Learning Algebraic Manipulation through Movement in Virtual Reality Spaces

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IDS 6916: RESEARCH PRACTICUM

FINAL PRESENTATION

DECEMBER 9, 2020

Background

Using virtual reality (VR) technology to improve secondary school aged student's algebraic formula manipulation understanding

Purpose of Study

To supplement existing curriculum for manipulating algebraic expression through VR technology. Using VR technology can help students better understand concept as well as practical application.

This will increase accessibility for mathematics to help with learner performance and transfer of knowledge. Algebra was chosen as it is such a major base that much of the rest of mathematics is built upon.

Our Project's Contributions

Increase ease of learning

Increase mathematics literacy

Decrease frustration with math

Increase accessibility to STEM careers for underrepresented groups

Problem Statement

Foundational mathematics skills are critical for learners of all ages. Students in primary and secondary school may miss out on important Algebraic foundations, such as equation manipulation, which impedes their confidence and ability to prepare for careers in STEM. **Schools need novel tools to help struggling students reach proficiency in base algebraic skills which will open the door for opportunities for many marginalized learners.**

Sweller, J. (1989). Cognitive technology: Some procedures for facilitating learning and problem solving in mathematics and science. *Journal of educational psychology*, *81*(4), 457.

How: Research Questions

Workload: How does VR affect cognitive load between low, medium and high- level algebraic math skill tasks?

Performance: What is the difference in performance measured by response time and accuracy based upon the algebraic math skill task in VR?

Complexity: How does VR affect how participants handle the difference between low- medium- and high-level complexity of algebraic math skill tasks?

(For Future Considerations) Practical Application: How does VR help learners understand algebraic skills and their transfer between similar and distinct applications? (between classroom and practical applications)

Justification: Why Algebra?

Mathematics is based on cumulative knowledge

Foundational skills are extra important

Low proficiency is difficult to recover from

Math literacy impacts career choices

Affects already underrepresented groups

Impacts confidence and is a barrier for entry to STEM fields

Gaps in existing tools

Novel approaches have been created for Geometry, Calculus, some Linear Algebra etc.

Justification: **Why** VR?

Common Current Learning Tools

- Worksheets
- You do, We do, I do

Improved Learning Tools

- MathLabs and Khan Academy
- More feedback and guidance

Needs for New Learning Tools

- Accessible, visual, and novel approach to catch and empower struggling students

