PEGASAS Project 33
Augmented Weather Interfaces Project

AWIP Presented by
Michael Dorneich, Iowa State University

2024 PEGASAS Annual Meeting

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Executive Summary Slide

- **Motivation**:
  - Instructors motivated to **create their own lessons in XR** due but widespread use limited by instructors' digital proficiency and the technical complexity of 3D authoring toolkits
  - Determine if **combination of XR headsets and flight simulation software** currently available can provide pilots with a realistic flight experiences
- **Aim**:
  - Develop and evaluate an **XR-training authoring framework** to create customized XR-enhanced weather training.
  - In collaboration with FlightSafety International (FSI) and FRASCA, gather an **increased understanding** of limitations, challenges and best practices.
- **Methods/Results**:
  - Developed and evaluate **XR-training authoring tool** to empower instructors to focus on developing XR aviation weather learning experiences rather than mechanics of XR
  - Adapt previously developed scenarios and integrate into **FSI MR Flight Simulator**
- **Next Steps:**
  - Comprehensive **summative evaluation of XR Authoring** with instructors, experts, and students
  - Initial **formative evaluation** of VMC into IMC weather avoidance XR training benefits

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Iowa State and Western Michigan Team

- Faculty
  - Michael Dorneich, Professor, Industrial and Manufacturing System Engineering (ISU)
  - Eliot Winer, Professor, Mechanical Engineering (ISU)
  - Geoffrey Whitehurst, Professor, College of Aviation (WMU)
  - Lori Brown, Professor, College of Aviation (WMU)
- Students (ISU)
  - Jiwon Kim, PhD Student, Industrial Engineering
  - Kexin (Kate) Wang, PhD Student, Human-Computer Interaction
- FAA
  - Gary Pokodner, Program Manager, FAA
  - Ian Johnson, Engineering Psychologist/Human Factors Lead, FAA

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Led by Iowa State University

XR Authoring Framework

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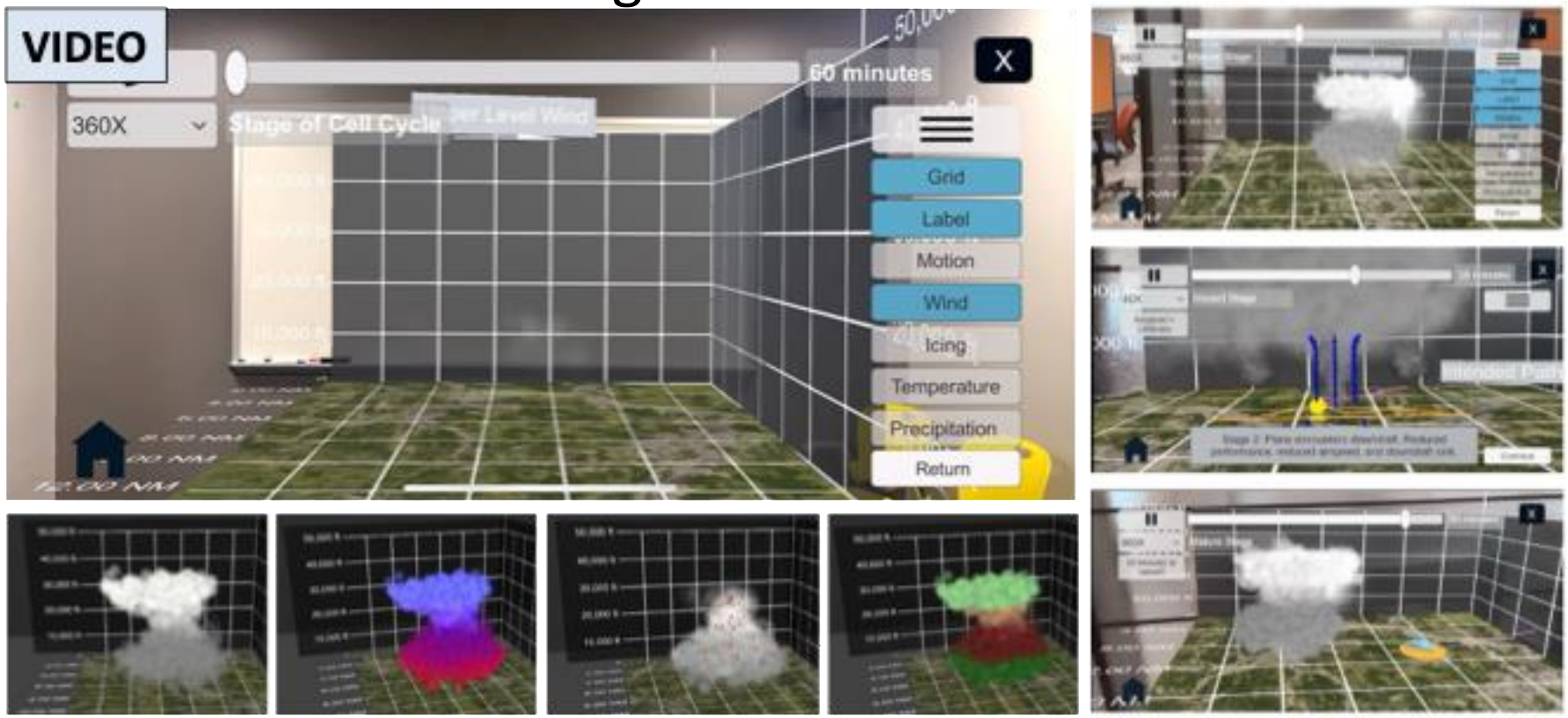
Augmented Reality Enhanced Aviation Weather Training

- Previous work demonstrated educational benefit of XR weather training



Motivation: Instructors Want to Create Their Own Lessons in XR

- 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
- Research interviews confirmed XR can **help students relate** to scenario-based training more effectively (Kim et al., 2024; Cassola et al., 2022)
- **Personalized learning** can tailor content to individual student needs (Ley et al., 2020)
  - offer interactive activities, quizzes, and simulations
  - cater to different learning styles

Challenges

- Although XR is recognized as useful in training, and instructors are motivated to use it, there are **limited options available** for non-tech instructors to create XR lessons

- 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)

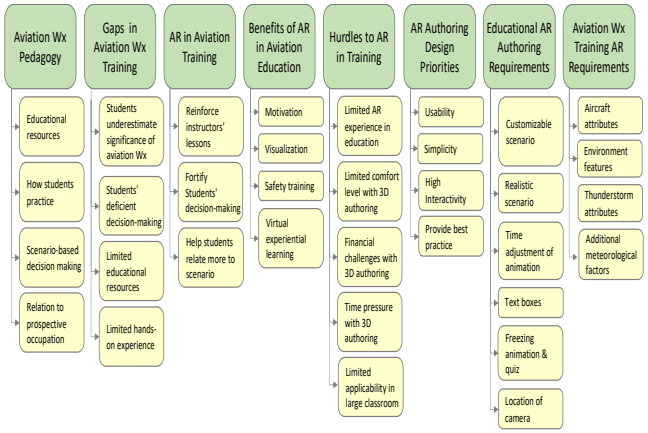
- Previous studies have highlighted challenges in:
  - Bridging the gap between technical XR authoring tools and instructors' digital proficiency (Ashtari et al., 2020; Nebeling & Speicher, 2018)
  - Necessity for user studies in the development of XR authoring tools
    (Dengel et al., 2022)

