Academically Meaningful Play in the Mathematics Classroom: Learning Symmetry and Transformations through Transformations Quest Educational Video Game

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Abstract: This paper aims to analyze how *Transformations Quest*, an educational block-based videogame designed using the academically meaningful play framework supports middle grade students' learning of geometric transformations. Data sources include video footage of 18 students' dialogue with researchers while playing the game on Zoom. We present one illustrative example as evidence of the students' geometric transformations learning using our game. Findings determined that the game helped students to productively hybridize everyday and mathematical formal experiences in favor of mathematical understandings beyond the curriculum, leading us to conclude that when games are designed with an academically meaningful play lens, they can support the building of conceptual understanding.

Introduction

Digital game design as a means of facilitating geometric transformation and symmetry learning is an emergent field of research (Hernandez-Zavaleta, Becker, Clark, Brady & Cao, 2022). Sedig (2008) is one of the few studies that investigates how games can be designed to help children learn about geometric transformations. Although, there are some games that focus on middle grade mathematics students learning about geometric transformations learning (e.g., *Transtar, Transformations Golf 2, Flip-N-Slide*), there is also a lack of research linked to whether these games are well designed for the development of disciplinary understandings. The purpose of this paper is to analyze how *Transformations Quest*, an educational block-based videogame designed by our research group at University of Calgary, supports middle grade students' learning of geometric transformations. In doing so, this study stands at the intersection of the educational game design, computational thinking, and mathematics education research.

Disciplinary Context for the Study: Geometric Transformations and Motion and Mapping Conceptions

A predominant theme across the geometric transformations research (Edwards, 2003; 2009; Edwards & Zazkis, 1993; Yanik, 2014) is that of helping students move their everyday experiences in the physical world (motion) to a more formal understanding (mapping). Research on geometric transformations suggests that in the motion conception scenario, students and teachers act as if the cartesian plane were a stage on which geometric shapes can be manipulated by providing them with physical properties (e.g., the application of a force is required for motion to exist) (Yanik, 2014; others). Also, this view includes embodied experiences as reported by Edwards (2003; 2009), where students often relate their embodied experiences when making sense of a figure's internal relationship. For example, when rotating they often relate to the turning of the hands on a clock. On the other hand, the idea of mapping is to define points as locations in space rather than as elements of a set. Edwards (2003; 2009) mentions that this vision considers bringing students to work with geometric transformations in the way that a mathematician would do "as mappings of the plane, rather than as simple motions of geometric figures." (Edwards, 2003, p. 6).

Scholars are aware that the transition between the motion and mapping views has not been fully understood (Edwards, 2003; 2009; Yanik, 2014). In facing this problematic some scholars have focused their efforts on how the mapping conception is constructed by human beings engaged in a world of physical and embodied experiences that change in constant interaction with their environment (Edwards, 2009; Edwards & Zaskis, 1993; Gadanidis et al., 2018; Hoyles & Healy, 1997; Jacobson & Lehrer, 2002). In terms of digital media, the use of programmable environments such as Logo or Scratch lead this perspective. Notably, some researchers suggest that using this kind of media provides an easy and intuitive vision for learning geometric transformations, by guiding new ways of constructing geometric understandings (Edwards, 2009; Gadanidis et al., 2018). Two questions remain, however: the first whether these understandings help people to develop a mapping vision of the plane (Edwards & Zazkis, 1993; Hoyles & Healy, 1997). The second about the relationship between students' motion and mapping conceptions and the nature of progression across these relationships.

Academically Meaningful Play a Framework for Game Design

Over the years, many scholars have explored how educational games might help students learn more effectively than traditional learning instruction (Chase & Aleven, 2017; Habgood & Ainsworth, 2011; Kafai, 2006; Kahila, 2020; Wouters et al., 2013). In this respect, Clark, Hernández-Zavaleta, & Becker (2021a) framed academically meaningful play based on Salen and Zimmerman's (2005) ideas of meaningful play as a response to how the design of games for learning influences understandings.

According to Salen and Zimmerman (2005) "meaningful play emerges from the interaction between the players and the system of the game, as well as from the context in which the game is played" (p. 60) Salen and Zimmerman explain that choices and decisions are meaningful in a game if the results of those choices are: (a) discernible to the player in the sense that the ramifications of the choices are communicated to the player and (b) integrated into the ongoing game in an impactful way. As an extension of these ideas, academically meaningful play considers four core pillars for a game design: discernability, integration, academic grounding, and accessibility (Clark, Hernández-Zavaleta, & Becker, 2021b). We summarize these four core pillars and their definition in Table 1.

Table 1

Core pillars of academically meaningful play (Clark, Hernández-Zavaleta, & Becker, 2021b).

