EMBODIED TRANSMISSION OF IDEAS: MATHEMATICAL THINKING THROUGH COLLABORATIVE CONSTRUCTION OF GEOMETRY VIDEO GAME CONTENT

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In one classroom of a Title 1 high school, students (n=12) were separated into groups and participated in a three-part study in which played and designed content for a 3D motion-capture video game, The Hidden Village (THV). This paper provides case-studies from group's work provided evidence of students' intuitions, insights, and explanations (including their gestures) of how students conceptualized the geometric transformations and how students embodied their ideas about geometry and how those ideas "traveled" (via directed actions) within and between student groups.

Keywords: Embodiment, Geometry, Collaborative Construction, Transfer

Introduction

The Hidden Village (THV) is a 3D motion-capture video game that allows players to embody mathematics learning (Swart et al., 2020). In the game, players perform movements (*directed actions*, see Nathan, 2017) prior to reading and evaluating a geometric conjecture. In effect, participants, nascent of the directed actions' relevance, are primed through body movements that are representative of both the structure of a geometric object(s) and enactive of the geometric transformation(s) of the object(s). A recent re-design of THV includes new modules that allow players to generate their own content (i.e., create new conjectures and new directed actions) to be played in the game. In the current study, students, working in groups, were invited to participate in a 3-day program to play THV, then collaboratively design their own series of directed actions for a given conjecture, and then play their conjecture and those designed by their peers. Researchers hypothesized that *directed actions* would foster mathematical insights crucial for students' insights and proofs. In this study, we present case study analyses in which students' verbal explanations, gesture production and the subsequent actions they designed to simulate geometric transformations can communicate concepts to their peers in a classroom setting.

Theoretical Background

The theory of *Gesture as Simulated Action* (GSA; Hostetter & Alibali, 2019), asserts that gestures, as spontaneous co-articulations with speech or thought, serve to activate perceptual-motor processes in the brain. In mathematics learning, Abrahamson & Sánchez-García (2016) effectively demonstrated how relative positioning of one's hands helped participants better understand concepts of ratio and proportion. According to Nathan's (2017) theory of *Action-Cognition Transduction* (ACT), sensorimotor experiences feedforward and feedback to a predictive cognitive architecture that inductively and deductively reasons about the behaviors of ideomotor systems. ACT is a part of a larger framework called *Grounded and Embodied Cognition* (GEC; Nathan & Walkington, 2017), which proposes that body movement complements learners' verbal expressions (often seen in spontaneous gesture) by grounding understanding via the physical relationships that are the origins of mathematical thinking.

THV leverages the actions, gestures, and other body-based resources in a physically interactive social settings like collaborative game play to create opportunities for players to embody their ideas. When other groups perform the directed actions designed by their peers, we can observe the embodied transfer of ideas across groups via movement (Alibali & Nathan, *in press*). In collaborative settings, we hypothesize that these socially supported actions provide a physical medium by which their ideas "travel" between players. Moreover, we hypothesize these actions become a type of physical vocabulary that students invoke in subsequent explanations as *dynamic depictive gestures* as they mentally and physically simulate transformations of mathematical objects through multiple states (Garcia & Infante, 2012). We explore these hypotheses in multiple cases to demonstrate how embodied mathematical ideas travel within and between student groups through the creation of directed actions for game play.

Methods

Materials

The Hidden Village Game Module. THV delivers an embodied geometry curriculum in which a 3D motion capture sensor detects players enacting an in-game avatar's movements and records players' reasoning about geometry conjectures (i.e., ever false or always true). Figure 1 shows the 5 main parts to each level of game play.

Figure 1: One level of THV gameplay.

The Hidden Village Conjecture Editor Module. Students add new conjectures and design what they consider to be mathematically relevant directed actions by manipulating the sequences of poses of the avatar (Figure 2). Student groups use the Pose Editor to generate 2-3 poses (starting, intermediate, and target pose) to collaboratively co-create directed actions for each conjecture and players can preview the movements as animations. User-generated content is stored in an online database and accessible for others to play in the game module.

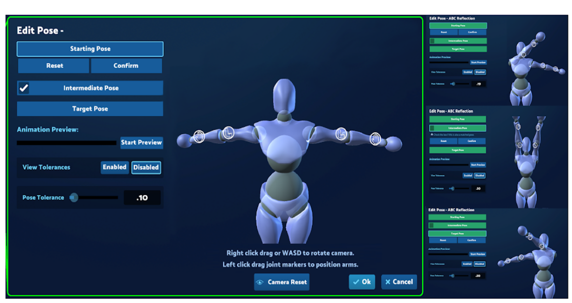


Figure 2: The THV Conjecture (authoring conjectures) and Pose Editors (for creating directed actions) and an example of a directed action sequence (far right).