Research Objective

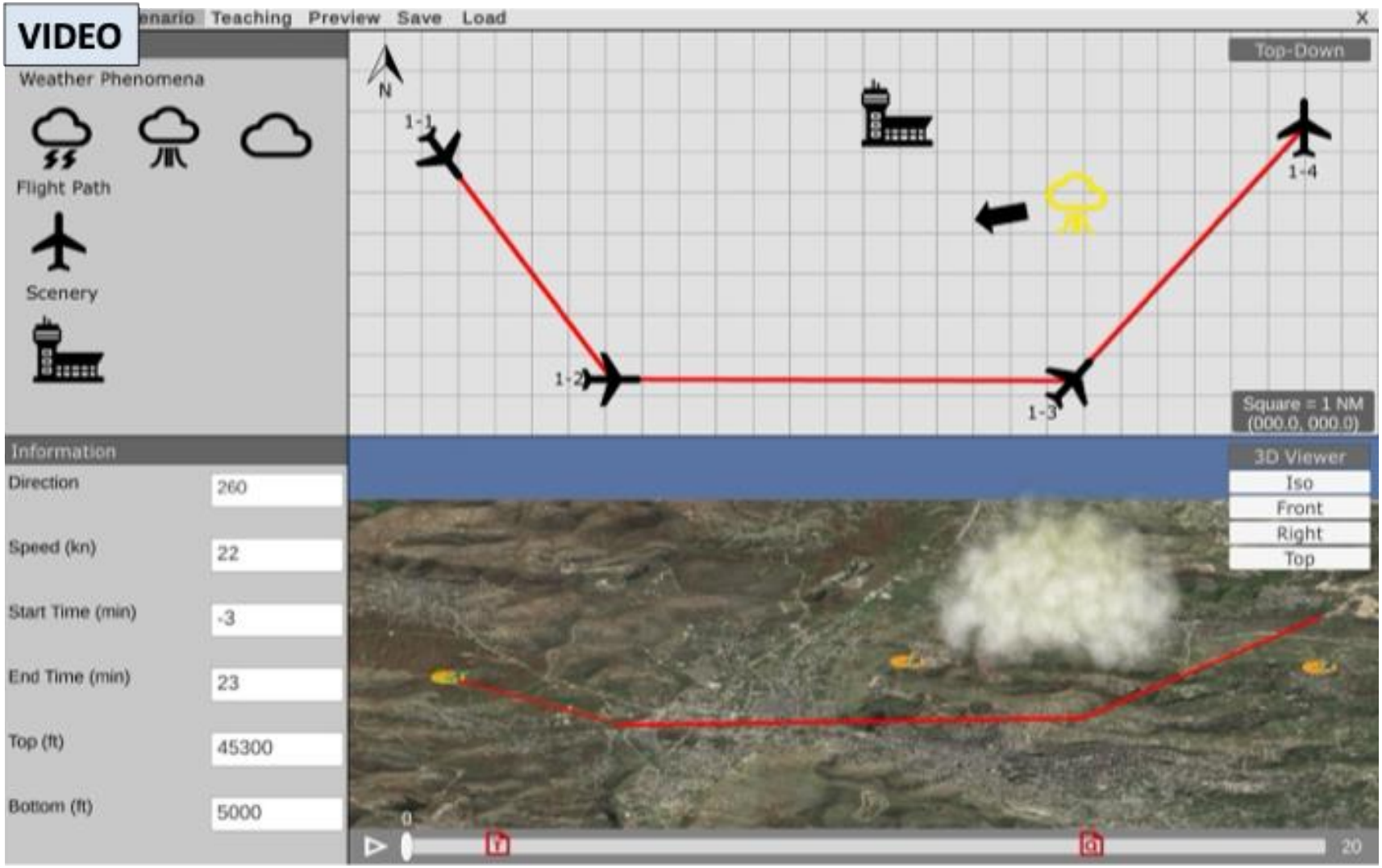
- Shift the focus from technology-centric toolkits to a **content-centered approach**
- **Empower instructors** with limited digital proficiency to interact with weather objects and scenario elements in aviation weather education using XR
- Incorporates an **instructor-centered approach**, utilizing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

Last Year's Work Summary

- Gather XR-training requirements
  - based on semi-structured interviews with 17 aviation instructors
- Develop XR-training test cases
  - SME identified aviation weather use cases for training scenarios
  - Test Cases: TS Lifecycle; TS Avoidance; MB effects on Flight
- Implement Initial XR-Authoring Toolkit
  - Transform requirements into authoring functions
  - Key features: UI setup; 3D editor; Teaching elements; Preview



XR-Authoring Tool Demonstration



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Approach: Formative evaluation of XR authoring framework

- Assess guidance and processes to **create and customize** XR-enhanced weather training
- Assess XR authoring prototype **using test cases** to provide formative feedback on the requirements
- Assess the effectiveness of the XR authoring tool in empowering instructors' ability to create immersive XR lessons

Method: Participants

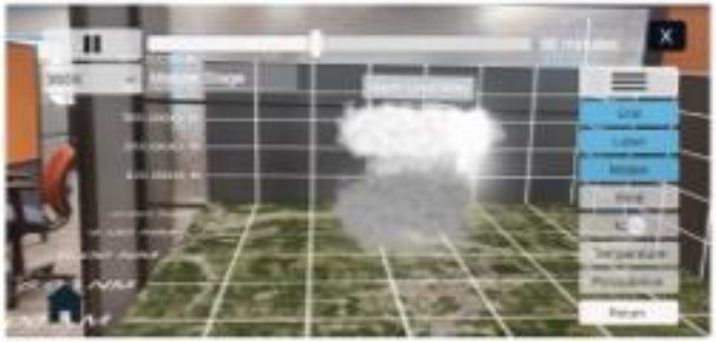
- 41 participants
- 37 flight instructors; 4 pilots
- Years of teaching aviation Wx: 11.5 (*SD* = 12.6)
- Comfort level on AR authoring: 2.6 of 5 (*SD* = 0.9)

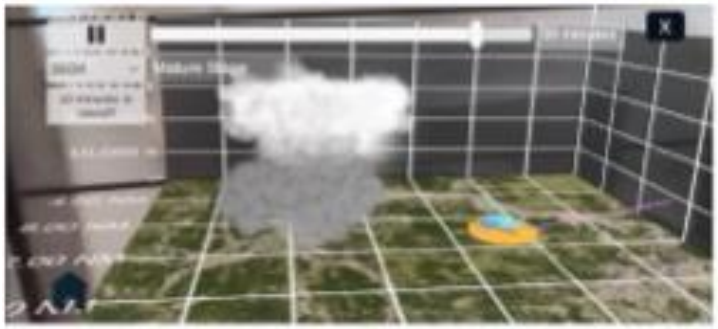
Method: Dependent Variables

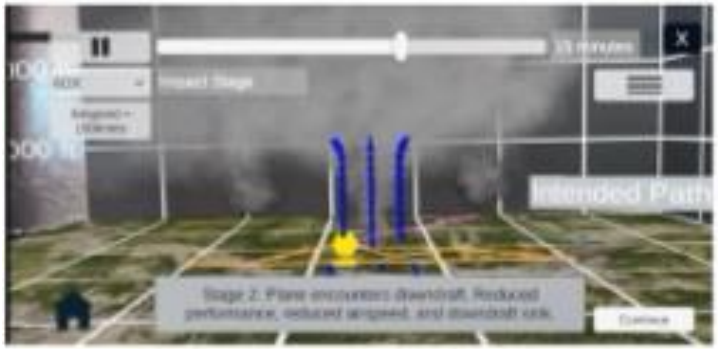
Measure	Metric	Data type (unit)	Frequency
Perceived workload	NASA task load index (TLX)	Scale 0-20	Post-task
Attitudes & Acceptance	Confidence in XR authoring	Scale 1-5	Pre-experiment; Post-experiment
	Perceived challenges in XR authoring	Scale 1-5	
	Perceived XR's educational values	Scale 1-5	
Efficiency	Time to complete a training scenario	Time (sec)	Post-task
Usability	System usability scale (SUS)	Scale 1-5	Post-experiment
	AR authoring tool usability questionnaire	Scale 1-5	
Satisfaction	Net promotor score (NPS)	Scale 0-10	Post-experiment
	Preference rating of functions	Scale 1-5	
Formative feedback	Written response	Text	Post-experiment

Method: Tasks

- Participants asked to create three XR learning experiences:
  - Thunderstorm Cell Lifecycle Characteristics
  - Thunderstorm Avoidance
  - Effects of the Microburst on Flight



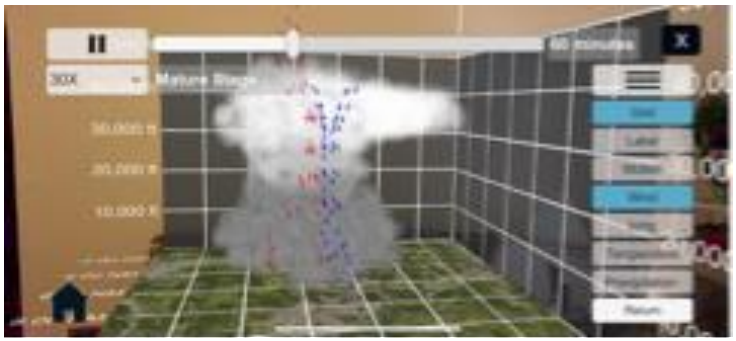


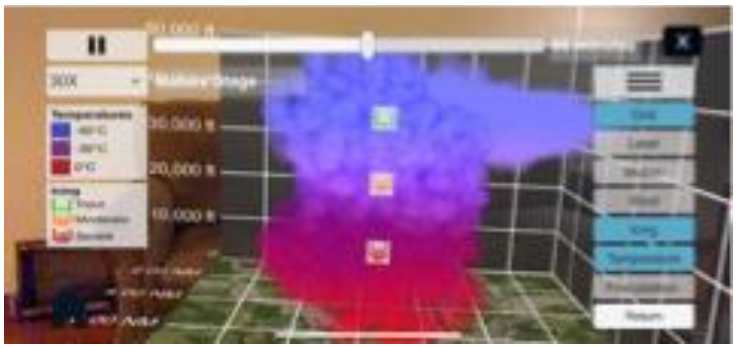


- Training scenarios were identified through SME and interviews

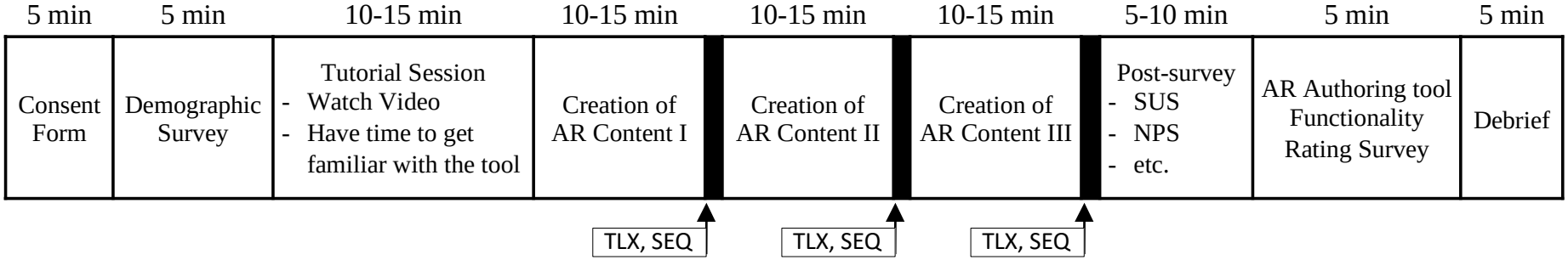
Test Case 1: Thunderstorm Cell Lifecycle Characteristics

