Exploring How a Simulation Game Connects Concrete and Abstract Learning

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Introduction

The abstract nature of mathematics makes it a challenging subject in secondary education. Among various secondary-level mathematics topics, vector addition is one of the most important skills because of its fundamental role in postsecondary level STEM education. However, overly relying on abstract concepts and symbols (criticized as "formalism first" by Nathan, 2012), current secondary-level vector addition learning may leave students with confusion and misconceptions. How to empower students to establish grounded vector addition skill is essential to both secondary educators and educational researchers.

For building students solid vector addition skill, "concreteness fading," which refers to an instructional approach allowing students to start learning an abstract concept with concrete learning materials in specific learning contexts and gradually transit to abstract learning materials in more general learning context (Fyfe et al., 2014; Goldstone & Son, 2005), seems promising for teaching vector addition. Learning with concrete materials or abstract materials only has their own advantages and disadvantages (Fyfe & Nathan, 2019), whereas "concreteness fading" can mitigate the weakness of either concrete or abstract learning and reinforce their strengths.

Inspired by Bruner's (1966) three phases (enactive, iconic, and abstract) of developing new concepts, a "concreteness fading" intervention should introduce students a new concept or skill in three stages with decreasing levels of concreteness. The second stage is essential as it fades the concreteness of the previous enactive learning activity and still provides learners with a level of concreteness, which affords the connections between physical materials and abstract representations. Thus, the representations in this stage ought to be similar to those in the first and third stage to make students able to notice the sequential connections and the mutual referents (Suh et al., 2020). Jaakkola and Veermans (2018) used a circuit simulation in the fading stage to teach circuit construction but there is still a question whether a simulation works when the learning content is more abstract, such as vector addition. Thus, in this study, we designed a simulation game as the learning material in the second stage and our research question is how can a simulation game bridge learning in a "concreteness fading" intervention that teaches vector addition?

Methods

Participants

This study had six participants who were 8th graders from a charter school in a large Midwestern city in the U.S. As being told by their math teacher, all the participants had learned the coordinate plane in their 7th grade and never been taught about vectors in a classroom setting before. Observed from warm-up activities, about half of them demonstrated strong interests in mathematics but the other half thought mathematical concepts were hard to understand and mathematics was overall difficult. They were divided into two groups randomly to take part in this study.

Procedures

The first part of this study was an individual knowledge test that lasted about 10 minutes to measure participants' initial understanding of vector addition. Then they formed a group of three to complete three "concreteness fading" learning tasks (see Table 1). After completing the learning tasks, they spent 30 minutes on another task called "constructionist problem design," building a story together to demonstrate what they had learned today. The last part was a 10-minute posttest in which participants needed to do another knowledge test to show their gaining from the study.

Table 1

"Concreteness Fading" Learning Activities

Task	Activity	Duration
Enactive Physicality	The participants tiled the floor with light and dark green cardboard tiles and randomly selected two tile's vertices to stand on and figure out a way to describe their position. Then they played a game in which they passed a football to experience informal vector addition.	20 mins
Iconic Depiction	The participants played a videogame built on similar concepts that introduced some formal representations such as axis and unit vectors.	20 mins
Abstract Representation	The participants worked on a question sheet with similar settings and more formal notation and symbols.	20 mins

Data collection and analysis

Two study sessions were conducted in spring 2022. Each study session lasted approximately 2 hours. During the study session, two video recorders were set up to capture video and audio data that the participants produced.

After completing all the study sessions, audio data was transcribed via Descript, an automatic transcription service, and then revised by the researcher to ensure the accuracy of the transcription. Discourse analysis was used to examine their languages before, during, and after the second task "Iconic Depiction" in which they played the simulation game together. According to Gee (2014), discourse analysis investigates the function of language and how meaning is constructed in different contexts. In this study, we inspected the participants' discourse and focused on their language to discover the development of their understanding in vector addition across the learning tasks. Although there was evidence that students demonstrated new understanding in the fourth task and the posttest, this paper primarily focuses on the three learning tasks.

Preliminary Findings

First and foremost, the same color we used across the three "concreteness learning tasks" caught the participants' attention. When being asked about the similarities among the learning tasks, two participants mentioned that the light and dark green tiles (see Appendix 1) used in the first task "Enactive Physicality" and the second task "Iconic Depiction" (see Appendix 2). Also, one participant mentioned the blue and red line used on the tiles were in the game and on the question sheet used in the third task "Abstract Representation" (see Appendix 3). Similarly, the consistent context-football passing-made the participants easier to make connections among different learning tasks. All the participants mentioned the context of football. Some participants mentioned that there were a quarterback and a wide receiver and they needed to get a touchdown. They also mentioned there were coordinates and points in both the tile activity and the game. In addition, the alike problem-solving played a role in helping students identify same learning content in different tasks. Four participants told the researcher that they needed to determine the values of X and Y to pass the ball in words like “the amount in this direction” or “the numbers on the axis” when dealing with those tasks.

