

Executive Summary

Objective: Compare lecture and VR-based manufacturing training using EEG, quiz performance, and behavior-change relevance in educational settings.

Methods: Fourteen participants completed declarative and procedural modules in either Lecture or VR; EEG and quiz data were collected.

Results: VR showed higher engagement and comparable or better quiz performance, while workload differed by learning type.

Interpretation: VR may create more immersive learning by making mistakes and consequences more salient, which may support behavior change.

Conclusion: EEG helps reveal cognitive effects of VR training that traditional measures may miss.

Practical Implications: VR training may enhance manufacturing instruction by improving engagement, supporting learning, and promoting safer behavior through immersive, consequence-based experiences.

Background

Benefits of VR in Manufacturing Training:

- Risk-Free Repetition.
- Standardized Instruction.
- Interactive Procedural Rehearsal.
- Continuous Data Capture.

From Mistakes to Meaningful Change:

Traditional measures may miss real-time responses to mistakes.

Cognitive states shift during error-based VR learning.

EEG can show whether VR promotes deeper learning and behavior change.

Research Questions:

- How do EEG-based workload and engagement differ across VR learning types, and what do they indicate about behavior change?
- How are EEG measures related to learning performance and behavior change in Lecture versus VR training?

Experimental Setup

- 14 participants: 8 male and 6 Female. Randomly assigned: Lecture (n=7) or VR (n=7)
- 2 × 2 mixed design: (Lecture vs. VR) between-subjects and within-subjects (module: Declarative vs. Procedural).
- Two EEG datasets were excluded due to quality issues, leaving 12 for EEG analysis.
- Lecture delivered as a standardized slide module
- VR training was built in Unity 3D and deployed on Meta Quest 3

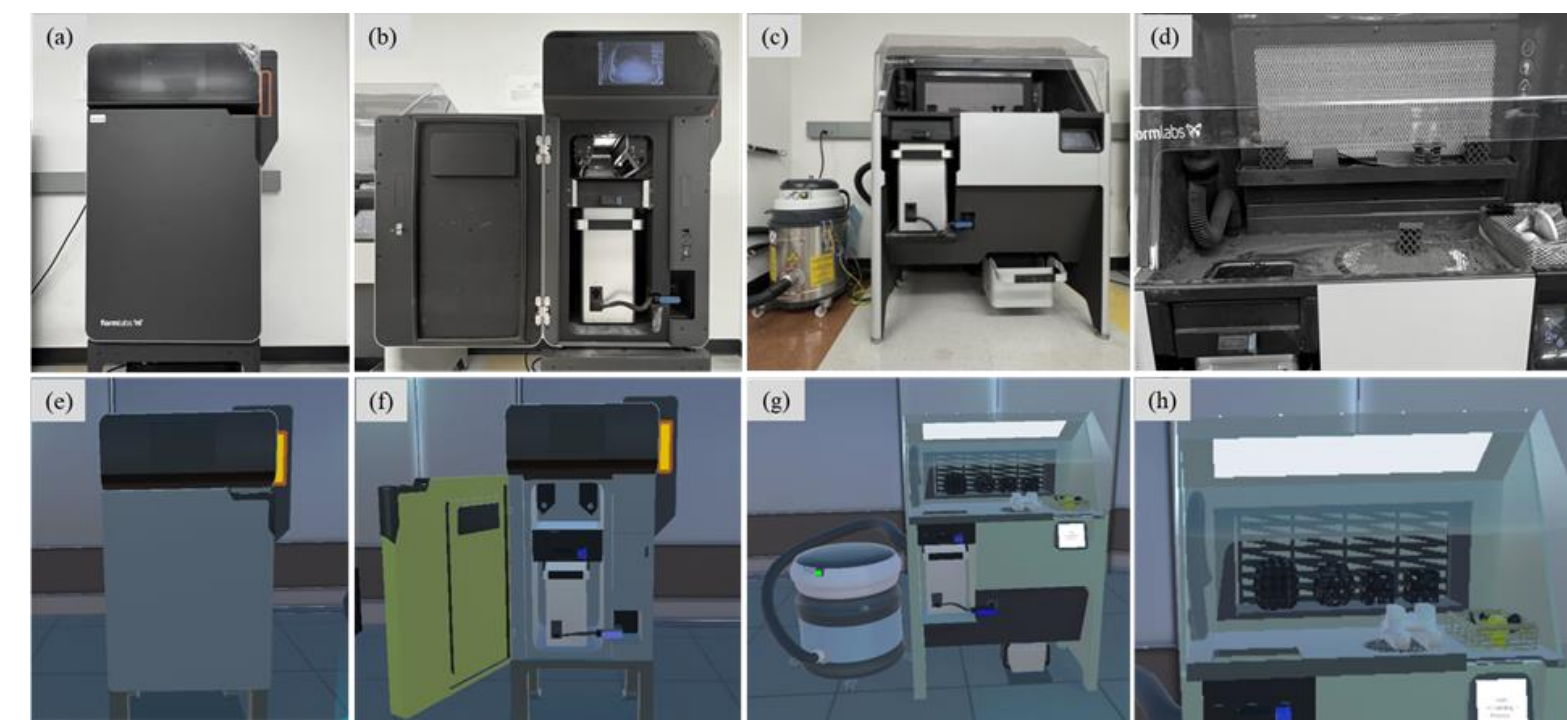


Figure 1: VR training content development



Figure 2: Lecture (left) and VR (right) training conditions

Experimental Test Plan

Study Protocol:

- Participants arrived and completed informed consent.
- Collected demographics (e.g., age, gender, prior VR/AM experience).
- Random assignment to training condition (VR or Lecture).
- EEG headset setup and signal quality check.
- Completed training module (VR or lecture; matched content).
- Completed post-training quiz.
- Completed post-study survey.
- Compensation and debrief.

Measures:

- **Subjective:** Cognitive Workload and Emotional Engagement.
- **Objective:** EEG Indices and Quiz Scores.

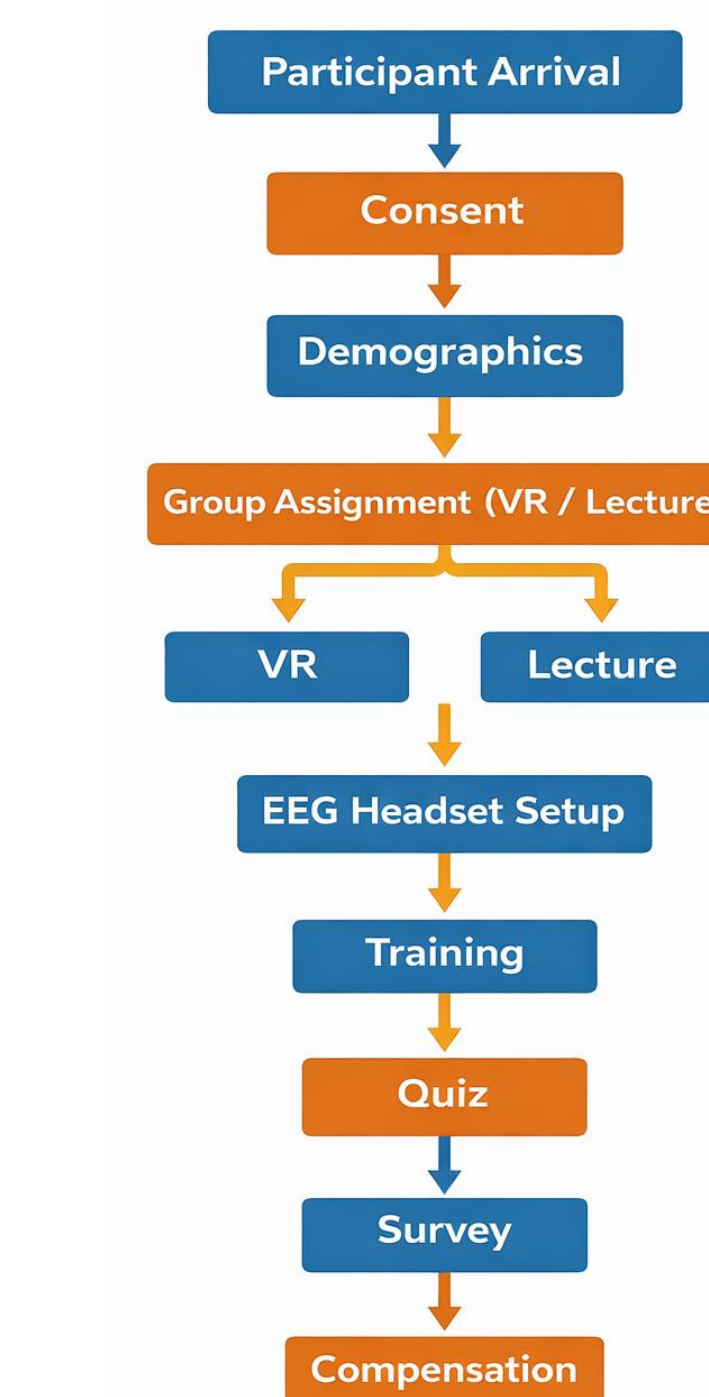


Figure 3: Experimental protocol



Figure 4: EMOTIV EPOCH EEG device



Figure 5: EEG data processing pipeline

Experimental Results

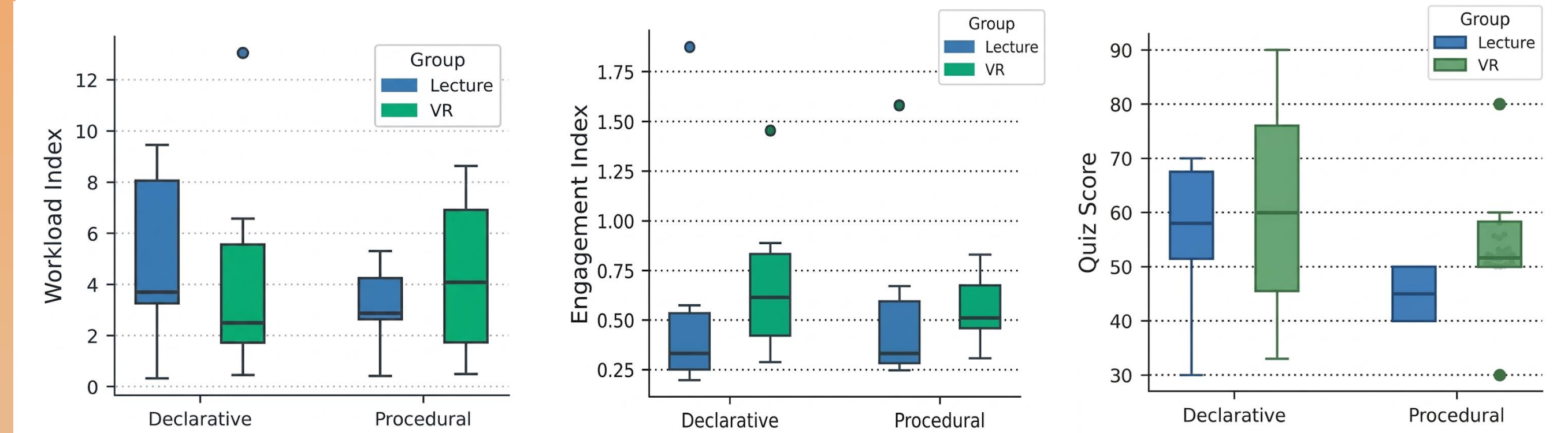


Figure 6: VR showed higher engagement and comparable or better quiz performance than Lecture, while workload varied by learning type. These findings suggest that VR may support behavior change by increasing attentional involvement and making training more meaningful.

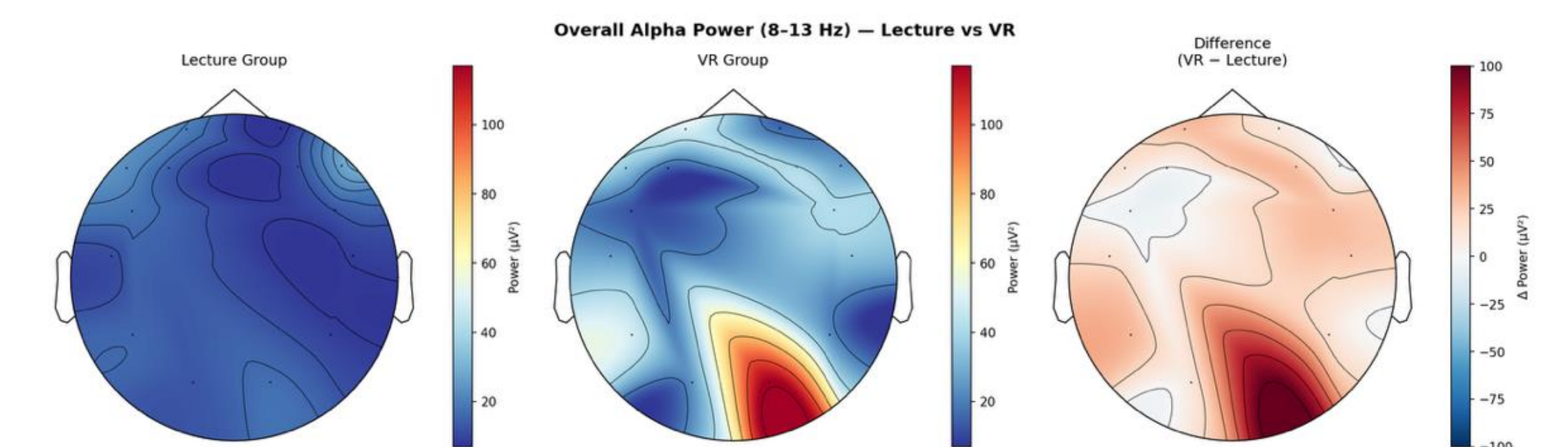


Figure 7: Topographic maps of alpha power (8–13 Hz) for Lecture and VR, with the difference map (VR – Lecture). The VR condition shows stronger alpha activity than Lecture, suggesting different attentional processing and neural engagement that may be linked to behavior change during training.

Conclusions

- VR training increased engagement and produced quiz performance comparable to or better than that of lecture-based training.
- Differences in workload across learning types suggest that trainees process declarative and procedural content differently.
- EEG captured real-time changes in attention and engagement that may not be visible in quiz scores alone.
- Stronger alpha activity in VR suggests distinct neural processing, indicating that immersive training may support safer behavioral responses by making mistakes and consequences more salient.
- **Limitation:** Behavior change was not directly measured, so conclusions about behavioral impact are based on cognitive and performance indicators.
- **Future research:** Future studies should directly assess behavior change, including safety decisions, error reduction, and retention over time in real manufacturing tasks.

References

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