- Learning objective:
  - Help students identify different stages of thunderstorm development and understand the hazards associated with each
- Authoring
  - Visualize motion of thunderstorm and wind patterns
  - Give students 3D visualization of up/down drafts at each stage
  - Icing, temperature, and precipitation visualization overlays
  - Instructors add instructional text boxes highlighting lifecycle stages
  - Incorporating quiz within XR activity





Method: Procedures

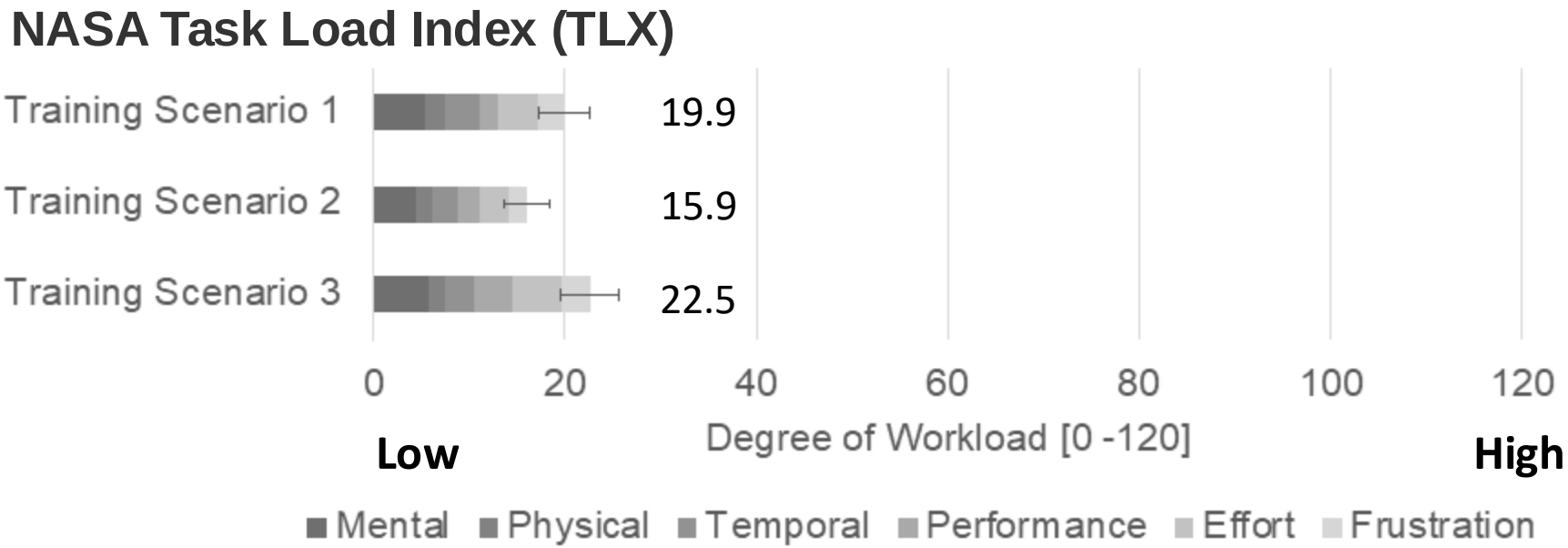


- **Pre-experiment survey:** Attitudes and acceptance toward XR integration (confidence, challenge, XR's value)
- **Tutorial Session**: Pre-recorded videos; training period 10-15 minutes
- **Creation of a series of three XR content:** Independently navigated the screens to develop the XR-based activity for each task
- **Post-task survey:** workload
- **Post-experiment survey**: Attitudes and acceptance toward XR integration (confidence, challenge, XR's value), System Usability Scale (SUS), Preference ratings of functions
- **Formative feedback** on the XR authoring framework

Results: Workload

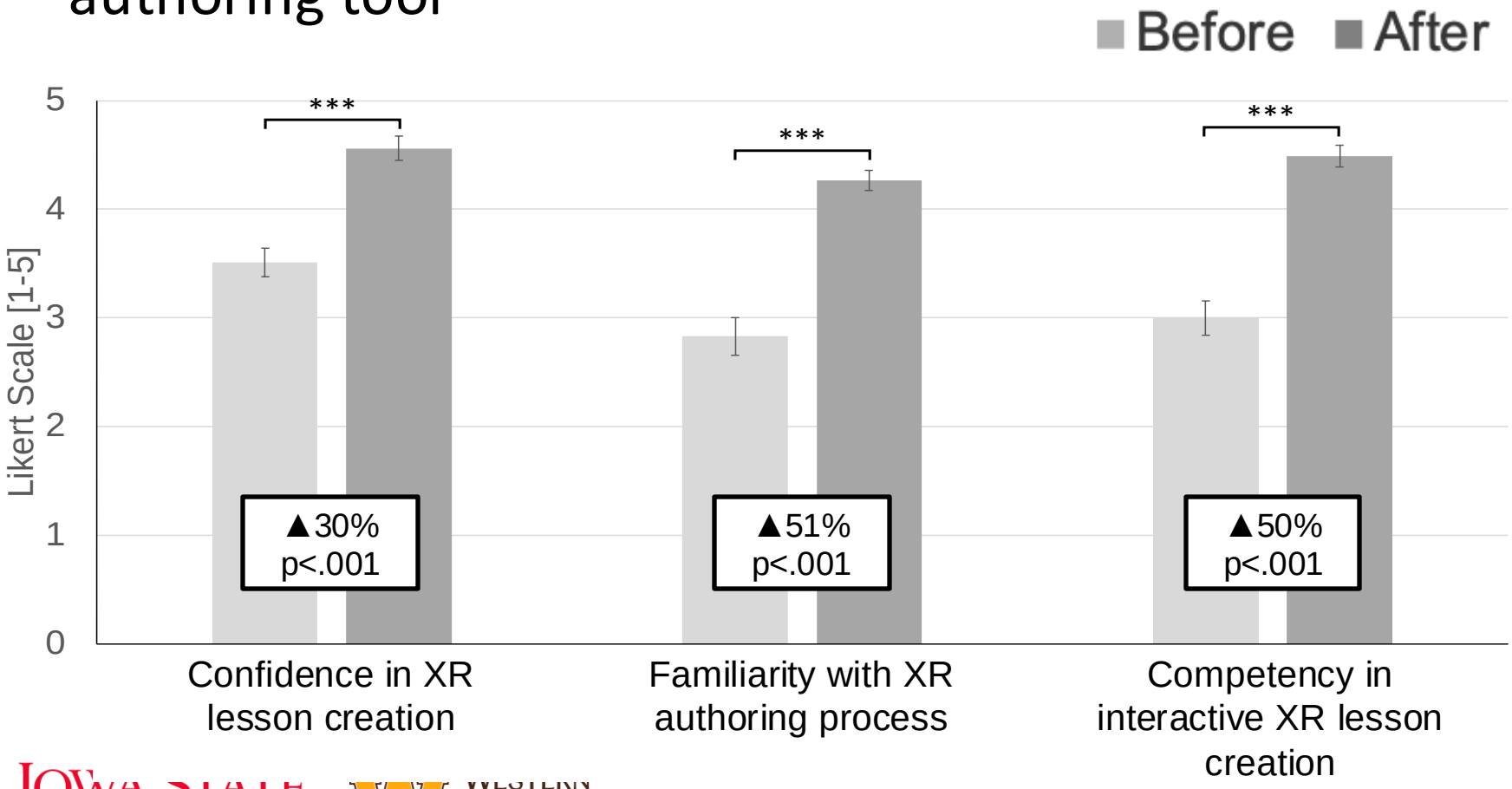
Participants felt training scenarios were easy to follow