What VR Brings To The Table

EMBODIED COGNITION

- BODY AS A DISTRIBUTOR
- BODY AS REGULATOR

KINESTHETICS

- MOVEMENT IN THE CLASSROOM

4 E'S

- ENGAGE
- EXPLORE
- EXPLAIN
- EXTEND

Example Problems: Algebraic Formula Manipulation

Easy

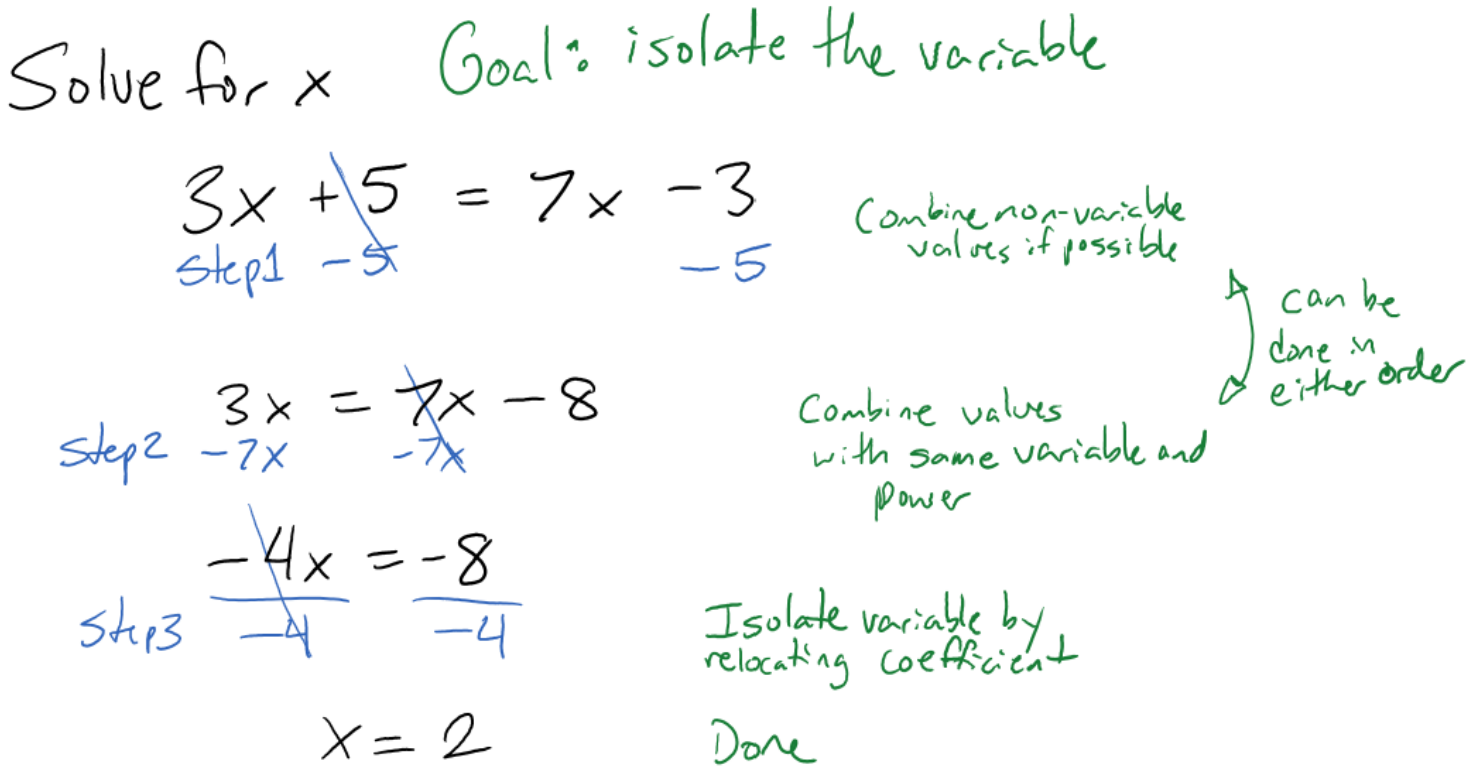
- Addition, Subtraction, Multiplication, and Division
- Variable only as a numerator

Medium

- Addition, Subtraction, Multiplication, and Division
- Variable includes fractions as coefficient.
- Equation may require distribution

Hard

- Addition, Subtraction, Multiplication, Division, and Roots.
- Variable in the denominator
- May be a formula that needs rearranging instead of an equation that can be solved



Proposed Solution

Brainstorming process

VR environment that allows for the manipulation of physical entities within an equation

Will include Learning, Practice, and Testing modes, as well as Easy, Medium, and Hard difficulty settings.

Technology Used

- Headset - Oculus Rift S
  - The reason the Oculus Rift S was used was due to the motion tracking support as well as motion driven controllers.
- Game Engine - Unity V2019.2.15
  - Chosen for familiarity, Oculus SDK support, and stability.
- Coding IDE – Visual Studios 2019
  - Built in debugging process for Unity makes this an easy IDE to develop code in Unity.

Storyboarding Prototype

Randomly generated problems based on High, Medium, Low difficulties.

Amount of time to solve problem is recorded to show delta in performance.

Assisted, non-assisted, test modes available to help get familiar with the system.

Hypotheses

Cognitive Load: There will be a statistically significant difference in cognitive load, such that the VR condition will have lower NASA-TLX scores than the traditional paper format.

Performance: There will be a statistically significant difference as measured by performance (ie: response time and time on task) that under the VR condition due to ease of use, reduction of cognitive load, and improved spatial awareness.

Complexity: There will be a statistically significant difference between high and low complexity scores based on performance parameters under the VR condition.

Research Methods

- **Mixed Methods Approach:** Collecting both qualitative & quantitative data
- **Participa**nts: High school math students
- **Materials / Apparatus:** Oculus Rift headset and hand controllers
- **Design:** Mixed Design with Two level between-subjects factor analysis
- Independent Variable: VR Technology
- Dependent Variables:

1. Performance: Percentage correct, time on task
2. NASA-TLX (Cognitive Workload)
3. Technology Acceptance Model (TAM)
4. Systems Usability Scale (SUS)
5. Demographics Survey
6. Virtual Reality Sickness Questionnaire

1. Demographics Survey

What is your current age? _____

What is your sex?
1. Male
2. Female
3. Other

What is your race/ethnicity?
1. White
2. Black or African American
3. Asian
4. American Indian/Alaska Native/Native Hawaiian/Other Pacific Islander
5. Hispanic or Latino
6. > One Race
7. Don't know/Not sure

Do you have normal or corrected-to-normal vision (20/20)?
1. YES
2. NO

What is your dominant hand to use?
1. Right
2. Left
3. Both

What is your highest level of completed education?
1. Some High School
2. High School/GED
3. Some College
4. Associated Degree
5. Bachelors Degree
6. Masters Degree
7. Advanced Degree (PhD, MD, ED, JD, etc.)

