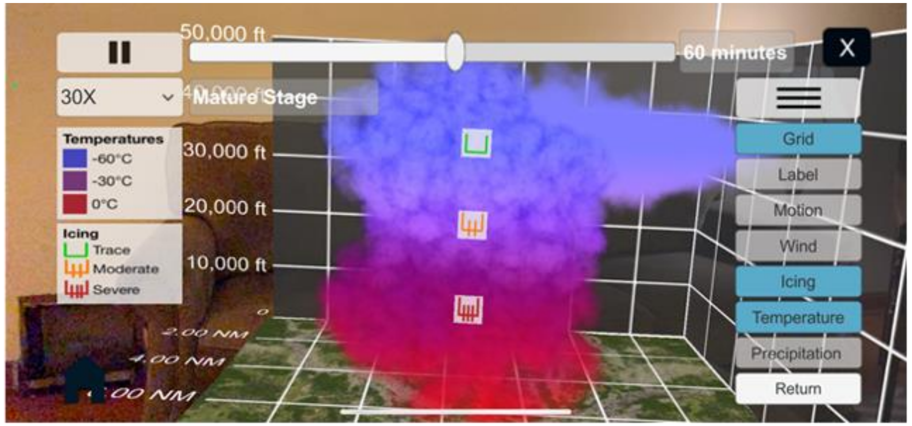


(a) Knowledge-based activity: Thunderstorm Life Cycle

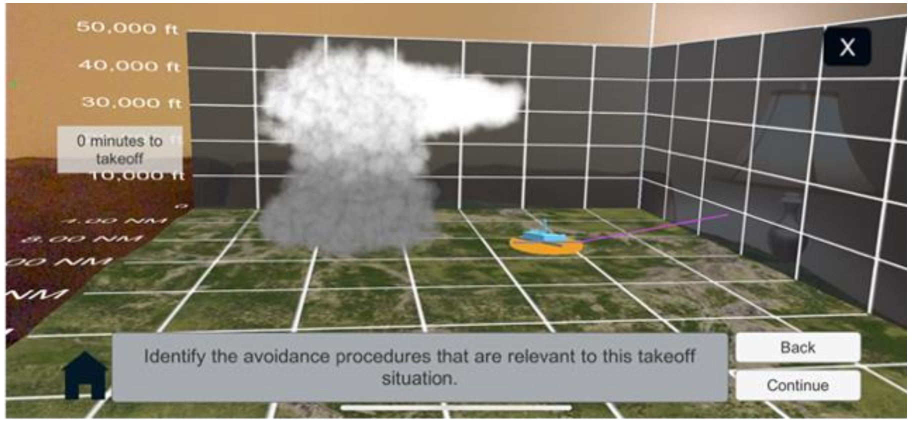


(b) Knowledge-based activity: Microburst

Interactive Print



(a) Knowledge-based activity: Hazards



(b) Knowledge-based activity: Thunderstorm

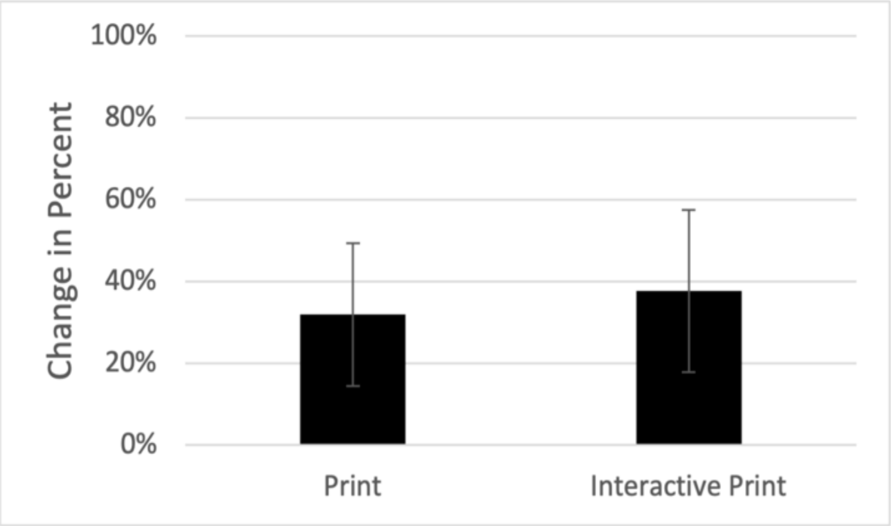
Dependent Measures

Groups	Dependent Variables	Metric	Data Type (Unit)	Method	Frequency
Learning	Change in Factual knowledge	Quiz score	Change %	Quiz	Pre/Post-training
Motivation	Motivation	RIMMS	Scale 1-5	Survey	Post-training
Engagement	Completion time	Time per activity	Seconds	Logs	During Trial