They completed scenarios with low workload



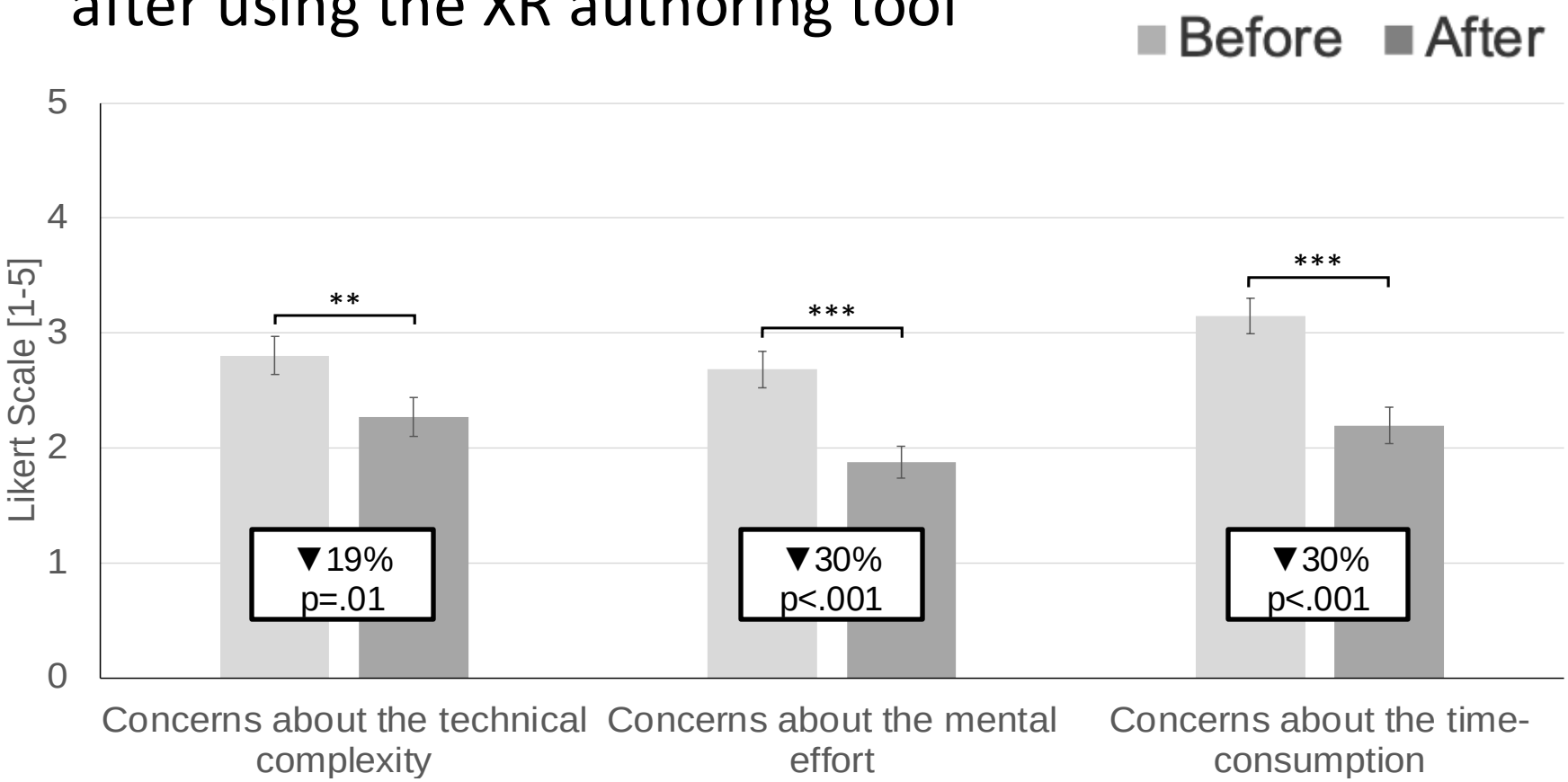
Results: Confidence in XR Authoring

- Increased confidence in XR authoring after using XR authoring tool



Results: Perceived Challenges in XR Authoring

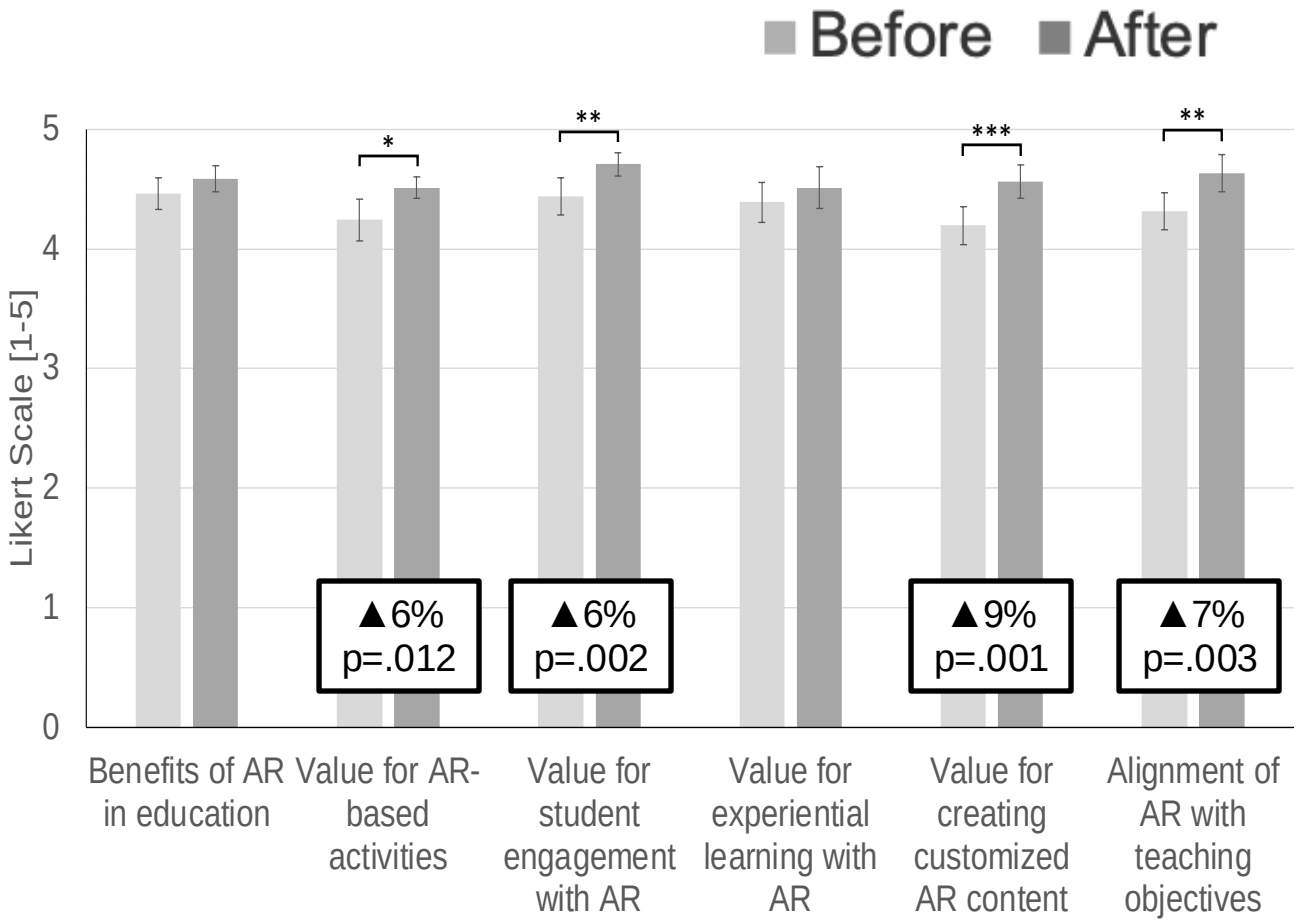
- Lowered concerns about challenges in XR authoring after using the XR authoring tool



