Geometris: A Collaborative Embodied Geometry Game

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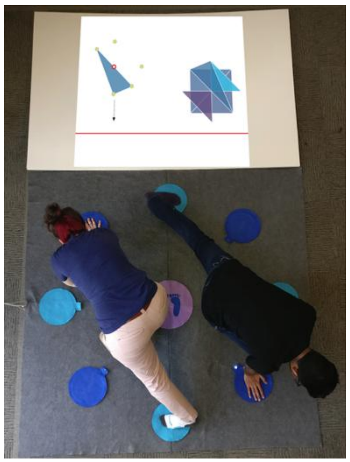

Figure 1. As a shape descends from the top of the projection area, players recreate the shape with their bodies on the interactive mat.

Abstract
Motivated to provide 6- to 11-year-old children with a way to experience mathematics as collaborative, tangible, and concrete, we present *Geometris*, a collaborative embodied geometry game. As shapes are projected onto the floor, players recreate those shapes on a 6x6ft interactive mat. At the end of each level, a geometric pattern - the result of overlaying all created shapes - is displayed.

In this paper, we share the hardware and software development work behind our functional prototype. We also share feedback from pilot testing sessions. We seek to continue refining *Geometris* to meet the needs of young mathematics learners.

CHI'17 Extended Abstracts, May 06-11, 2017, Denver, CO, USA
ACM 978-1-4503-4656-6/17/05.
http://dx.doi.org/10.1145/3027063.3048413

Author Keywords
Educational game; embodied learning; collaboration.

ACM Classification Keywords
K.3.1 [Computers and Education]: Computer Uses in Education: Collaborative learning.

Introduction
Mathematics is often depicted as a solitary domain of formulas and abstractions, a reputation that does little to engage young learners. With *Geometris*, we present a different experience of mathematics. This embodied, collaborative game relies on interpersonal communication and cooperation. It leverages players' physical movements as a resource for talking, thinking, and learning about shapes. Moreover, play is scored with a beautiful geometric design.

Players interact with *Geometris* on a 6x6ft interactive floor mat. Shapes are projected onto the floor next to the mat, and players create these 2D shapes by touching pressure-sensitive pads corresponding to the corners of the projected shape (Figure 1). As some shapes have more than four corners, players must work in pairs, adding a collaborative aspect to gameplay.

Related Work
Geometry has been recognized as a fundamental pillar of mathematics [11]. The Common Core State

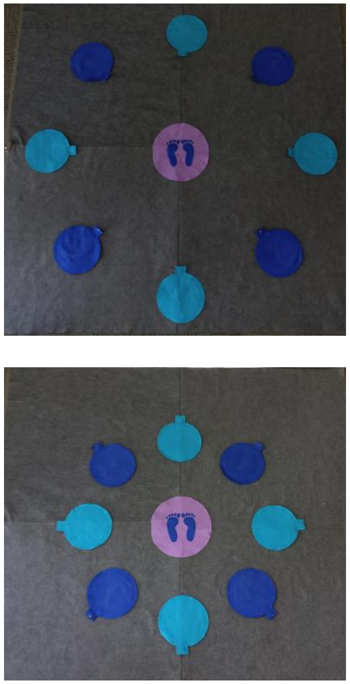

Figure 2. The adult (top) and child (bottom) configurations of the pressure-sensitive pads.

Standards in Mathematics emphasize comparing shapes by number of sides and corners, distinguishing identifying features (e.g. number of corners) from non-identifying features (e.g. size), and recognizing symmetry [10]. Additionally, the National Council of Teachers of Mathematics suggests that students' spatial visualization skills include "manipulating mental representations of two- and three-dimensional objects and perceiving an object from different perspectives" [7, p. 41]. Simple as these skills may seem, they represent significant learning achievements.

To address these challenges, some researchers emphasize the role of physical movement [8]. Proponents of embodied learning argue for physical movement as an essential educational resource [1]. Other lines of education research emphasize collaborative learning, particularly for reasoning tasks [9]. We ground *Geometris* in these research findings.

Geometris's gameplay was inspired by Twister® and Tetris® [6, 12]. We sought to recreate Twister®'s sense of humorous frenzy in coordinating multiple players within a shared space. We also borrow the convention of colored circles a mat, with game play organized around them. Geometris differs from Twister® in that colors serve a purely aesthetic role, and the augmented mat communicates with a computer, much as in DanceDanceRevolution [4].

As in Tetris®, shapes move from the top of the screen to the bottom, with a time constraint imposed to increase the intensity of gameplay. Unlike in Tetris®, *Geometris* players use spatial reasoning to create a shape on a physical mat rather than fitting it into a puzzle.

Design

Players interact with *Geometris* using a body-sized interactive mat and an adjacent projection surface (Figure 1). The mat consists of 8 pressure-sensitive pads and a center point (Figure 2), the latter included as a frame of reference to establish a mapping between the projected image and the mat. We further explain *Geometris* by describing its constitutive parts: the hardware and the software. The design was based on bodystorming practice [3].

We designed the physical mat and touchpads to be playful, comfortable, and large enough to allow collaboration. The touchpads are custom binary switches connected to an *Arduino Uno* microcontroller. Each pad also contains a sequin LED to provide immediate point-of-contact feedback. The size and spacing of the touchpads are based on median adult and child leg lengths and hip abduction (outward rotation) angles [5]. The mat allows two configurations of the touchpads to accommodate both child and adult bodies (Figure 2). We aimed for a gender-neutral color palette of bright and dark blues on a neutral gray background.