Activity Effectiveness	Activity preparation	Rating	Scale 1-5	Survey	Post-task
Decisions	Task correctness	Score	%	Questions	During Trial

Change in factual knowledge

Both conditions showed an improvement of knowledge test scores.

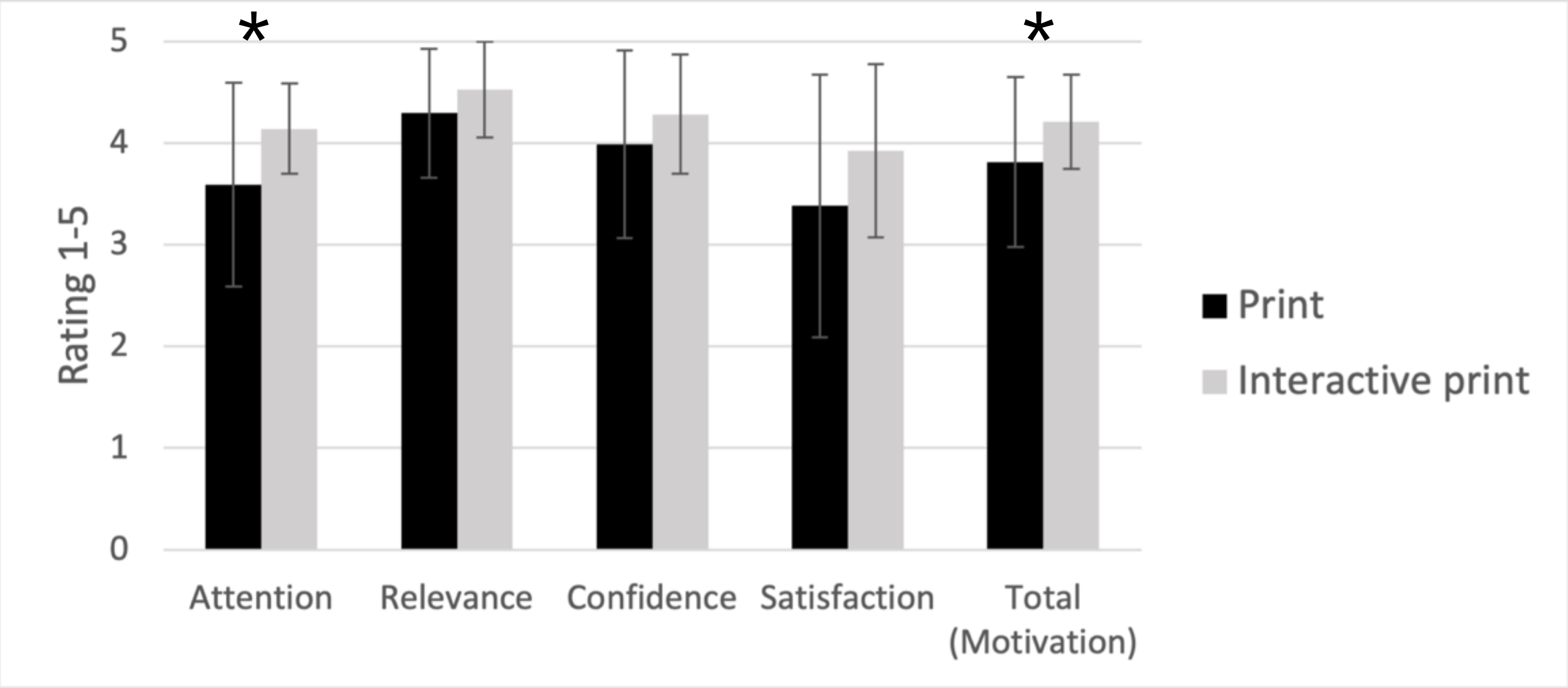
- Print condition improved from pre-test (**M = 58.5%**, SD = 19.5%) to post-test (**M = 90.4%,** SD = 10.8%), $t(50) = 1.85$, $\boldsymbol{p < .001}$.
- Interactive print condition improved from pre-test (**M = 54.2%**, SD = 20.4%) to post-test (**M = 91.9%**, $SD = 8.5\%$), $t(50) = 1.32$, $p < .001$.



