Game Features and Individual Differences: What Makes a Spatial Skill Training Video Game Effective?

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Abstract
This document gives an overview of my current research project investigating how children develop spatial reasoning skills through video game training. I describe the motivation and goals of the project and the progress made so far.

Author Keywords
Spatial reasoning; Learning; Cognitive science; Children; Video games; Education.

ACM Classification Keywords
K.3.1; H.5.2

Introduction
Spatial reasoning skills are crucial for success in STEM disciplines. Longitudinal studies have demonstrated that spatial skills in adolescence predict success in STEM majors and careers [10,13]. In addition, gender differences in spatial ability begin to emerge in early childhood; girls tend to have lower spatial ability than boys [2]. Fortunately, research has found that spatial skills are malleable and transfer to different tasks [12]. Therefore, it is crucial to design training interventions

Types of spatial skills

Mental Rotation: The ability to imagine how an object would look after being rotated in a certain manner.

Spatial perception: The ability to imagine how an object would look when viewed from a different perspective.

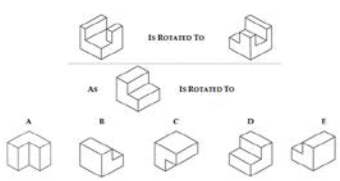

Figure 1: A sample mental rotation task. The subject must circle the letter of the shape that completes the rotation analogy.

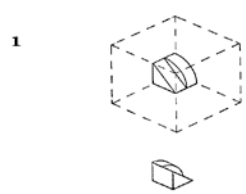

Figure 2: A sample perception task. The subject circles the corner of the box representing the view shown below the box.

for children before low spatial skills become a barrier to careers in STEM, especially for girls.

Our approach uses video games to produce improved learning gains relative to traditional instructional methods. Video games have been shown to produce high levels of motivation and engagement [4]. They also scaffold the learning experience, incorporating tutorials, hints, and progressive difficulty levels to gradually introduce the player to new mechanics and concepts in a way that account for individual differences in player skill [9]. In addition, learning in games takes place in a constructivist context: the player constructs their understanding through their actions and experiences in a virtual world rather than through formal instruction [5]. Both scaffolding and constructivist learning have been shown to increase learning gains in different educational contexts [7,8].

Certain video games, such as Super Mario and Tetris, are effective at training spatial skills in children [1]. However, not all videogames are effective. Portal 2, a popular commercial game, has been shown to improve spatial skills, while Lumosity, a cognitive training game developed by neuroscientists, seems to have no effect on any cognitive skills [11]!

Unfortunately, off-the-shelf games like Lumosity and Portal 2 offer little control over specific game features, which makes it difficult to systematically determine what game features make games like Portal 2 and Tetris more effective at training spatial skills than Lumosity. Furthermore, different people enjoy certain game genres more than others, which may affect their motivation and learning negatively if the genre of a training game does not interest them. Thus, we designed our own game, *Homeworld Bound,* to systematically analyze the elationship between spatial skill learning gains, game features, and individual player differences in behavior and demographics.

The Game

Homeworld Bound is an adventure and construction game designed to teach two types of spatial skills to children: *mental rotation* and *spatial perception* (see sidebar). The research literature demonstrates that not only do these two subskills predict future success in STEM fields [13], but are also the two subskills with the largest gender gap [3]. Thus, we focus our efforts on designing features that train mental rotation and spatial perception with our game.

The premise of the game is that the player has crash-landed on an alien planet and must scavenge parts from the game world with which to rebuild their spaceship. The player must switch repeatedly between two game modes: Exploration Mode, where the player navigates the game world searching for parts (Figure 1), and Construction Mode, where the player builds items using the parts they have already found (Figure 2). Each game mode is designed to train one of the two spatial subskills we are targeting. Exploration Mode is designed to train spatial perception, while Construction Mode is designed to train mental rotation.

Modular, separable levels in both modes allow me to isolate and test the theory-driven game features I have developed to train mental rotation and spatial perception. Exploration Mode is a series of navigational tasks based on egocentric (relative to oneself) and allocentric (relative to external objects) navigation. Examples of levels are shown in Figures 3 and 4. In

Figure 3: Egocentric navigation in the *Canyon* level. The player uses nearby small landmarks to orient themselves when making turns along different paths through a narrow canyon.

Figure 4: Allocentric navigation in the *Highlands* level. The player orients themselves relative to a large, distant landmark visible from anywhere in the level.

Construction Mode (Figure 5), the player builds useful items by placing different parts in the 3D environment, selecting which parts to attach together, and rotating them until they are lined up properly to attach.

Research Questions

RQ1: What specific game features contribute to a video game's effectiveness at training children's spatial skills?

RQ2: How is game effectiveness influenced by individual player differences such as gender, age, video game experience, and strategy?

Research Plan

The overall structure of this project is an iteration cycle. I first test and analyze subjects' spatial skill gains after playing *Homeworld Bound*. Then, I revise the game to emphasize more effective features and introduce adaptive gameplay to address any demographic or individual learning differences I observe. This test-design cycle will continue until the end products of this project are achieved: a set of game features effective at training spatial skills, and a complete game which can be used to train children's spatial skills so they can succeed in STEM disciplines.

