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XR - Titration and Civil Engineering:

Design Issues & Preliminary Results

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Designers and creators of educational content need evidence-based design guidelines that balance the advantages of multi-dimensional platforms with the potential for cognitive overload.

- Our research explores ways to present complex educational content on the XR spectrum - from Mixed Reality (MR) to Virtual Reality (VR) - and to promote effective comprehension and retention.
- Experiment 1 focuses on low versus high embodied interfaces.
- Experiment 2 focuses on scaffolding complexity while gathering biometrics in VR.

EXPERIMENT 1-Titration with MR

Goal: To test the efficacy of a desktop simulation of acid-base titration with or without an interactive 3D-printed burette.

Hypothesis:

Participants in the high-embodied condition with a haptically congruent interface will use more verbal idea units and meaningful gestures when recalling titration compared to participants in the low-embodied control condition.

METHOD 2 X 2

2 (High-embodied vs. Control condition) X 2 (Pretest vs. Posttest)

N = 57, for preliminary results.

Mixed Reality: All participants went through a 30 minute virtual titration simulation. Drops of base are added to the beaker.

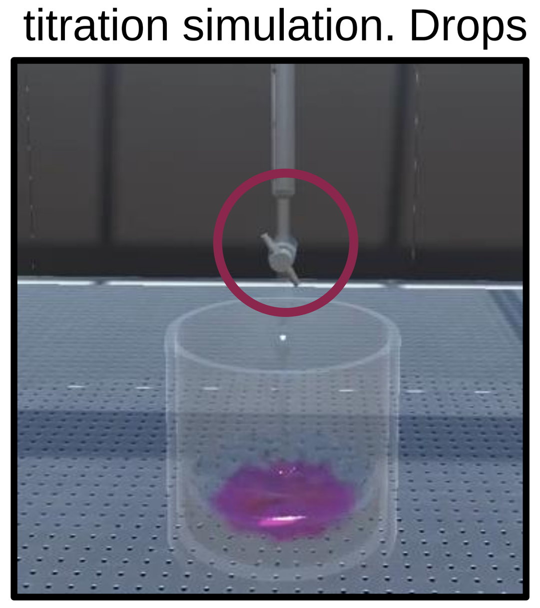

Fig. 1. Virtual Burette

- Figure 1 shows the virtual burette, and the water sample in the virtual beaker.
- In the control condition, virtual drops are added via the keyboard presses on the left or right arrows. This is considered low-embodied since it Is not gesturally congruent.

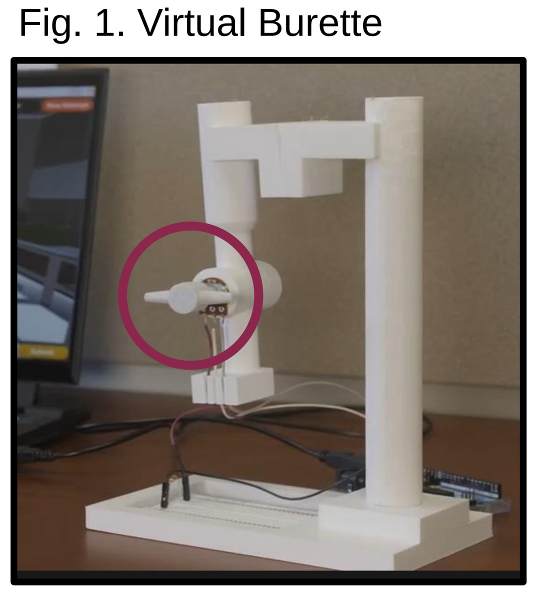

Fig. 2. 3D-Printed Burette

- Figure 2 shows the 3D-printed burette used in the high-embodied condition, the red circle highlights the stopcock.
- Similar to usual glassware in a lab, a left and right turn of the hand on the physical, tangible stopcock controls the burette and the speed of droplets from the burette.

Chemistry Knowledge Assessment:

- Question formats include: multiple choice, drag-&-drop, numerical response, and textual free-response.
- Post-Intervention includes video-recorded response to the query:

"Pretend that you are a teacher, how would you explain titration to a student?"