Effect of training type on student test score improvement was not significant, $t(50) = -1.11$, $p = .27$.

Motivation

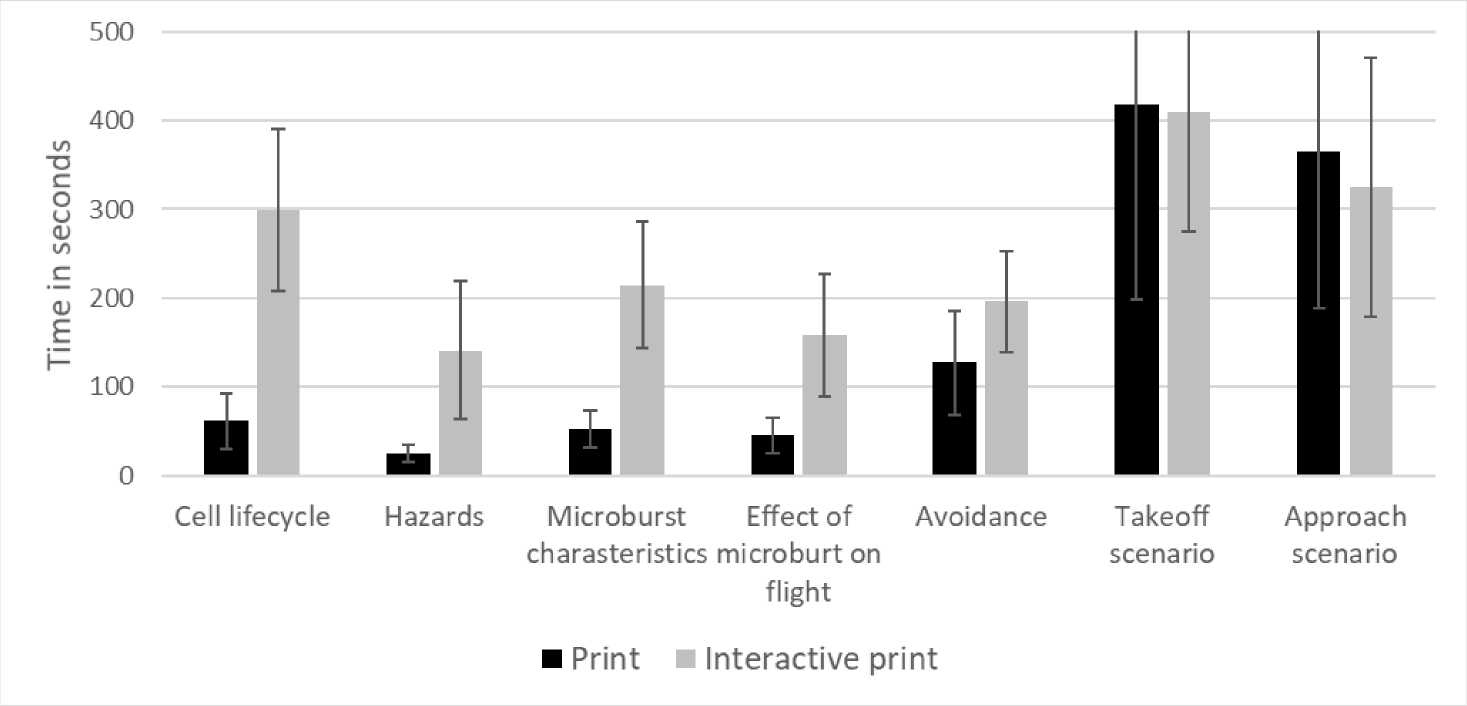
Interactive print training group (***M* = 4.2**, *SD* = 0.5) significantly higher than the print training group (***M* = 3.8**, *SD* = 0.8), *t*(50) = -2.16, ***p* = .04**, *d* = 0.66.