Discernability	Outcomes and implications of choices clearly communicated to player. Essentially, this core pillar lets players know what is happing when action is taken.
Integration	Outcomes of choices are meaningfully integrated into the larger context of the game such that an action not only has immediate outcomes and significance but also affects the play experience in the unfolding of the system states at a later point in the game.
Academic Grounding	Core meaningful game choices are grounded in classroom/disciplinary big ideas. This means supporting the teacher and students providing foundations for a robust understanding of disciplinary practices.
Accessibility	Design affords thematic access and challenge for all students. *Thematic access* seeks to include more subtle and diverse representations of players and game environments beyond the historically white, heterosexual, and male hegemony in the design. *Challenge access* seeks to structure disciplinary ideas to offer players low floor/high ceiling opportunities for all skill level players.

The *Transformation Quest (TQ)* game was developed by team of researchers led by Author 3. In the game, consisting of 11 levels, players used a limited number of code blocks to instruct the movement of a triangular shape to positions on the plane. In seven of the levels (gems levels), players collect gems by landing on them. In four levels (creative levels), players land on triangles, with different colours representing different point values (visit https://mathgame.ucalgary.ca/ to try the game).

Discernability. We designed *TQ* to achieve high academic discernability by spotlighting the salient characteristics of specific transformations. For instance, the code blocks include the name of the transformation to perform (e.g., horizontal translation by) and parameters that give meaning to specific concepts (e.g., magnitude and direction). An important part of the design is the emphasis we gave to coordinate nature of the plane and the precise mapping correspondences.

Integration. We looked for integration in *TQ* by designing three different challenges in each level to collect bronze, silver, or gold shields. In this regard, choices are not arbitrary but rather dependent upon understanding, exploring, and differentiating between the characteristics of the different types of transformations and the salience of the specific parameters designated for each transformation. These shields represent the player's accomplishments and mastery of the game.

Academic Grounding. The academic ground design in *TQ* was informed by two sources: (1) the curricular academics goals around geometric transformations suggested by Alberta Education (2016) and National Council of Teachers [NCTM] (2000) curricular programs and (2) using the motion and mapping framework informed by the research in mathematics education (see previous section). Curricular goals include making predictions about the outcomes of the three basic types of transformations (translation, rotation, and reflection) in terms of the resulting positions of a geometric shape on a Cartesian plane. The motion and mapping framework emphasizes a mapping conception and correspondences based on players' motion experiences, which provides a stronger foundation for students in high school to be thinking more productively about the transformation of functions and equations, thereby providing a good foundation for the study of symmetry groups and group theory.

Accessibility. In terms of thematic accessibility, we designed the game in conjunction with a survey we conducted in a pilot study testing a beta version of TQ. Students presenting as both male and female indicated the space theme would be the most engaging of the themes that we pitched. We therefore decided to go with the current space theme, with the caveat that the color scheme, imagery, and narrative text needed to be fun and inviting. In terms of challenge access, *TQ* provides clear and simple tutorial levels when a new translation type or control type is added to the game to "lower" the access floor, while new transformation blocks are gradually and incrementally added to the game as the challenge level increases. In addition, after completing the bronze shield challenge of a level, players might choose to attempt a silver or gold shield challenge on that level before moving on to the next level topic.

Research Questions

Whereas the disciplinary context and the game design by separate suggest questions that enrich their own field. The current manuscript explores a question that arose a multidisciplinary perspective and point to contribute to both perspectives: *How can designing for academically meaningful play support productive hybridizing of embodied and formal understandings of geometric transformations?*

Methodology and Data Analysis

For the purposes of this study, we engaged in a comparative case study (Merriam & Tisdale, 2015; Thomas, 2011) to explore how 14 students working in pairs and 4 in solo settings (grade 7 and 8 students) got involved in a *TQ* gameplay to create understandings of geometric transformations. Selecting case study allowed us to consider each couple or individual as a separate case of study (Harrison et al., 2017). It also enabled us to compare how each participant or couple case created solutions for each level and to look for individual participant and inter-participant pattern similarities and differences (Gaikwad, 2017).

Participants

Given limitations to accessibility due to COVID-19 and adhering to the university ethics board requirements, we utilized two recruitment strategies through our own networks. Participants included grade seven and eight students working in pairs from a local school, and individuals in the local community. All our interactions with participants were online. The video footage of student participation was recorded in a virtual setting (Zoom and Meet), where the participants shared their screen with the researchers while participating in the game play.

Data Analysis

The data analysis process involved observations of the videos to determine essential pieces of evidence followed by clarification, interpretation, and categorization of patterns based on the theoretical constructs drawn from the discipline of mathematics and computational thinking (Gaikwad, 2017; Merriam, 2009). In order to ensure internal validity, we focused on attending to the patterns in the participant's embodied, spoken, and digital writing explanation building, and analysis of changes in their understanding over time (Gaikwad, 2017). The inscription foci were derived from a combination of learning outcomes as outlined by the provincial curriculum (Alberta Education, 2016) and NCTM (2000).

Findings

Our analyses demonstrate that TQ supports middle grade students' learning of geometric transformations in a very particular way. The students' engagement with the game indicated a dynamic transition between motion and mapping creating a *hybrid motion and mapping conception* as the level of difficulty increased. These findings also present insights regarding three specific design elements we identified in our analysis that influenced the development of mathematical learning and computational thinking, and which we think contributed to academically meaningful game play. Due to the length of this manuscript, we provide one example to illustrate these three design elements.