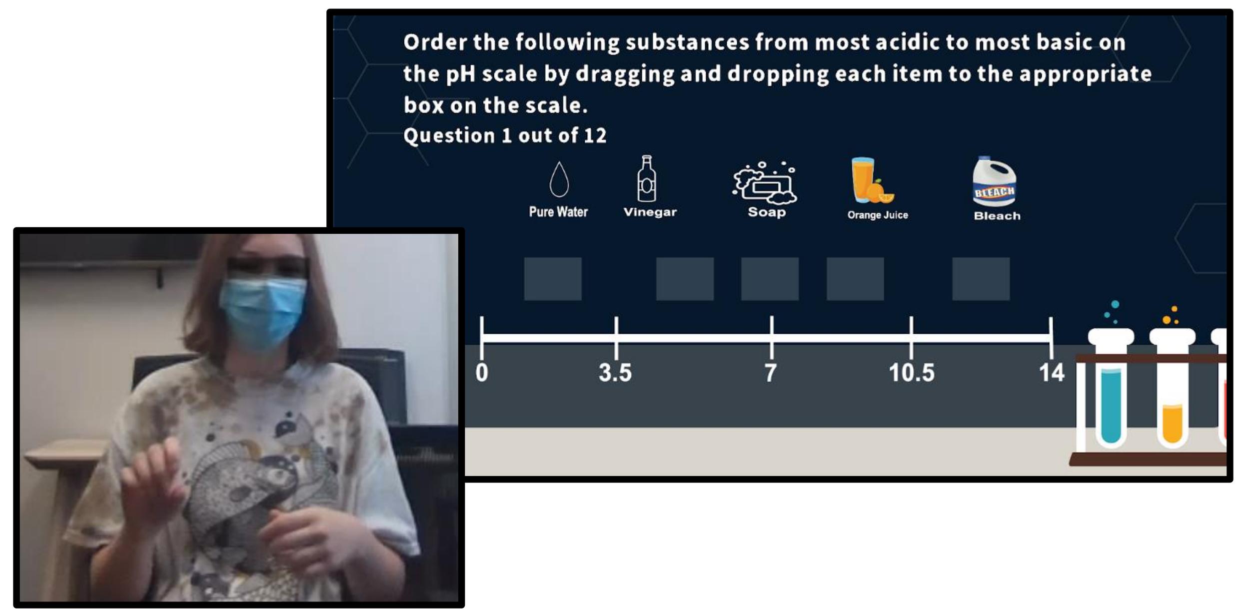

Fig. 3. Example of a drag-&-drop question: Video of gesture during recall

Gesture & Idea Units Coding:

- Main gesture of interest: **stopcock turning gesture**.
- Titration explanation (recall): sum of expected **13 idea units** that were either concept-related, procedure-related, or math-related.

RESULTS (preliminary)

Gesture, χ^2 Test: The high-embodied condition produced significantly more stopcock turning gestures (n = 12) than the control condition (n = 2), $\chi^2 = 11.58$, $p < .001$.

Verbal Idea Units, Regression: There was not a main effect for condition. Pretest was significantly predictive (p <.001) of idea units, and the interaction of pretest by condition was significant, $t = 2.28$, $p = .027$.

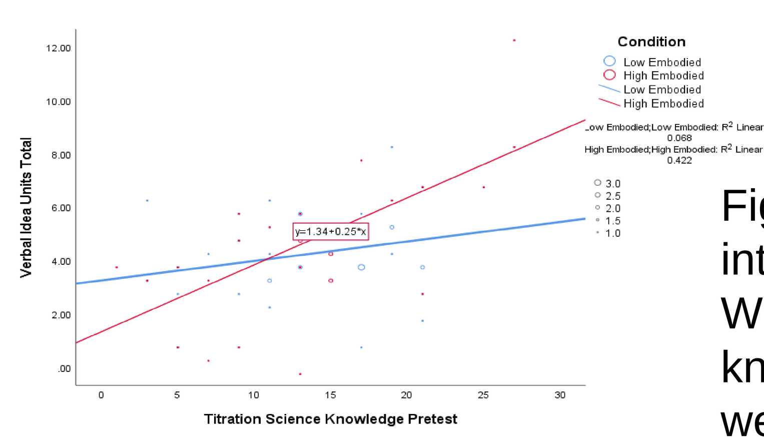

Figure 4. Significant pretest by condition interaction

Figure 4 shows the interaction effect. When higher prior knowledge students were in the high-embodied condition, they produced richer, more full recalls of titration.