"I prefer [the AR] because it held my attention really well when I probably would've gotten bored with a presentation or reading a textbook."

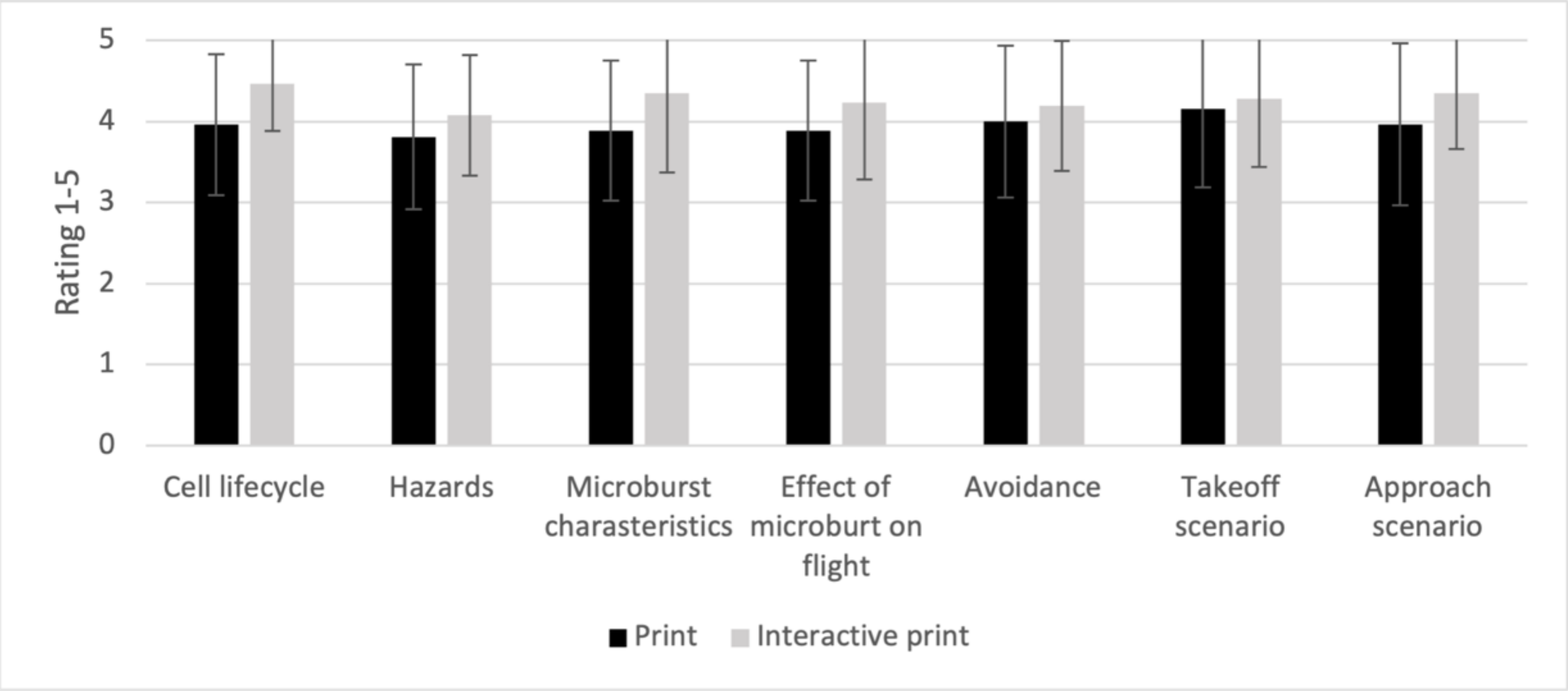
Completion time for each activity

Overall average completion time in interactive print training group (***M* = 249.2** *SD* = 132.3) was significantly higher than the print training group (***M* = 156.4**, *SD* = 186.6), *t*(362) = 30.0, ***p* < .001**, *d* = 0.57.



Effectiveness of the activity for understanding the topic

Interactive print training group (***M* = 4.3**, *SD* = 0.6) marginally significantly different than print training group (***M* = 4.0**, *SD* = 0.7), *t*(50) = -0.79, ***p* = .07**, *d* = 0.46.