Productive Hybridizing of Motion and Mapping in Transformations Quest

In this example we observed how the student used and improved his understanding of geometric transformations through productively hybridizing motion and mapping conceptions as he integrated the continuous sense of a transformation, grounded in his experiences of motion in a physical/continuous world, with the discrete nature of motion, built into the environment. Essentially, this student conceptualized the continuous action of turning around in terms of a series of 90° angle turns, where his motion conception supported a continuous image of circular motion, and his mapping conception allowed him to visualize before/after states of partial rotations along the circle, creating quarter-circle turn-units. This episode is a consequence of the challenge access provided by the gem positions (see Figure 1).

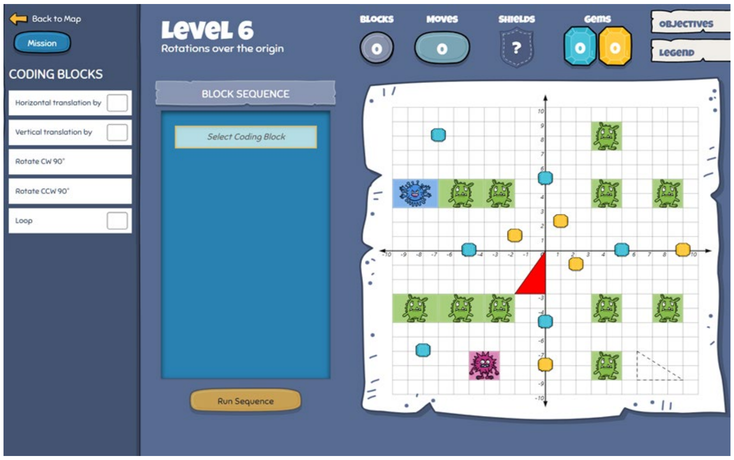

Figure 1
Initial Set-Up for Transformations Quest Level 6

The student's description of his plan using words like "going, spinning, cartwheeling around" suggested he used his understanding of the continuous sense of a transformation grounded in his embodied motion experiences as a jumping off point in the game. Yet, the game incentivized him to think in discrete steps. His explanation "go clockwise three" suggested he represented his solution with a series of definite actions that would lead him to land on specific gems to collect them. We came to call this design element, which supported the student's interaction with the computational environment, *discretizing.* By this we mean students made sense of before/after motion effects produced individually by each block of code.

Also, important to note is that this student came to see the *unit 90° CW rotation* in relation to the *system* of rotations that it could generate. For instance, the student recognizes that [Loop 5 [Rotate 90° CW]] would bring the triangle to the same position that a single application of the [Rotate 90° CW] transformation would achieve. We came to call this design element, which supported the student's interaction, *parametrizing*. Here, parametrizing is related to sense making of the "range of motion" of a chosen concrete "unit" transformation, through repeated applications of that transformation.

Another important moment in the student's interaction with the game was the reuse of chunks of coding blocks in the solution of more difficult problems. In this example, this student used the structure [Loop 5 [90° CW]] to secure the bronze shield and the silver shield. We came to call this design element, which supported the student's interaction, *composing-and-encapsulating*. This interaction is linked to the computational representation of procedures and the creation of complex compositions of geometric transformations. This was activated by the integration pillar in the academically meaningful play framework.

This student engaged in productive hybridizing of motion and mapping when he blended his everyday experiences with the represented discrete nature of motion in the Transformations Quest game, allowing him to integrate geometric transformation understandings into big mathematical ideas (e.g., the beginnings of a group theoretic understanding of a cyclic group generated by a rotation). In this example, we could see indications of how the conceptual frameworks of motion and mapping materialized in the interactions between students and *TQ*. An important fact for mathematics education research is the students' productive hybridizing of both motion and mapping instead of seeing each as a separate conception that builds in a linear way. In doing so, it generated understandings about geometric transformations based on the development of "big" mathematical ideas, in this case, cyclic groups. This hybridizing of motion and mapping was expressed by the student in the identified concrete interactions of discretizing, parametrizing, and composing-and-encapsulating.

Final Thoughts

The mathematical experiences in *Transformation Quest (TQ)* present opportunities for classroom teachers in terms of mathematical learning. To this end, the academically meaningful play framework has showed to be useful for the design of meaningful game play experiences for middle school students that develop mathematical and computational understandings. Though we found evidence to suggest that videogames designed under the academically meaningful play framework could provide access to opportunities for rich learning about geometric transformations, we are in the search of further evidence by looking at other episodes in our data set. In concordance with mathematics education research, exploring how students *productively hybridize motion and mapping* conceptions acknowledges "the need to study the transition phases in the progress of geometrical concept formation" (Sinclair et al., 2016, p. 696). In addition, we advocate for the use and development of discretizing, parametrizing, and composing-and-encapsulating interactions as possibilities for academically meaningful play by providing discernibility, integration, academic grounding, and accessibility in the classroom delivery of the game.

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