In designing the software, we aimed to create a game with various levels of difficulty and with qualitative scoring. The game's three levels - easy, medium, and difficult - vary by the number of vertices in each shape (i.e. the number of limbs required to make it) and by the diversity of shapes prompted (all triangles vs. triangles, pentagons, etc.). We also designed a practice level to allow players to familiarize themselves with the interaction. To be consistent in conveying an alternative, non-numeric experience of mathematics,

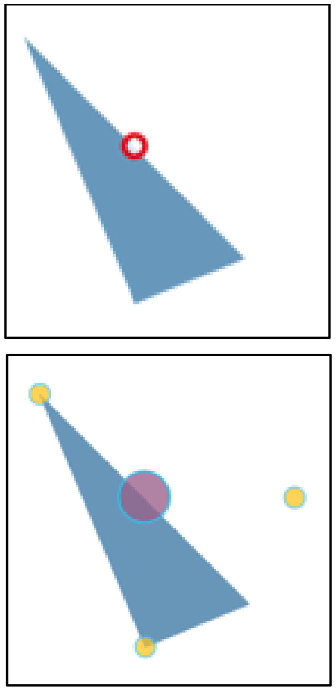

Figure 3. To strengthen the visual mapping, the center red dot (top) was replaced with a larger purple circle (bottom) to match the mat's center point. Additionally, orange dots indicate in real time where players touch.

scores are displayed as a geometric design rather than a number.

In each level, the game play is as follows. Children are prompted to recreate eight shapes, one at a time, by simultaneously activating particular pressure-sensitive pads on the mat. Each shape descends from the top of the projection area toward a red line at the bottom, nearest the mat (Figure 1). Each shape also contains a circle, intended as a frame of reference, to indicate the position of the shape's sides and corners relative to the mat's central point (Figure 1). As the shape approaches the red line (time is running out), the music is layered with a warning tone. When players complete a shape, the game emits a celebratory phrase ("Yay!" or "Well done!"), and a new shape appears. Completed shapes are overlaid into a composite design in the lower right hand corner of the screen (Figure 1). If users fail to reproduce the shape before it reaches the red line, that shape will not appear in the composite design. After the eighth shape, the composite design is displayed in the middle of the screen, accompanied by congratulatory music. The more shapes the players completed, the more intricate the composite design.

Pilot Evaluation and Discussion

We pilot tested *Geometris* with adults during two 1.5-hour sessions. In these sessions, the body-sized scale and the spatial mapping task seemed to provide players with an engaging challenge. And collaborative play effectively prompted users to share their experiences in the moment.

Pilot players offered enthusiastic comments such as "This is like *Twister*® but more fun" and "My 9-year-old would really like it." People seemed to enjoy playing and willingly worked through the initial learning curve. To support longer-term engagement, future work with *Geometris* could better develop the role of the composite designs formed in each level. These designs could be collectibles within a broader game narrative or perhaps serve as elements of a visual landscape.

During pilot testing, users took longer than expected to learn the visual mapping between the projected shapes and the physical mat, often completing only 2-3 of the 8 shapes in the easy level on their first attempt. Accordingly, we increased the size of the center point in the projection and changed its color to match the purple circle on the mat (Figure 3). We also added real-time feedback to the projection in the form of orange circles that reflect the pads being activated by the players (Figure 3). Finally, we increased the time allotment for each shape. With these changes in place, users seemed to learn the mapping in fewer rounds of gameplay and with fewer instructions.

Future work could evaluate the educational impact of the real-time feedback. If it gives too much information, players could continually guess and check their position instead of developing a spatial mapping. We need to evaluate conditions that support players in developing their spatial reasoning, perhaps by reducing this feedback as the levels progress.

Finally, we observed extended collaboration among pilot players. As anticipated, paired players expressed themselves more, verbalizing their thinking. Teaching behaviors also emerged in pair play, especially when one user was more experienced than the other. We witnessed many moves of direct instruction ("You touch that one"), delegation ("You take the top, and I'll take the bottom"), and negotiation ("I can't see." "Well I'll tell you where to go"). Future work could evaluate conditions that support more equal collaboration, as assessed through the power relations present in players' discourse [2].

Conclusions

We created *Geometris* to provide children with an experience of geometry as tangible, intimate, and collaborative. Pilot testing suggests *Geometris* to be an appealing and immersive game. The preliminary results suggest that our game could be improved to support the development of spatial reasoning. Furthermore, players helped us to realize that our platform has the potential to go beyond the realm of mathematics. Its versatile hardware design allows it to become a full-body musical instrument or even workout equipment, to mention two examples.

Work remains to ensure the game's long-term appeal as well as to best support players in developing equitable collaboration. We are excited to continue adapting *Geometris* to suit the physical, social, and developmental needs of young mathematics learners.

Acknowledgements

We thank Dr. Kimiko Ryokai and Noura Howell for their guidance in developing a *Geometris* prototype. We also thank our classmates in UC Berkeley's Tangible User Interfaces course for their advice as well as the pilot participants for their time and feedback.

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