Discussion

The preliminary findings reveal that in a “concreteness fading” intervention, the in-between “fading” stage should have the affordance of connecting concrete and abstract learning by providing the learners with consistent color code, context, and problem-solving. The learners first encounter unfamiliar topics and need their previous knowledge and experience to tackle the problem in the first phase of “concreteness fading” so introducing too much formal abstract mathematics symbols seems inapt at this time. When they got familiar with the context and the problem-solving process, they can pay more attention to the underlying mathematics content of the activity. Therefore, adding some formal notation such as axes and numbers is appropriate in the second phase in which the same problem is presented in a form of simulation game. Also, the same color code reduces the participants’ cognitive load (“cognitive load theory,” see Sweller, 2011) and as a result, they are able to focus on exploring the learning content rather than be distracted by the extraneous features of the learning materials. However, this preliminary study only has a small sample size so it might be hard to generalize to a large population. Also, the intervention used in this study needs revision to make it compatible with real classroom teaching and learning as we only observed qualitative understanding of vector addition from our participants in this study.

References

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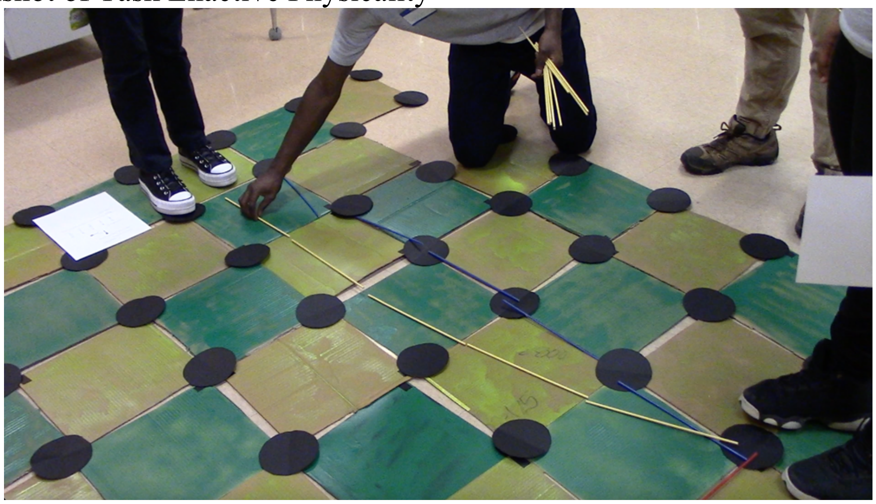
Appendix

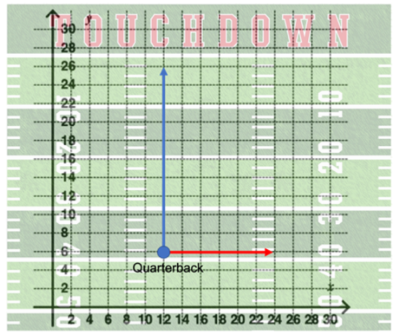
1. The screenshot of Task Enactive Physicality



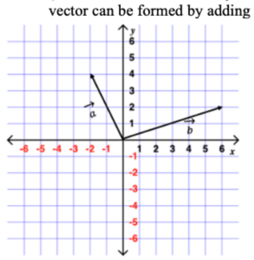
2. The screenshot of the game used in Task Iconic Depiction

3. The questions in Task Abstract Representation

1. Suppose you are the coach of a junior football team, and the team is practicing passing today. Today's wind speed is 12 mph towards East (red vector), and the average passing speed of the quarterback is 20 mph towards North (blue vector). Assuming the football is being thrown from the blue dot, please draw the velocity of the ball in the wind.
(Hint: write down how many units along the x and y axis each vector has.)



2. Suppose you are training the placekicker in your team. Today's wind speed is $\vec{a}$ = (–2**x** +4**y**) and the initial velocity of the ball is $\vec{b}$ = (6**x** +2**y**). Please figure out the resultant (sum) of these two vectors and draw it on the coordinate system.
(Hint: write down how many units along the x and y axis each vector has and how a third vector can be formed by adding those units along each axis.)



$\vec{a} + \vec{b} = \vec{c}$