CONCLUSION

When learners have higher prior knowledge, a higher embodied and gesturally-congruent simulation/lesson improves recall.

EXPERIMENT 2-Engineering with VR

Tuned Mass Damper (TMD):

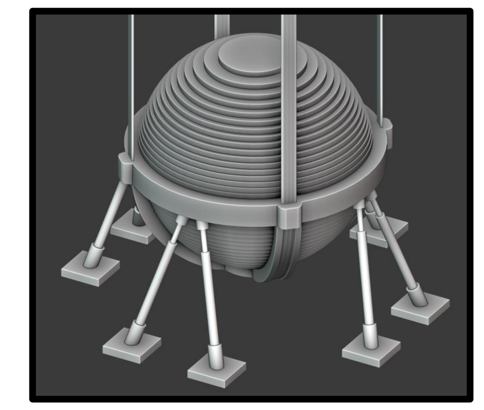

Fig. 5. Model of a TMD

Background: TMD are earthquake mitigation systems, they attenuate the sway of buildings during excitation. They can be very complex, but this example only highlights three variables under the engineering student's control, e.g., mass of the damper, length of cables, and stiffness of pistons).

- The immersive Virtual Reality (VR) lesson focuses on the pedagogy supporting teaching complex, multi-dimensional STEM topics, called scaffolding.
- The TMD damper lesson is counterbalanced with a 2nd type of damper called base isolators (BI).

Hypotheses:

1. Excess cognitive load negatively affects learning outcomes.
2. Self-reports of cognitive load will correlate with VR-gathered biometrics.
3. Scaffolding control over the number of variables that learners interact with will attenuate cognitive overload.

METHOD 2 X 2 X 2

2 (2D PC vs. 3D VR) X 2 (Unscaffolded vs. Scaffolded) X 2 (Base Isolator vs. TMD).

Content Condition	Time 1	Time 2
BI First (n=24)	BI Scaffolded	TMD Full
BI First (n=24)	BI Full	TMD Scaffolded
TMD First (n=24)	TMD Scaffolded	BI Full
TMD First (n=24)	TMD Full	BI Scaffolded

Table 1. Conditions by Counterbalanced Intervention Order (time)