Study 3

Authoring Toolkit for Aviation Instructors to Develop AR Learning Modules

Kim, J., Wang, K., Dorneich, M.C., Winer, E., Brown, L., & Whitehurst, G. (2024). "Preliminary Evaluation of Extended Reality Authoring Tool for General Aviation Weather Training," IEEE/AIAA 43rd Digital Avionics Systems Conference. San Diego, CA, Sep 29-Oct 3.

Objective and Participants

Objective: To evaluate the effectiveness of the XR authoring tool from the perspective of flight instructors, focusing on their perceptions and experiences

Participants

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

Experimental Tasks and Protocol

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

▲ Post-Task Survey ▲ Post-Task Survey

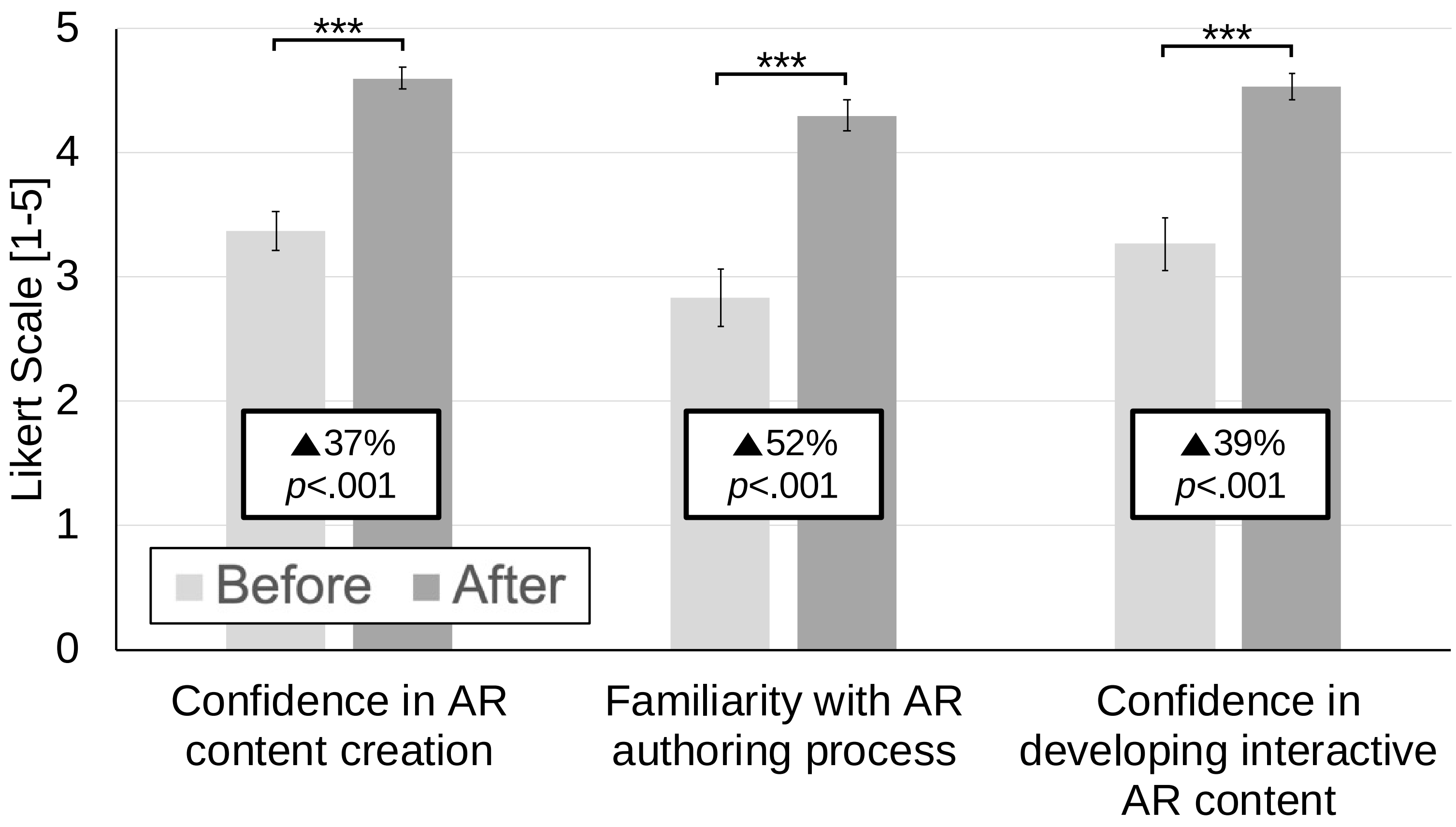
Task: Develop two XR lessons

- Sample training scenario: Thunderstorm avoidance (with prebuilt lecture notes)
- Free-form XR lesson creation based on their own choice of topics