Do you consider yourself to be a video gamer?
8. YES
9. NO

5. NASA-TLX

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?
Very Low — Very High

Physical Demand — How physically demanding was the task?
Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?
Very Low — Very High

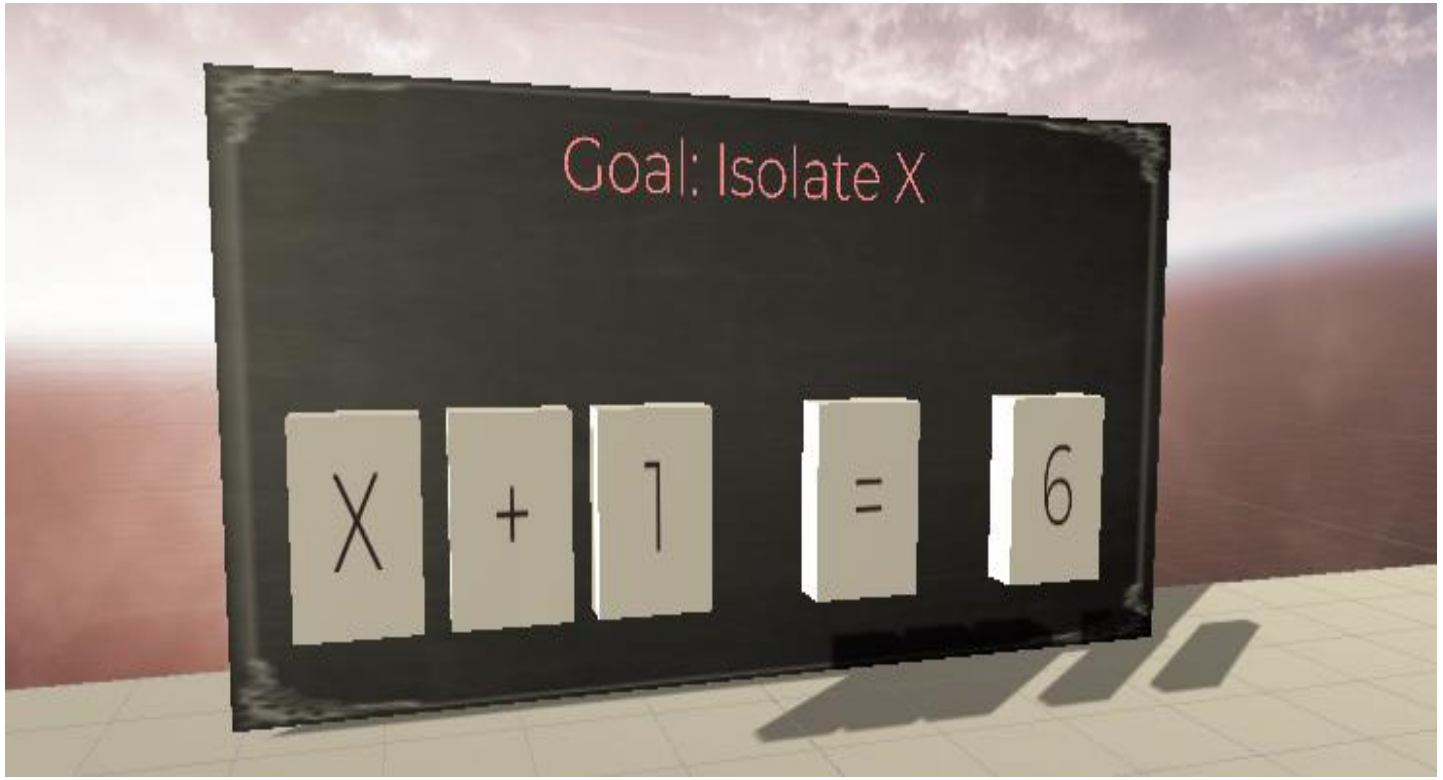
Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Conducting the Experiment

