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Embodied Transmission of Ideas: Collaborative Construction of Geometry Content and Mathematical Thinking

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Abstract: This study looks at how students embody their ideas about geometry conjectures and how those ideas travel within and between student groups. In one classroom of a Title 1 high school, students participated in a three-part program in which they: (1) played *The Hidden Village*, a motion-capture video game where they assess the veracity of geometric conjectures (i.e., if it is always true or ever false) while their intuitions, insights, and rationales (including their gestures) are video recorded, (2) designed their own directed actions (i.e., a sequence of movements that represents a body-based interpretation of the structure and transformation of a spatial configuration), and (3) re-played the game with a mixture of previous conjectures combined with the conjectures designed by their peers. Multiple cases revealed ways that simulated enactment and collaborative construction can convey mathematical ideas.

Keywords: Embodiment, Geometry, Collaborative Construction, Transfer

Introduction

Students played a motion-capture video game, *The Hidden Village,* and then were provided opportunities to make new content for the game. Students were invited to think, act, and talk through the ways that their bodies could *represent* geometric objects in the conjectures--statements that are provable false or true. We hypothesize that these embodied sequences, called *directed actions*, can foster mathematical insights crucial for students' understanding. Students designed their own directed actions using their bodies to express their conceptualizations of geometric conjectures to themselves and their fellow group members in the context of the game. Analysis of students' gesture production, simulating the actions of geometric transformation, demonstrated how students explore and explain their thinking.

Theoretical Background

Studies have shown that mathematics can be learned through action-based interventions (Abrahamson & Sánchez-García, 2016). *The Hidden Village* (THV; Swart et al., 2020) is an educational video game. It draws on the theory of *Gesture as Simulated Action* (GSA; Hostetter & Alibali, 2019), which asserts that gestures activate perceptual-motor processes in the brain when co-articulated with speech or thought. These sensorimotor experiences can induce cognitive states through the process of *Action-Cognition Transduction* (ACT; Nathan, 2017). From this, Nathan and Walkington (2017) developed the *Grounded and Embodied Cognition* (GEC) framework, which proposed that directing players' bodily movements (via directed actions) will complement learners' verbal expressions of mathematical reasoning.

An embodied theory of transfer (Alibali & Nathan, *in press*) posits that concepts are ultimately represented by the actions, gestures, and other body-based resources embedded in various physical and social settings, like collaborative game play. We call this form of embodied transfer "travel." By prompting players to explain their answers, THV primes players' production of *dynamic depictive gestures* that mentally and physically simulate transformations of mathematical objects through multiple states (Garcia & Infante, 2012) that can "travel" to other players.

In the current study, we explored two research questions: (RQ1) How does a student group designing new game content develop their mathematical ideas and create their own directed actions intended for others to play? (RQ2) How does the intention of the original group's mathematical ideas "travel" to other student groups through subsequent game play, and show up as the embodied transfer of those ideas in other groups' gesture and speech? Thus, we investigate how student groups created directed actions for geometry conjectures and formed their ideas about geometric transformations, hypothesizing that students' embodied mathematical ideas "travel" through player-generated content in the form of direct-action movements.

Methods

Materials

The Hidden Village (THV) Game
THV is a 3D motion-capture collaborative video game that offers an immersive embodied geometry curriculum in which each player emulates in-game avatar's movements and then reasons about geometry conjectures to prove whether it is either *false* (F) or *always true* (T).

The Hidden Village (THV) Conjecture Editor
The THV Conjecture Editor enables students to create new movement-based game content. Students add new conjectures and then design mathematically relevant directed actions by manipulating the sequences of poses of the avatar (Figure 1). Using the Pose Editor, student groups collaboratively generate 2-3 poses (starting, intermediate, and target pose; see middle panel of Figure 1) to create directed actions for each conjecture. Once poses have been designed, players can preview the movements as an animation. Once completed, user-generated actions are stored in the online database of THV and accessible to any other users to access and play.