Results: Perceived XR's educational values

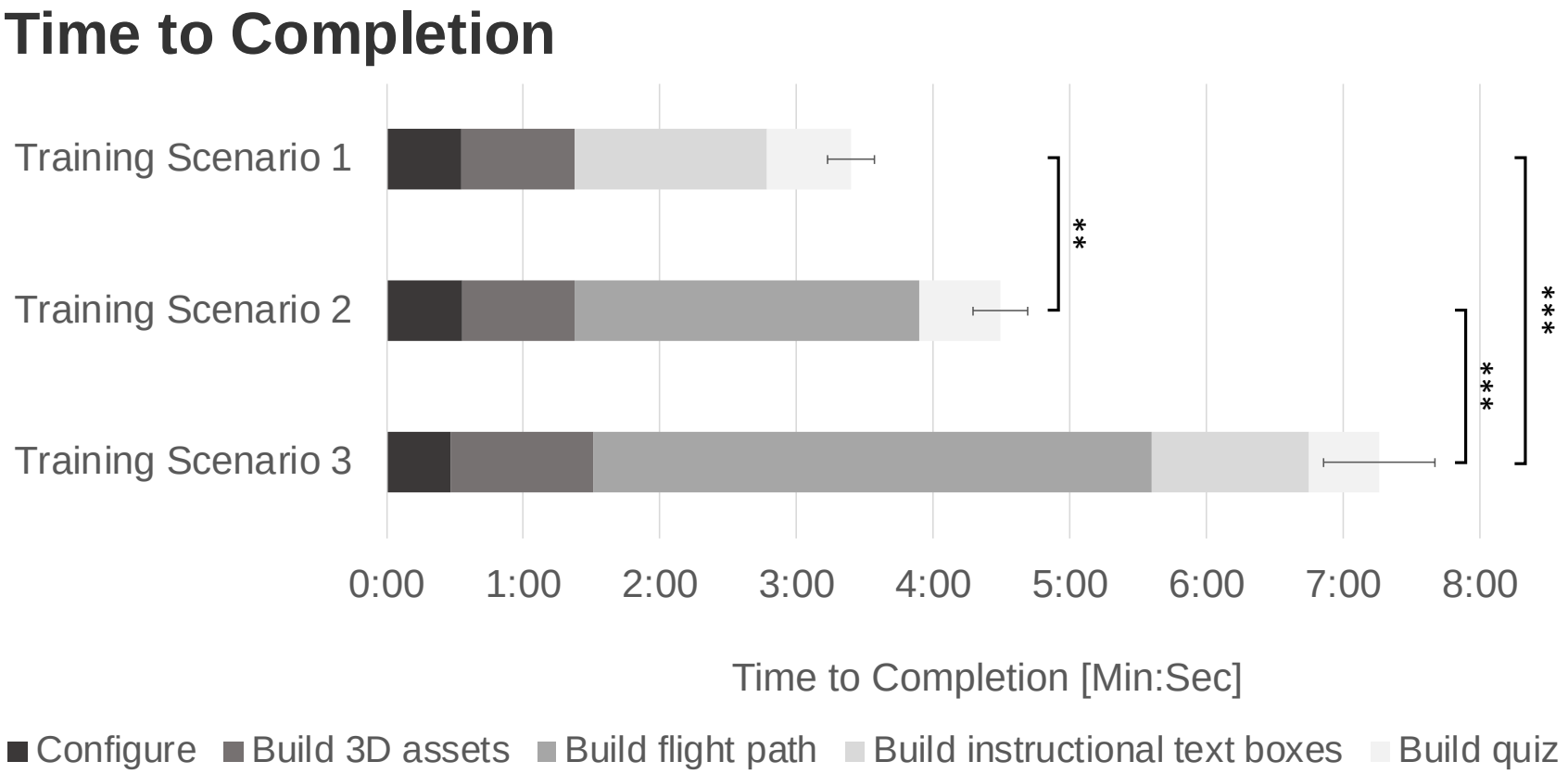
Perceived value of XR in education rose after using XR authoring prototype

Note that perceived value was high to start with



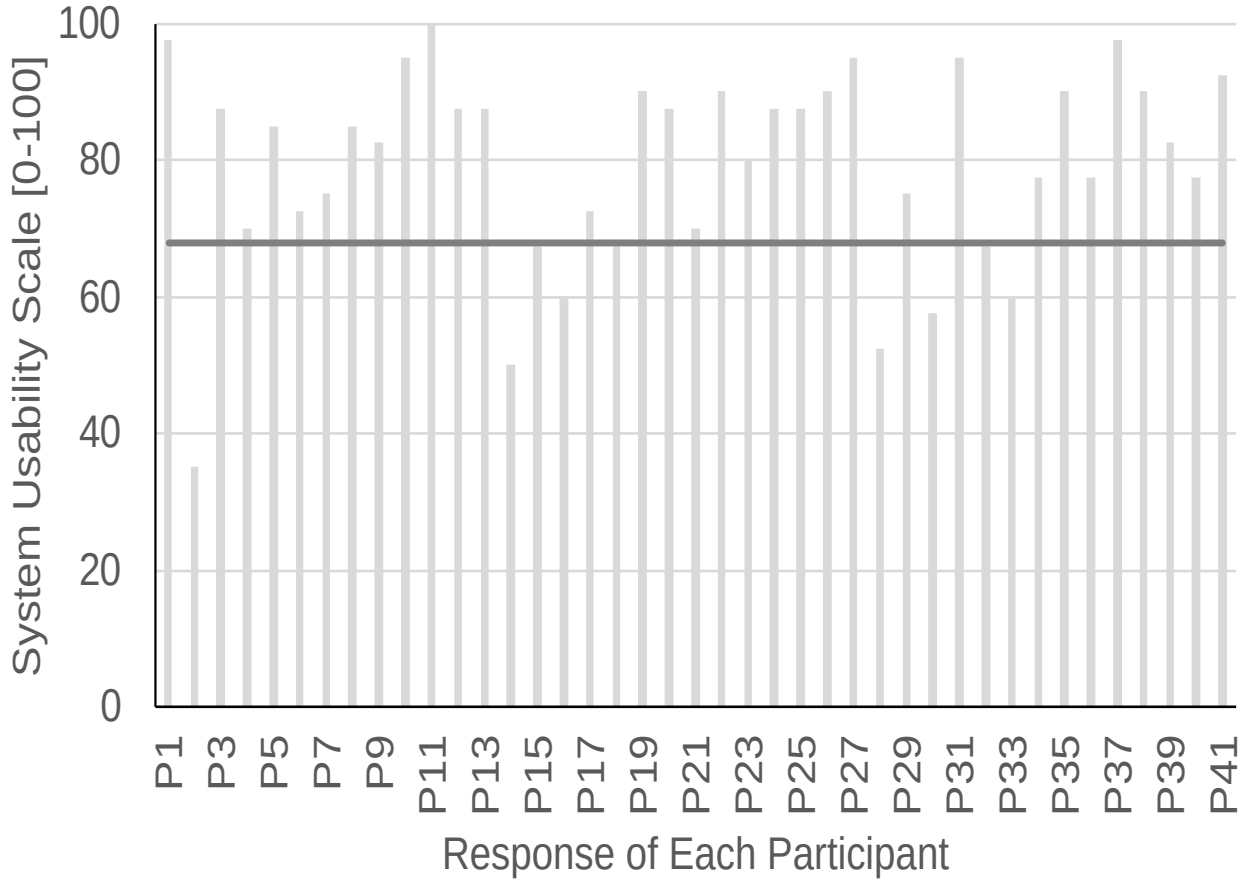
Results: Efficiency

- The most challenging scenario completed < 7.5 min



Results: Usability

System Usability Scale



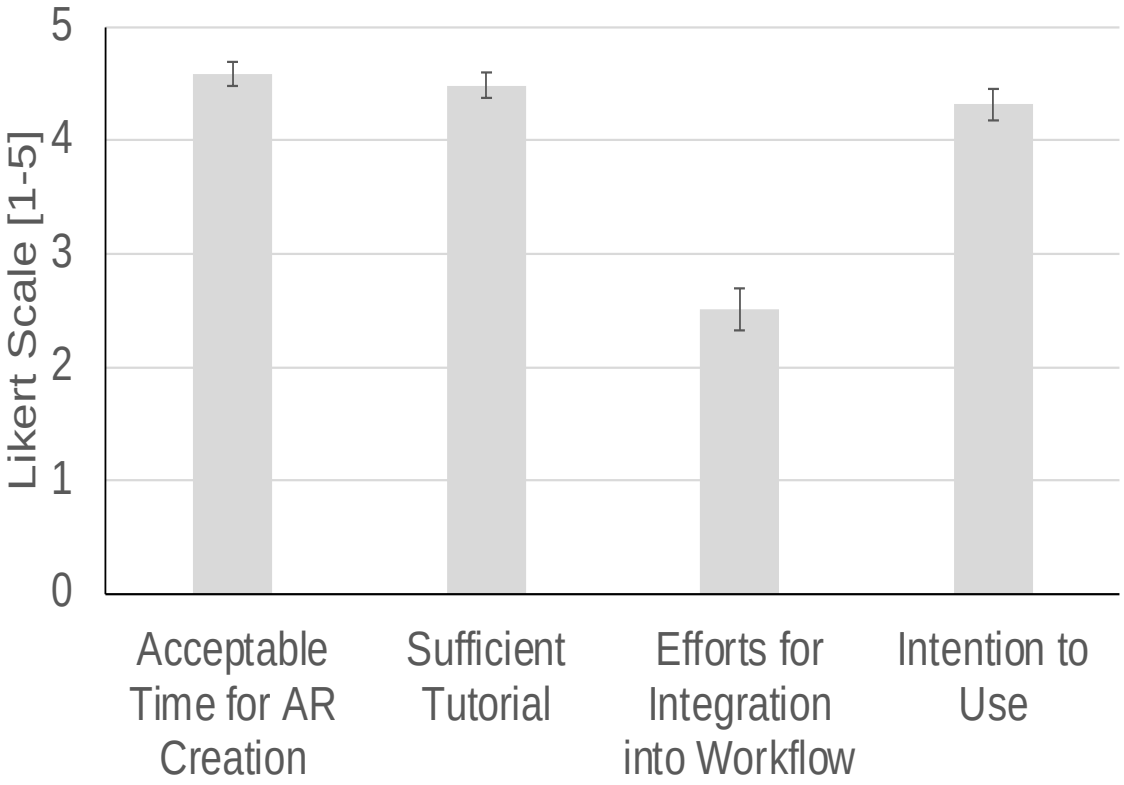
SUS: 79.2 (14.6)

32/41 ≥ 68, which aligns with widely accepted industry standards for positive usability

(Sauro & Lewis, 2016)