Step	Time
Participant will complete an informed consent.	3 minutes
Participant will receive an introduction to the study as well as training on PowerPoint and the ability to interact with the technology, ask questions and take Demographics Questionnaire.	30 minutes
1st Condition Scenario	5 minutes
1st Condition Surveys (NASA-TLX, TAM, SUS, VR-Sickness)	15 minutes
2nd Condition Scenario	5 minutes
2nd Condition Surveys (NASA-TLX, TAM, SUS, VR-Sickness)	15 minutes
Debriefing	3 minutes
Total	~ 90 minutes

Table 1. Study Timeline

Complexity Level- Easy

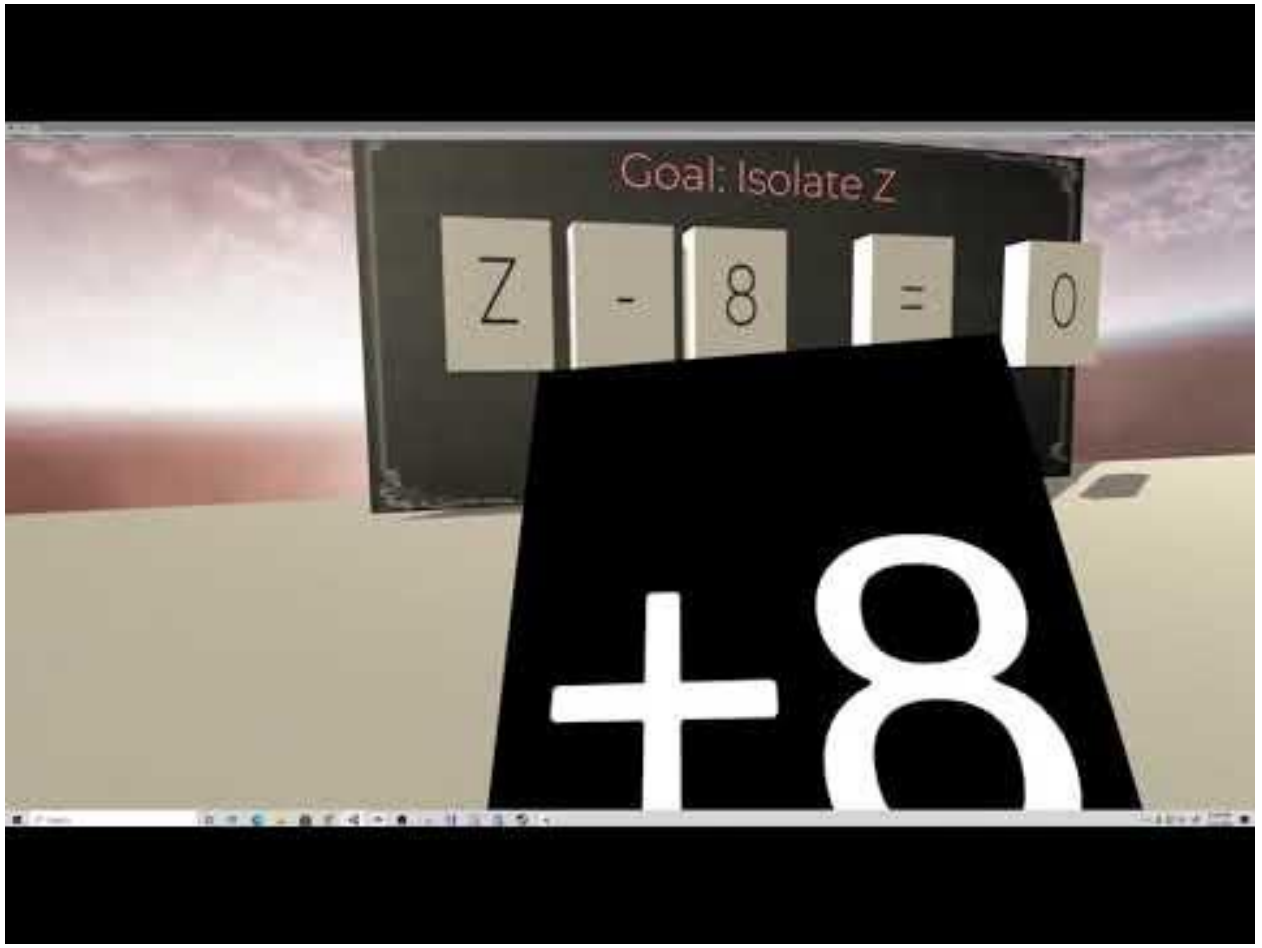


- Addition, Subtraction, Multiplication, and Division
- Variable only as a numerator