Participants and Procedure

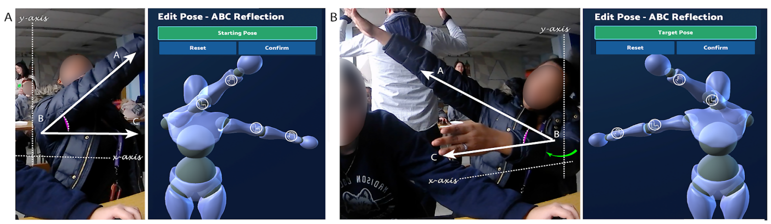
In this study, 12 students in a Title I high school in the midwestern United States were randomly assigned to groups of three or four to participate in a three-day embodied mathematics curriculum focused on geometric thinking. This paper focuses on three of the student groups.

On Day 1, group members took turns playing six conjectures in THV game module. On Day 2, student groups collaboratively constructed their own directed actions for a newly-assigned conjecture. On Day 3, student groups took turns playing the new THV curriculum (8 conjectures; 3 repeated from day 1, 3 newly designed by student groups, and 2 transfer conjectures.

Results

Within-Group Analysis

Upon noticing that the student's initial discussion of the conjecture produced a sequence of directed actions that produced the desired outcome of the geometric transformation,



Transcript 3**:** (*N.B. S1 indicates Student #1;* brackets [...] indicate gestures.)

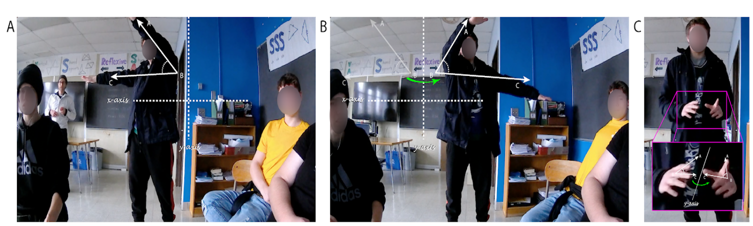
[1] S1: Oh, wait. This is not the starting pose. Is that the starting pose? [Uses arms to make ∠ABC on the left
[2] side of the body] We are going like, this is the angle [shifted arms directly to the right side of
[3] her body by performing a reflection across the body vertical axis]... Boom! That's the angle!

Figure 5: For *ABC Reflection* conjecture, Student 1 in Group 1 embodies the starting pose physically (also shown as designed in THV Pose Editor, panel A) and S1 performs the entire directed action, finishing on the target pose.

This transcript indicates the starting and target poses (see Figure 5) the student group used for the *ABC Reflection* conjecture. S1 embodied the idea of "using your body as the midline" through this directed action as they narrated their actions, shifting the angle from the right side over the body to the left side, which solidified their understanding of a reflective transformation.

Between-Groups Analysis

Students in Group 4 played the *ABC Reflection* conjecture as designed by Group 1. One player per group performed the directed actions while the other group members observed. Researchers analyzed students' speech and gestures to track how Group 1's ideas traveled to peers (RQ2).



Transcript 4: (*N.B. S3 indicates Student #3;* brackets [...] indicate gestures.)

[1] S3: False. Because it can be proportionally the same, have the same angles [using hands to make an
[2] angle] while being in different locations. [S3 then, selects the correct multiple-choice answer]

Figure 6: S3 3 in Group 4 performs the directed actions (Panels A & B) for *ABC Reflection*. In Panel C, S3 provides intuition and rationale, gesturing the reflection.

In the process of proving the conjecture, S3's spontaneous gesture enacted an embodied conceptualization of the ∠ ABC that results from the transformation. In effect, this gesture is a truncated version of the authoring group's directed actions and complements S3's rationale.

Discussion

These case studies show the promises of an embodied, collaborative mathematics curriculum by demonstrating instances of how mathematical ideas "travel" through embodied actions. Students created content that explored embodied ways of reasoning those ideas were shared when their peers performed those directed actions during game play. This study provides preliminary evidence that directed actions can serve as a malleable factor that scaffolds cognition through its connections to the body, leaving historical traces that learners can feel, reinforcing their mathematical reasoning and complement their verbal explanations as conceptualization occurs. Embodied cognition offers promising ways to foster the transfer of mathematical ideas through students' collaboratively constructed movement.

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