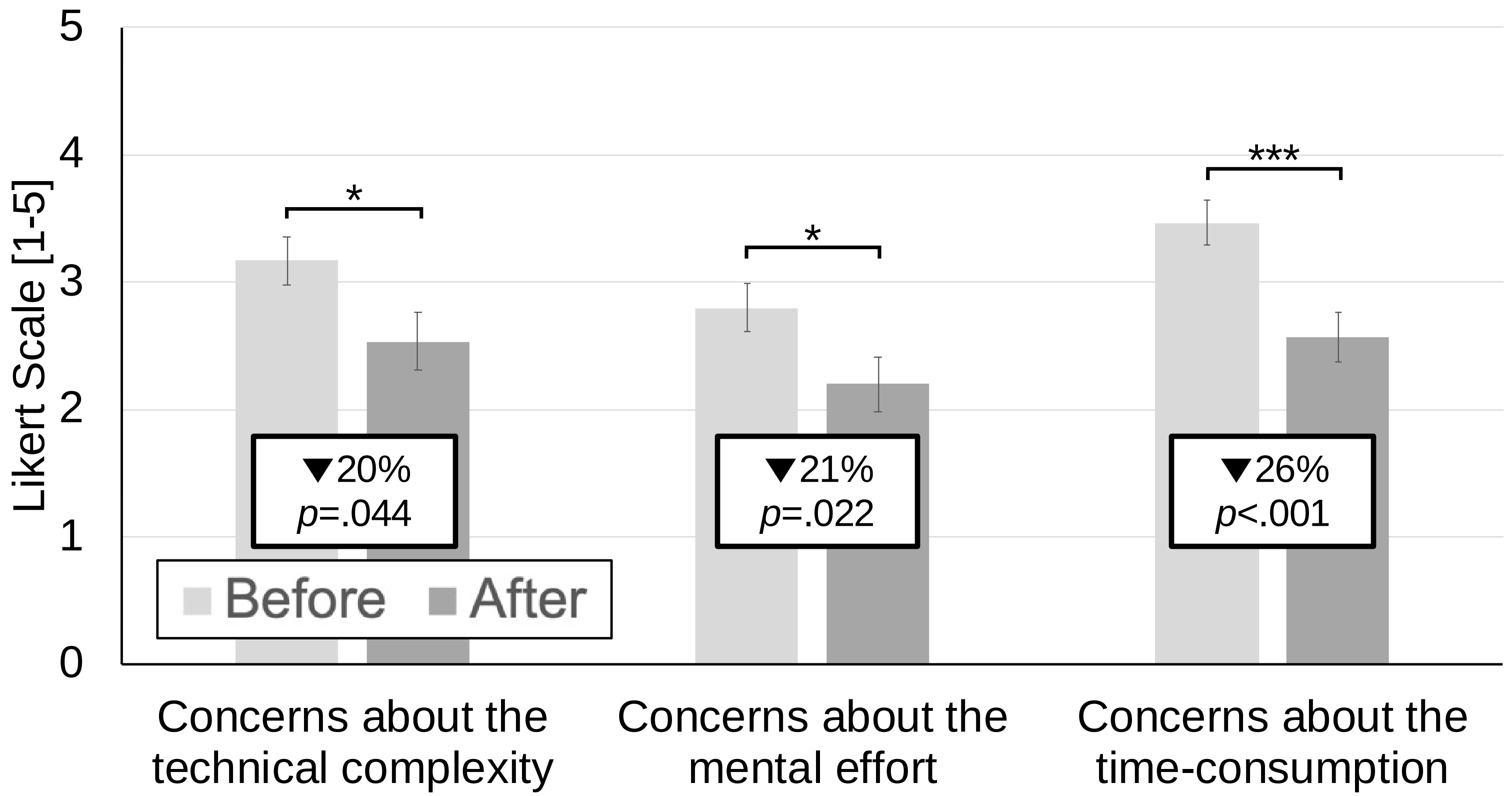
Dependent Measures

Type	Data Type	Frequency	Reference(s)
Confidence in XR Authoring	Scale 1-5	Pre and Post-Experiment	Ashtari et al., 2020; Tzima et al., 2019; Huang et al., 2016
Perceived Challenges in XR Authoring	Scale 1-5	Pre and Post-Experiment	Gandy & MacIntyre, 2014; Park, 2011
Perception of XR's Educational Value	Scale 1-5	Pre and Post-Experiment	Arcos et al., 2016; Kim et al., 2024; Ahn et al., 2004
NASA Task Load Index	Scale 0-20	Post-Task	Hart & Staveland, 1988
System Usability Scale	Scale 1-5	Post-Experiment	Brooke, 1996
Time to Completion	Time (second)	Post-Experiment	Lee et al., 2004; Dias et al., 2003
Use cases of XR	Multiple-choices	Post-Experiment	-