Complexity Level- Medium

- Addition, Subtraction, Multiplication, and Division
- Variable includes fractions as coefficient.
- Equation may require distribution

Current Tool Prototype- Video



Takeaways/Lessons Learned

- Complexity in the algebra problem results in exponentially larger code development time and our initial concept of a hard problem was a bit ambitious.
- Could have leveraged existing tools like Wolfram Alpha API to handle much of the mathematical processing.
- Performing tasks in a digital environment allows for an increased amount of data analytics to be gathered which can be used in the measurement of performance.

Future Additions and Research

How we would use the tool right now: Use as a check for understanding of basic equation manipulation. Use as an engagement strategy. Test current hypotheses (Cognitive Load, Performance, Complexity) and gauge further interest.

Things to add: Difficulty modes/adaptive scaling, guidance/feedback mode, testing mode. More operations/complexity, application extension mode. Accessibility features, size scaling, visual and audio tools. Teacher/proctor analytics/controls

How we would use the tool in the future: Include research questions on how the tool helps students transfer knowledge through application. Test use of learning versus testing modes. Can better reach all audiences that may have a use for the tool.

References/Resources

Kuo, H. C., Tseng, Y. C., & Yang, Y. T. C. (2019). Promoting college student's learning motivation and creativity through a STEM interdisciplinary PBL human-computer interaction system design and development course. Thinking Skills and Creativity, 31, 1-10.

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

Barrett, R., Gandhi, H. A., Naganathan, A., Daniels, D., Zhang, Y., Onwunaka, C., ... & White, A. D. (2018). Social and tactile mixed reality increases student engagement in undergraduate lab activities. Journal of Chemical Education, 95(10), 1755-1762.

Miller, D., & Dousay, T. (2015). Implementing augmented reality in the classroom. Issues and Trends in Educational Technology, 3(2).

Antonioli, M., Blake, C., & Sparks, K. (2014). Augmented reality applications in education. The Journal of Technology Studies, 96-107.

Lai, A. F., Chen, C. H., & Lee, G. Y. (2019). An augmented reality-based learning approach to enhancing students' science reading performances from the perspective of the cognitive load theory. British Journal of Educational Technology, 50(1), 232-247.

Burrows, A., Lockwood, M., Borowczak, M., Janak, E., & Barber, B. (2018). Integrated STEM: Focus on informal education and community collaboration through engineering. Education Sciences, 8(1), 4.

Jackson, C., Appelgate, M., Seiler, G., Sheth, M., & Nadolny, L. (2016). Using a Virtual Environment to Uncover Biases, Assumptions, and Beliefs and Implications for Mathematics Teaching. Conference Papers -- Psychology of Mathematics & Education of North America, 1333–1336.

Hwang, W. Y., & Hu, S. S. (2013). Analysis of peer learning behaviors using multiple representations in virtual reality and their impacts on geometry problem solving. Computers & Education, 62, 308-319.

Kaufmann, H., Schmalstieg, D., & Wagner, M. (2000). Construct3D: a virtual reality application for mathematics and geometry education. Education and information technologies, 5(4), 263-276.

Khan, M., Trujano, F., & Maes, P. (2018, June). Mathland: Constructionist Mathematical Learning in the Real World Using Immersive Mixed Reality. In International Conference on Immersive Learning (pp. 133-147). Springer, Cham.

Hall, C. R., Stiles, R. J., & Horwitz, C. D. (1998, March). Virtual reality for training: Evaluating knowledge retention. In Proceedings. IEEE 1998 Virtual Reality Annual International Symposium (Cat. No. 98CB36180) (pp. 184-189). IEEE.

Wilson, Robert A. and Lucia Foglia, "Embodied Cognition", The Stanford Encyclopedia of Philosophy (Spring 2017 Edition), Edward N. Zalta (ed.), https://plato.stanford.edu/archives/spr2017/entries/embodied-cognition

Griss, S. 2013. The power of movement in teaching and learning. EdWeek. http://bit.ly/2nRDjPE

Marshall, J. C., Horton, B., & Smart, J. (2008). 4E x 2 Instructional Model: Uniting Three Learning Constructs to Imrpve Praxis in Science and Mathematics Classrooms. Springer Science+Business Media, B.V.

Thank you….
any questions?