Results: Usability

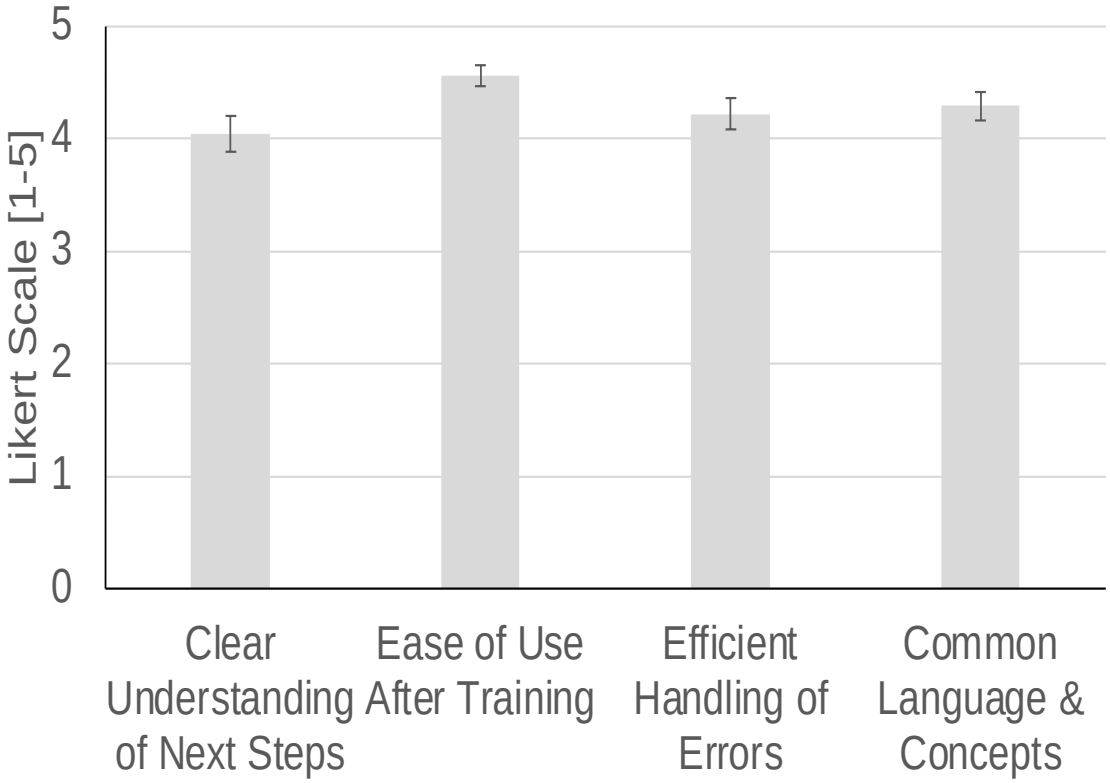
Willingness to Integrate XR



Participants reported high willingness to integrate XR authoring into their workflow

Results: Usability

User Experience in XR Authoring



Participants reported high satisfaction (≥ 4.0) with user experience in XR content creation

Results: Satisfaction

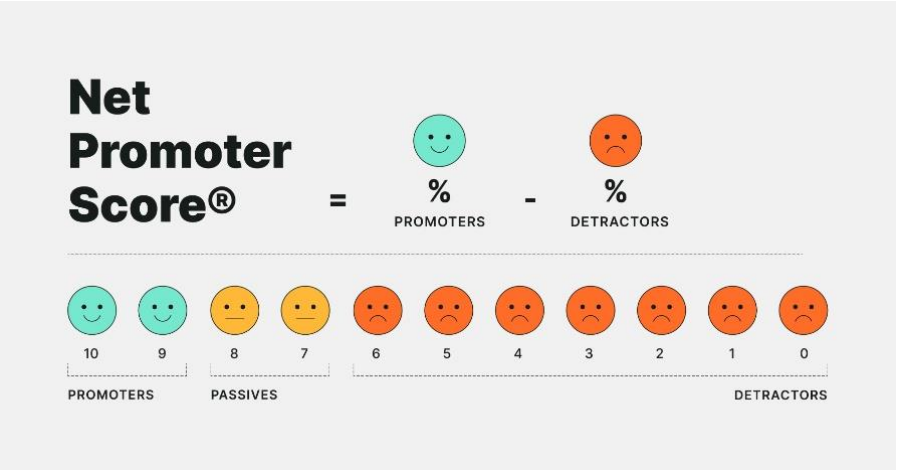
Net Promotor Score: 39%

(Promotor 51% - Detractors 12%)

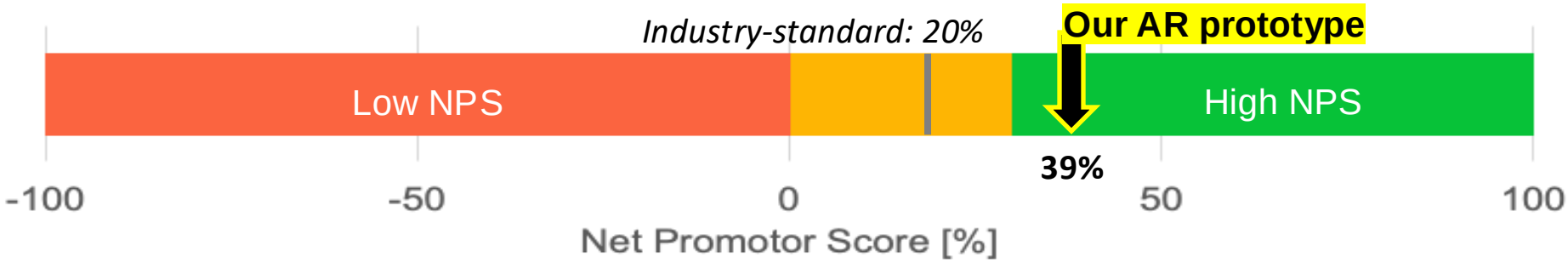
- *Scores above 20% considered favorable*
- *Scores above 0% considered good*

raw Net Promotor Score: 8.1

(SD=2.2) out of 10



How likely are you to recommend this XR authoring toolkit to a friend or colleague?"



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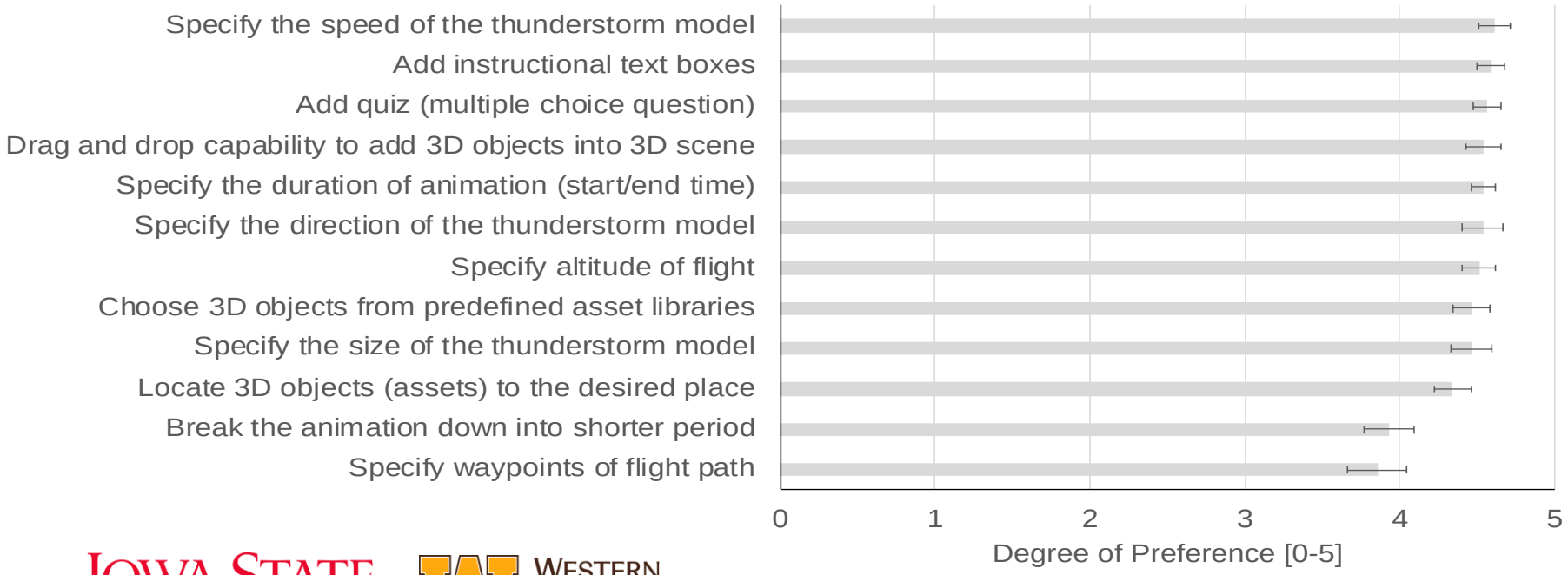
Results: Preference Rating of User Requirements

Proposed XR authoring tool meets key user requirements (all functions are rated ≥ 3.9)