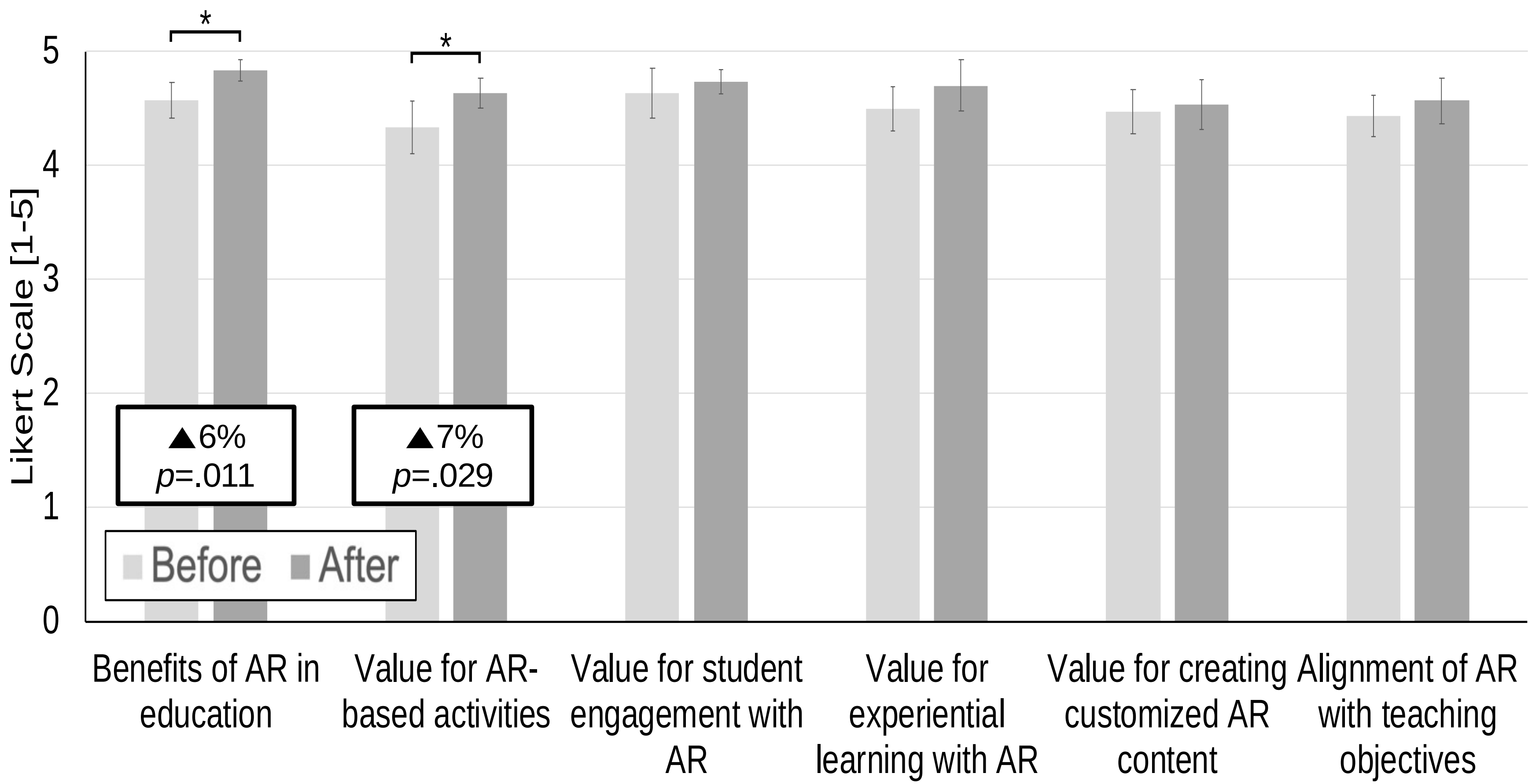
Confidence in XR Authoring



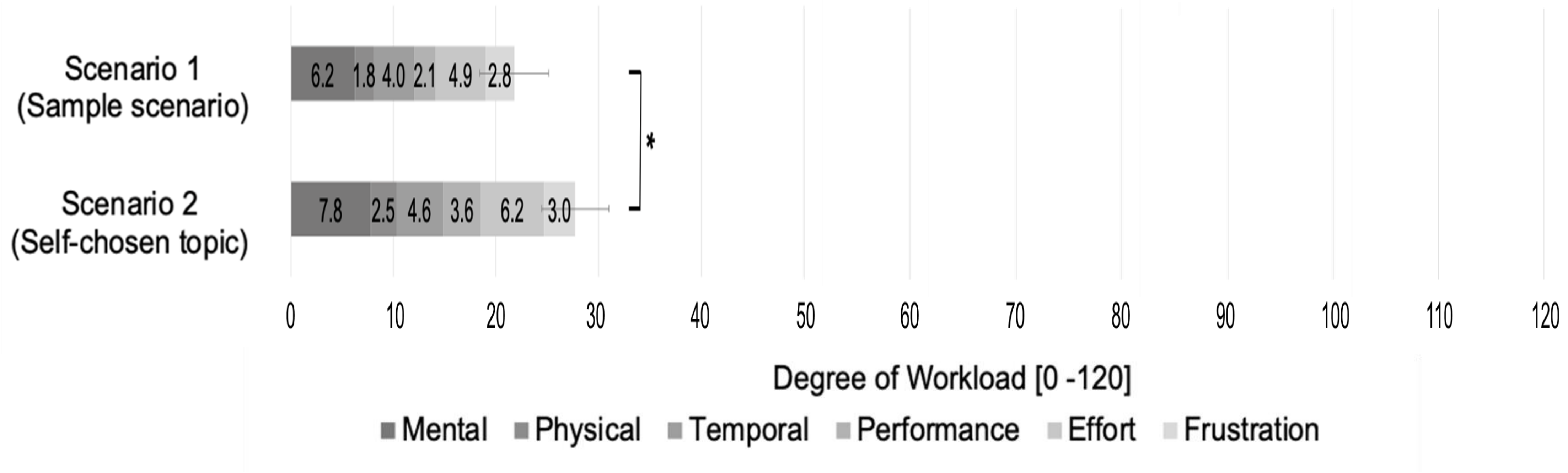
Perceived Challenges in XR Authoring



Perception of XR's Educational Value



Workload



Scenario 1
(Sample scenario)
Scenario 2
(Self-chosen topic)
6.2
1.8
4.0
2.1
4.9
2.8
7.8
2.5
4.6
3.6
6.2
3.0
*
0
10
20
30
40
50
60
70
80
90
100
110
120
Degree of Workload [0 -120]
Mental
Physical
Temporal
Performance
Effort
Frustration

Efficiency & Usability

Time to complete XR authoring

- Sample scenario: 9 min 34 s (*SD* = 38 s)
- Self-chosen topic: 17 min 10 s (*SD* =1 min 19 s)

System Usability Score: 78.1 (*SD* = 13.8)

- 25 of 30 participants rated above 68 (Industry standard)