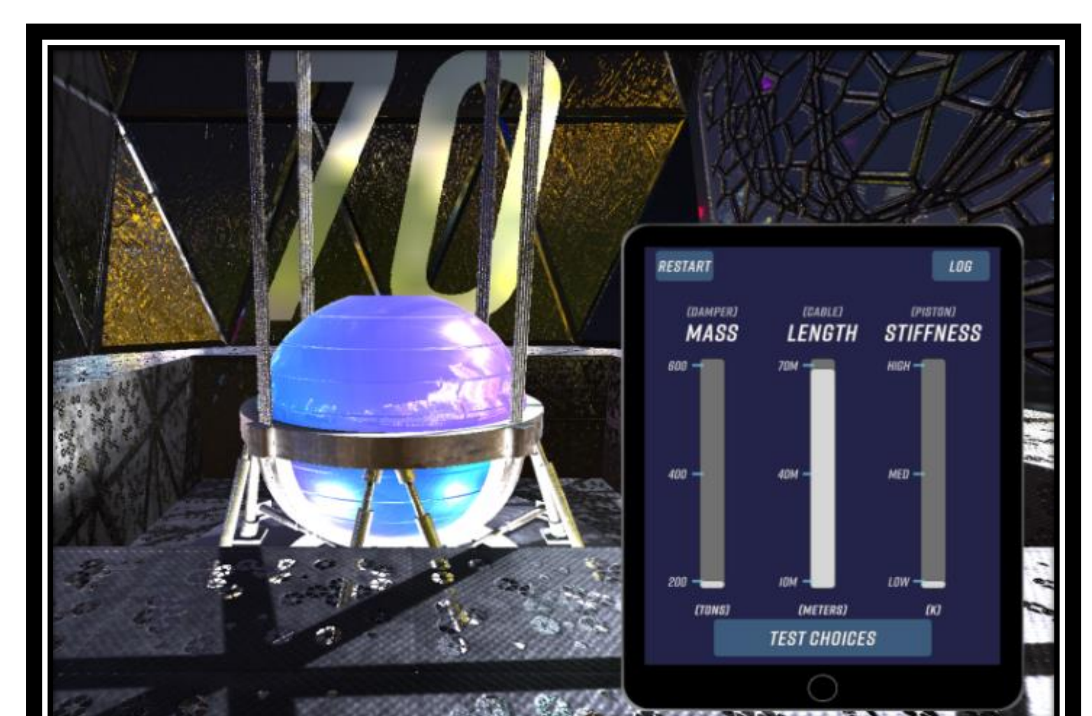

Fig. 6. Damper Room View

- Figure 6 shows the TMD room where participants use a virtual tablet to adjust the engineering design variables.
- In this scene, the participant has control over three variables.

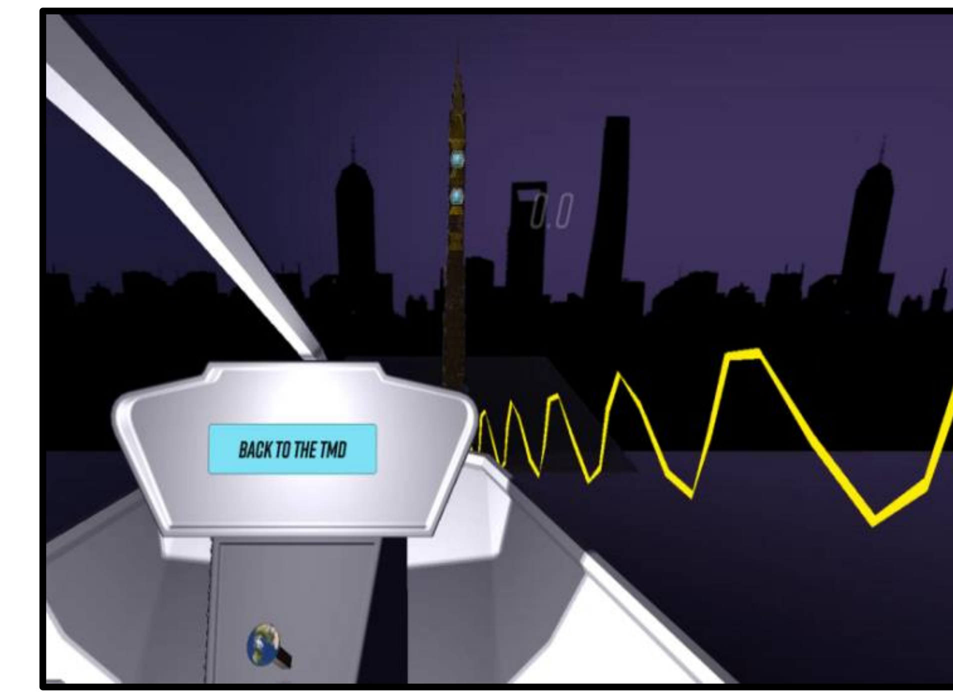

Fig. 7. Helicopter Interior View

- Participants then teleport to a helicopter, and in an embodied manner start an earthquake.
- Figure 7 shows the helicopter view. On the right is the sine wave that is user-created with a hand controller/mouse. The damper is in the building with two windows. The building will fall if the damper is designed incorrectly; this serves as feedback.

Cognitive Load Measures:

- participants self-report cognitive load multiple times in-game
- In-game performance data
- Biometrics: EEG and pupilometry

Content Knowledge and Other Tests:

- Pretest and posttest on structural engineering
- N-Back test
- Science identity
- Pretest and posttest on spatial skills in VR

EXPECTED OUTCOME

The expectations are that self-reported cognitive load correlates with the VR-gathered biometrics and that proper scaffolding decreases cognitive load.

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