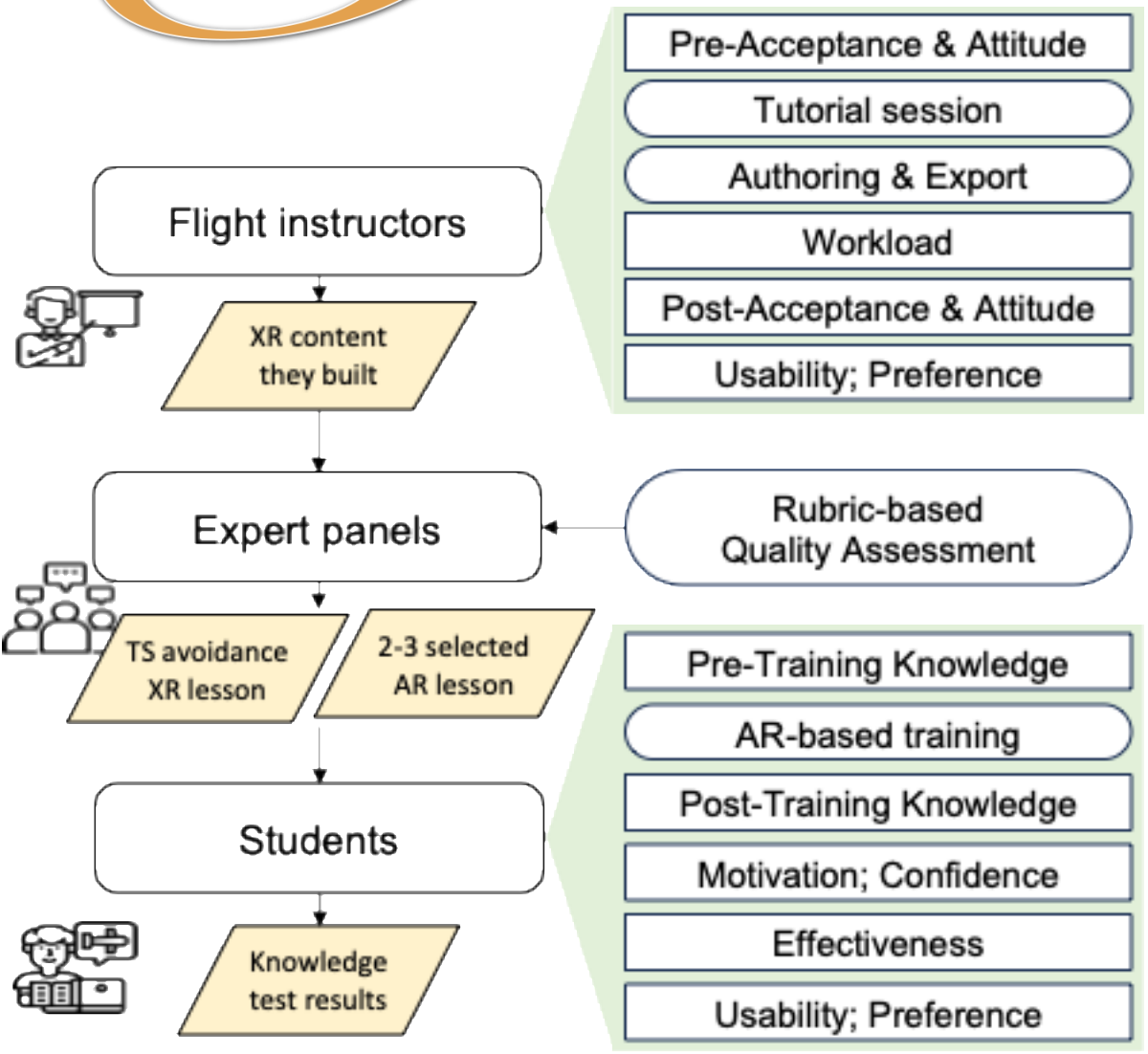
10/12 major functionalities achieved high satisfaction scores (4.3+/5.0)



Immediate Next Steps

- Summative evaluation of XR authoring framework
  - Assess the effectiveness of the XR-enabled GA weather training framework
  - Assess the XR authoring tool's usability and workload based on instructors' perspectives
  - Assess the effectiveness of XR lessons produced by non-tech instructors using the XR authoring tool
- Procedures:
  - Phase 1: Instructors
  - Phase 2: Expert panels
  - Phase 3: Students

Immediate Next Steps



Instructors will develop 2 scenarios:

1. Training test case: TS avoidance
2. Instructors' own choice of topic

SMEs will evaluate the quality of the XR content

Students will be trained with subset of XR module developed by instructors

Led by Western Michigan University

Formative Evaluation of Benefits of XR Weather Avoidance Training

Iowa State University

Western Michigan University

Executive Summary Slide

- **Motivation**:
  - Growing availability of XR technology through mobile, tablet, headset, and wearable devices has led to **increased research and development** on XR applications in aviation.
  - XR has potential to provide immersive, controllable environments for **safety-critical training**
- **Aim**: **Evaluate** the potential of XR in enhancing pilot training, **gather** an increased understanding of limitations, challenges and best practices.
- **Methods/Results**:
  - Adapt previously developed scenarios to **investigate the feasibility and benefits** of using XR to improve GA pilot application of knowledge, and subsequent decision-making when encountering hazardous weather phenomena.
  - In collaboration with **FlightSafety International (FSI) and FRASCA**, determine if a combination of XR headsets and flight simulation software currently available can provide pilots with a realistic experience of inadvertently flying from VMC into IMC.
- **Next Steps:** Initial **formative evaluation** of the VMC into IMC weather avoidance training benefits from the use of XR to enhance low-time pilot recognition of adverse weather and their avoidance decision-making.

FSI MR Flight Simulator

- Delivered a non-motion version to WMU
- Highly dynamic 6DOF motion platform
- 3 dimensional 360 degrees panoramic view
- Flight Controls-control loading
- Haptics-Vibration
- Realistic weather scenarios
- Course MR (Varjo XR-3 Near Focal Edition)
- FSI proprietary VITAL image generators
- You can see and interact with the real avionics. Tactile muscle memory.

FSI MR Flight Demonstration ITSEC, 2023

XR Flight Simulator

- FlightSafety International MR Flight Simulator

XR Flight Simulator Scenario

- XR Flight Simulator gradual decreased visibility Scenario

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Developing a Roadmap for XR Use in Aviation

- Identify Fidelity of various XR technologies and motion combinations
- Map to Learning Objectives
- Map to FAA ACS Codes
- Align fidelities that could enhance objectives of specific aviation courses and government CIP Codes

Map XR Fidelities to Aviation Learning Objectives

Map to Blooms Taxonomy

Table 2.8.1 Examples of aviation-related learning objectives, assessments, and methodologies

Learning objective	*Examples of aviation-related assessment activities*	*Examples of appropriate methodologies for instruction and assessment of aviation-related objectives*
Interpret Classify Compare	Activities that require students to: classify, categorize, compare two or more theories, events, or processes.	This can include classroom discussion, papers or interpretation of schematics depending on the subject matter. For technical subjects, printed images, or electronic depictions of aircraft schematics such as synoptic displays allow students to interpret system conditions, compare systems states, etc. Classification can be accomplished with labeling, matching or drag and drop activities.
Apply Execute Perform Demonstrate	Activities that require students to: use procedures, solve problems, or complete tasks.	Performance labs or assessments can utilize serious gaming, interactive 3D models experienced in VR, AR, MR, or simulation to allow the student to practice, apply, and demonstrate knowledge, skills, and ability to execute checklists or implement procedures. Examples includeVirtual Preflight, Cockpit Flows, Practice Quick Reference Handbook (QRH) malfunctions, cabin safety check,aircraft familiarization and maintenance operations.
Analyze	Activities that require students to: determine how aircraft components, systems, and crew function together, and troubleshoot malfunctions.	Can include discussion, papers, projects, or research. Examples include accident investigations, case studies, papers or labs using written manuals, documents, serious gaming, or video.