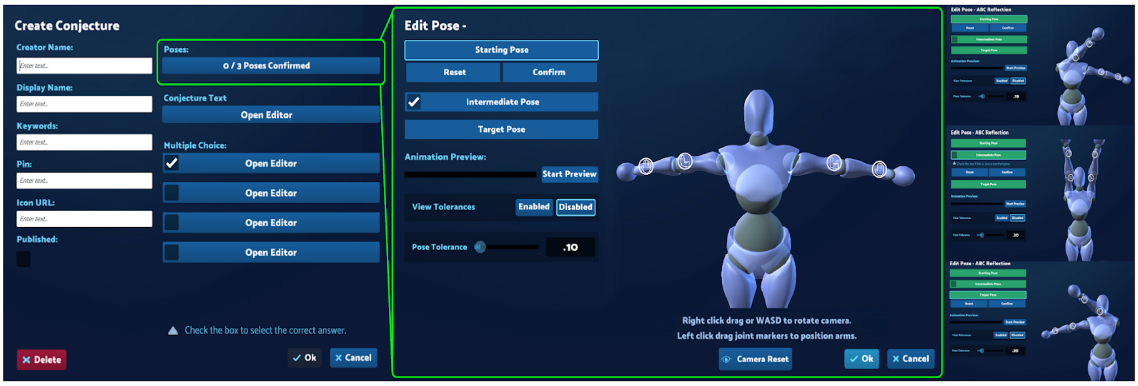


Figure 1. The THV Conjecture Editor and THV Pose Editor (for creating directed actions) with an example of a directed action sequence (far right).

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

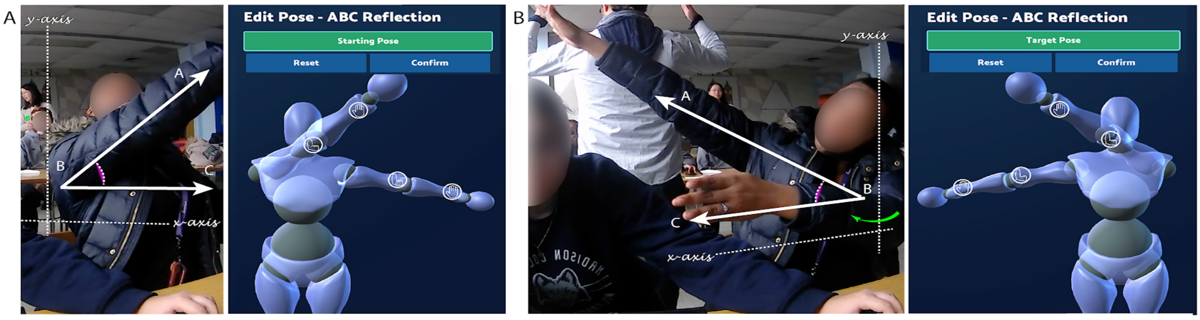
Procedure
The three-day curriculum extended over three class periods over three successive weeks: (Day 1) group members take turns playing six conjectures in THV; (Day 2) student groups collaboratively construct their own directed actions for a new conjecture, and (Day 3) student members take turns playing a new THV curriculum (eight conjectures total; three repeated from Day 1, three designed by student groups on Day 2, and two new (transfer) conjectures). The *in situ* curriculum was administered during normal class time and students' group gameplay data (including student's (1) intuitions, (2) insights, and (3) explanations of conjectures) and co-design activities were video recorded, transcribed and coded by researchers.

Results

Within-Group Analysis
To understand learning processes in the co-design activity, researchers analyzed students' (Group 1) collaborative multimodal interactions during group discussions, including both gestural and verbal communication (RQ1). Students in Group 1 co-constructed directed actions for their chosen conjecture. Figure 2 is a photo-illustrated transcript of Group 1's discussion of their mathematical ideas (RQ1).

In the course of designing their directed actions, students used multiple dynamic depictive gestures (i.e., action-speech pairings, Nathan, 2017) while deliberating which directed actions would best assist players to grasp the geometric relations relevant to proving their conjecture, the *ABC Reflection* (which is false):

Given three points A, B, and C, and their reflected images about a line, A', B', and C', then ∠ABC and ∠A'B'C' are not equal.



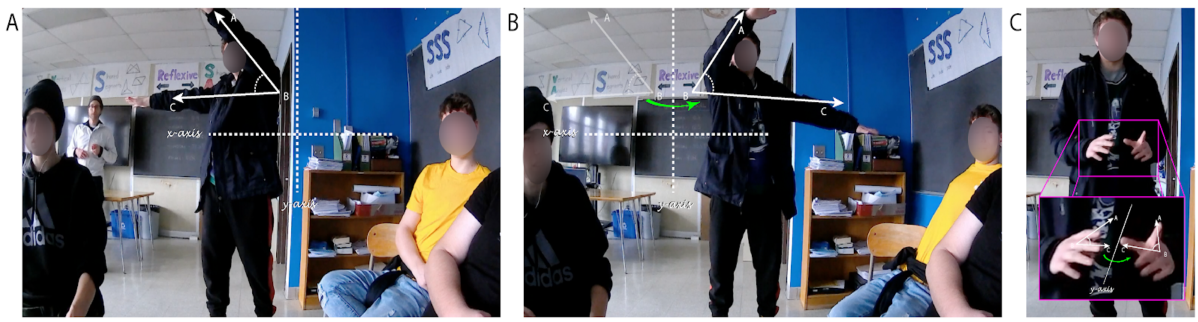
Transcript #1: (*N.B. S1 indicates Student #1;* brackets [...] indicate gestures.)
[1] S1: Oh, wait. This is not the starting pose. Is that the starting pose? [Uses arms to make ∠ABC on the left
[2] side of the body] We are going like, this is the angle [shifted arms directly to the right side of her
[3] body by performing a reflection across the body vertical axis]... Boom💥! That's the angle!