Preliminary Results

We launched our first controlled study at a local elementary school with 23 students. Each student took a pre- and post-test of spatial skills and was assigned to play either Homeworld Bound or a control game, *Little Alchemy,* for 3 hours over 2 weeks. Students who played *Homeworld Bound* improved on spatial perception, but this was only marginally significant. When broken down by gender, only boys improved.

To investigate potential causes of the gender difference, we launched two follow-up studies. The first was a correlational study associating players' demographics (age, gender, prior game experience) and in-game behavior with pretest scores, with 20 children. We found that boys' scores were correlated with better performance on some of the harder Construction and Exploration Mode levels, while the association was much less substantial for girls. This provided tentative evidence that game features related to both object rotation (Construction Mode) and navigation (Exploration Mode) in *Homeworld Bound* were tapping into players' spatial skills, and harder tasks exercised players' spatial skills more.

Post-study surveys indicated that girls did not find the game less enjoyable than boys. Therefore, a likely cause of the observed gender differences may have been the spatial skills test's lack of sensitivity for those with lower spatial ability (girls). Alternatively, girls' playing strategies may have been different because they reported less familiarity with similar games like Minecraft and Roblox.

To investigate both hypotheses, and to determine whether the correlations observed between pretest scores and in-game behavior translated to actual learning gains, we launched a second study with the same structure as our first one, but with an easier version of our spatial skills test to increase test sensitivity. I have just finished this study; data analysis will focus on possible gender disparity, as well as individual disparity, in learning gains and behavior.

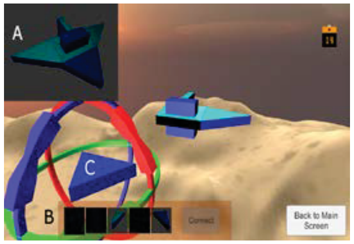

Figure 5: Construction Mode. The player builds the item shown in the image (A) in a series of steps. First, the player chooses parts to add from the bottom menu (B). Then, the player selects two faces to attach and rotates the part they have added (C) along all three axes until the two faces are lined up. If the correct two faces are selected and aligned properly, the player can attach them.

Future Directions

In future work, I hope to explore two main directions: how players' emotional response to the game affects in-game learning, and how intelligent game features can address individual or demographic learning differences. Since emotional events are remembered more easily [6] and commercial video games focus more on emotional experiences than cognitive training games like Lumosity, provoking player emotion may increase learning effectiveness. I plan to test this hypothesis by adding emotional, character-driven in-game interactions to *Homeworld Bound*. And depending on what individual or gender differences I discover in my latest study, I also plan to add intelligent game features that alter the game (branching storylines or side quests, for example) or provide hints based on players' in-game behavior or demographics.

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References

1. Kühn, Simone, et al. "Playing Super Mario induces structural brain plasticity: gray matter changes resulting from training with a commercial video game." *Molecular psychiatry* 19.2 (2014): 265-271.
2. Levine, Susan C., et al. "Early sex differences in spatial skill." *Developmental psychology* 35.4 (1999): 940.
3. Linn, Marcia C., and Anne C. Petersen. "Emergence and characterization of sex differences in spatial ability: A meta-analysis." *Child development* (1985): 1479-1498.
4. McClarty, Katie Larsen, et al. "A literature review of gaming in education." *Gaming in education* (2012).
5. Prawat, R.S. and R.E. Floden, *Philosophical perspectives on constructivist views of learning.* Educational Psychologist, 1994. **29**(1): p. 37-48.
6. Richter-Levin, G. and I. Akirav, *Emotional tagging of memory formation—in the search for neural mechanisms.* Brain Research Reviews, 2003. **43**(3): p. 247-256.
7. Rosen, Y. and G. Salomon, *The Differential Learning Achievements of Constructivist Technology-Intensive Learning Environments as Compared with Traditional Ones: A Meta-Analysis.* Journal of Educational Computing Research, 2007. **36**: p. 1-14.
8. Sanders, D. and D.S. Welk, *Strategies to scaffold student learning: Applying Vygotsky's zone of proximal development.* Nurse Educator, 2005. **30**(5): p. 203-207.
9. Schell, J., *The Art of Game Design: A book of lenses*. 2014: CRC Press.
10. Shea, Daniel L., David Lubinski, and Camilla P. Benbow. "Importance of assessing spatial ability in intellectually talented young adolescents: A 20-year longitudinal study." *Journal of Educational Psychology* 93.3 (2001): 604.
11. Shute, Valerie J., Matthew Ventura, and Fengfeng Ke. "The power of play: The effects of Portal 2 and Lumosity on cognitive and noncognitive skills." *Computers & Education* 80 (2015): 58-67.
12. Uttal, David H., et al. "The malleability of spatial skills: a meta-analysis of training studies." *Psychological bulletin* 139.2 (2013): 352.
13. Wai, Jonathan, David Lubinski, and Camilla P. Benbow. "Spatial ability for STEM domains: aligning over 50 years of cumulative psychological knowledge solidifies its importance." Journal of Educational Psychology 101.4 (2009): 817.