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Aligning FAA ACS Codes with XR Technologies

Map to FAA ACS Codes

Task	*B. Weather Information*
References	14 CFR part 91; FAA-H-8083-25, AC 00-6; AC 00-45, AIM
Objective	To determine the applicant exhibits satisfactory knowledge, risk management, and skills associated with obtaining, understanding, and applying weather information for a flight under IFR.
Knowledge	The applicant demonstrates understanding of:
IR.I.B.K1	Sources of weather data (e.g., National Weather Service, Flight Service) for flight planning purposes.
IR.I.B.K2	Acceptable weather products and resources utilized for preflight planning, current and forecast weather for departure and en route operations and arrival phases of flight.
IR.I.B.K3	Meteorology applicable to the departure, en route, alternate, and destination for flights conducted under Instrument Flight Rules (IFR) to include expected climate and hazardous conditions such as:
IR.I.B.K3a	a. Atmospheric composition and stability
IR.I.B.K3b	b. Wind (e.g., crosswind, tailwind, windshear, mountain wave, etc.)
IR.I.B.K3c	c. Temperature
IR.I.B.K3d	d. Moisture/precipitation
IR.I.B.K3e	e. Weather system formation, including air masses and fronts
IR.I.B.K3f	f. Clouds
IR.I.B.K3g	g. Turbulence
IR.I.B.K3h	h. Thunderstorms and microbursts
IR.I.B.K3i	i. Icing and freezing level information
IR.I.B.K3j	j. Fog/mist
IR.I.B.K3k	k. Frost
IR.I.B.K3l	l. Obstructions to visibility (e.g., smoke, haze, volcanic ash, etc.)
IR.I.B.K4	Flight deck displays of digital weather and aeronautical information.
Risk Management	The applicant demonstrates the ability to identify, assess and mitigate risks, encompassing:
IR.I.B.R1	Factors involved in making the go/no-go and continue/divert decisions, to include:
IR.I.B.R1a	a. Circumstances that would make diversion prudent
IR.I.B.R1b	b. Personal Weather Minimums
IR.I.B.R1c	c. Hazardous weather conditions to include known or forecast icing or turbulence aloft
IR.I.B.R2	Limitations of:
IR.I.B.R2a	a. Onboard weather equipment
IR.I.B.R2b	b. Aviation weather reports and forecasts
IR.I.B.R2c	c. Inflight weather resources
Skills	The applicant demonstrates the ability to:
IR.I.B.S1	Use available aviation weather resources to obtain an adequate weather briefing.
	Analyze the implications of at least three of the conditions listed in K3a through K3l above

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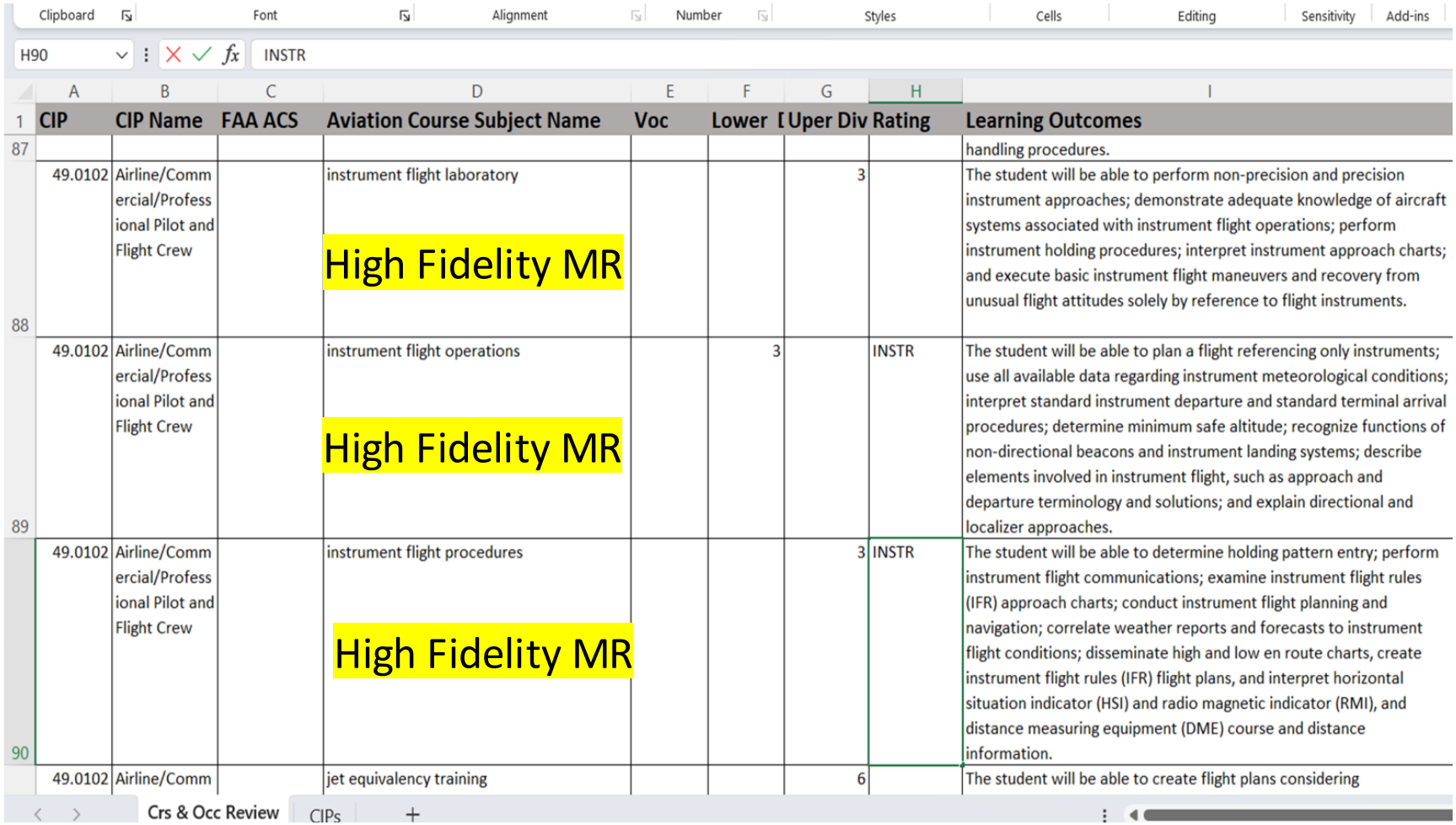
Map XR Technologies to Current Aviation Courses and Outcomes



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H90 | INSTR

	A	B	C	D	E	F	G	H	I
1	CIP	CIP Name	FAA ACS	Aviation Course Subject Name	Voc	Lower [	Uper Div	Rating	Learning Outcomes
87									handling procedures.
88	49.0102	Airline/Commercial/Professional Pilot and Flight Crew		instrument flight laboratory High Fidelity MR			3		The student will be able to perform non-precision and precision instrument approaches; demonstrate adequate knowledge of aircraft systems associated with instrument flight operations; perform instrument holding procedures; interpret instrument approach charts; and execute basic instrument flight maneuvers and recovery from unusual flight attitudes solely by reference to flight instruments.
89	49.0102	Airline/Commercial/Professional Pilot and Flight Crew		instrument flight operations High Fidelity MR		3		INSTR	The student will be able to plan a flight referencing only instruments; use all available data regarding instrument meteorological conditions; interpret standard instrument departure and standard terminal arrival procedures; determine minimum safe altitude; recognize functions of non-directional beacons and instrument landing systems; describe elements involved in instrument flight, such as approach and departure terminology and solutions; and explain directional and localizer approaches.
90	49.0102	Airline/Commercial/Professional Pilot and Flight Crew		instrument flight procedures High Fidelity MR			3	INSTR	The student will be able to determine holding pattern entry; perform instrument flight communications; examine instrument flight rules (IFR) approach charts; conduct instrument flight planning and navigation; correlate weather reports and forecasts to instrument flight conditions; disseminate high and low en route charts, create instrument flight rules (IFR) flight plans, and interpret horizontal situation indicator (HSI) and radio magnetic indicator (RMI), and distance measuring equipment (DME) course and distance information.
	49.0102	Airline/Comm		jet equivalency training			6		The student will be able to create flight plans considering

Crs & Occ Review | CIPs

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Opportunities for Future Work

- Can the XR authoring framework be adapted for wide use by instructors and students by addressing key **deployability and architecture** challenges
- Does experience gained using XR training enhanced training improve **pilot knowledge and understanding** of deteriorating weather conditions and their avoidance decision-making?
- Do limitations of XR-enhanced training influence or affect pilots' instrument **scan patterns**?
- Can **behavioral models** lead to adaptive behavior to improve GA pilot recognition and avoidance of adverse weather?
- Does the addition of a pilot-specific **AI tutor**, in an XR environment, improve pilot knowledge and understanding of weather-related decisions?

Conclusion

- Implemented an **interactive XR authoring prototype** to enable evaluation of XR authoring framework
- Shifted focus from technology-centric toolkits to a **content-centered approach** to lower hurdle to incorporate XR into teaching workflow
  - Participants completed the most challenging task quickly (≤7.5 minutes) and with a low cognitive workload (22.5 out of 100)
  - The XR authoring tool was effective in increasing participants' confidence in XR authoring (▲30%) and reducing technical concerns (▼19%)
  - XR authoring tool meets instructor-informed requirements (≥ 3.9)
- Integrated VMS to IMC scenario **into FSI MR Flight Simulator**
- **Map** XR fidelities to aviation learning objectives, aligning FAA ACS codes with XR technologies, and map XR technologies to current aviation courses and outcomes

Deliverables

- 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., Wang, K., Miller, J., Dorneich, M. C., Winer, E., Brown, L., & Caldwell, B. (Accepted). Creating augmented reality-based experiences for aviation weather training: Challenges, opportunities, and design implications for 3D authoring. *Ergonomics*, 1-17.
  - Kim, J., Miller, J., Wang, K., Dorneich, M.C., Winer, L., & Brown, L.J. (Submitted). "Empowering Instructors: Augmented Reality Authoring Toolkit for Aviation Weather Education," IEEE Transactions on Learning Technologies.
- Conference Papers
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