Figure 2. For *ABC Reflection* conjecture, Student 1 in Group 1 embodies the starting pose (also shown as designed in THV Pose Editor, panel A) and S1 performs the entire directed action, finishing on the target pose.

Figure 2 indicates the starting and target poses (see panel B) the student group used for the *ABC Reflection* conjecture. Narrating their actions as they reflect the angle from the right side of the body to the left, S1 embodied the idea of "using your body as the midline" through this directed action. In finalizing these directed actions, the group members solidified their understanding of the conceptual difference between reflection and rotation in the process of designing their pose sequences in the THV pose editor.

Between-group analysis

On Day 3, students played THV with a mixture of conjectures from Day 1, conjectures designed by their peers on Day 2, and two previously unseen conjectures. Students in Group 4 played the *ABC Reflection* conjecture as designed by Group 1. One player per group performed the directed actions prompted within THV, while the other group members observed. To track how Group 1's embodied mathematical ideas traveled to other groups (RQ2), researchers analyzed students' gestures and discourse.



Transcript #2: (*N.B. S2 indicates Student #2;* brackets [...] indicate gestures.)
[1] S2: False. Because it can be proportionally the same, have the same angles [using hands to make an angle]
[2] while being in different locations. [S2 then, selects the correct answer from the multiple-choice options]

Figure 3. Student 2 in Group 4 performs the directed actions (panels A & B) for *ABC Reflection*. In panel C, S2 provides their intuition (i.e., T or F) and rationale, using their hands to represent the reflection of ∠ABC.

After performing the directed actions during game play (see Figure 3), Student 2 (Transcript #2) states their intuition ("False"). S2 provides their rationale (Lines [1-2]) with spontaneous gestures (panel C). In the process of proofing the conjecture, S2's spontaneous gesture demonstrates an embodied conceptualization of the ∠ABC that results from the transformation. In effect, this truncated gesture complements S2's verbal rationale and extends Group 1's original idea for embodying the reflection of an angle over an axis.

Discussion

This study demonstrated instances of how mathematical ideas "travel" through embodied actions. THV served as a vehicle to reify geometric relations as movements of an avatar. Students created content that coupled geometric conjectures with movements intended to help players to embody these mathematical ideas. We found that students used the posable avatar as a way to explore embodied ways of reasoning and then share those ideas through subsequent game play. Performing these directed actions facilitated new players' mathematical intuitions and helped them articulate their justifications for transformational proofs.

Within Group 1, students communicated their ideas to each other about the *ABC Reflection* conjecture through their discussion and design of their directed actions. By embodying the geometric transformation in the conjecture, student's garnered insights about angles and axes in the course of reflecting the angle across the y-axis. Developing these actions enabled them to work through any misconceptions about reflection and contributed to Student 1's reconsideration of how to enact a directed action that more accurately depicted the reflection of ∠ABC. Through collaborative co-construction, this group exemplified how embodying mathematical thinking travels within a group as a design team and helped finalize their directed actions for the conjecture.

Between Group 4 and Group 1, the directed actions in *ABC Reflection* conjecture demonstrated how embodied mathematical ideas traveled successfully. The geometric transformation depicted by the in-game directed actions helped Student 2 interpret and explain the concept of reflecting an angle over an axis. Moreover, after performing these gross-motor movements with their arms, Student 2 generated a truncated spontaneous gesture using only their hands, a type of marking (see Kirsh, 2010) to represent the outcome of the geometric transformation. Nathan et al.'s (2017) *Grounded Embodied Cognition* framework contends that the directed actions primed the sensorimotor stimulation (i.e., feedforward and feedback) that preceded Student 2's gestural reaffirmation that the reflected angle across the y-axis was indeed congruent.

These case studies identify some of the promises of an embodied mathematics curriculum. Directed actions are a malleable factor that can scaffold cognition and produce historical traces that can give rise to spontaneous gestures and task-relevant speech in support of successful mathematical reasoning and proof.

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Acknowledgments

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