Crafting Spatial Skills: The Use of a Minecraft-Based Intervention to Aid in the Development of Elementary Learners' Spatial Ability

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Abstract: This investigation was conducted to empirically measure how intentional spatial reasoning training using the Minecraft (Mojang, 2016) virtual 3D building system might improve the spatial intelligence of elementary students. The ability to make spatial judgment and visualize has been shown to be a strong indicator of students' future achievement in STEM-related courses. Further, research has also shown that relatively short training exercises can close the spatial reasoning gap between males and females. Therefore, the intent of this investigation is to determine if inclusion of the Minecraft-based design challenges that target specific spatial skills differentially influence learners' spatial abilities compared to less targeted game play. Data collection and analysis will focus on which design challenges most positively influence spatial skills, and how learning varies by gender. Data collection is currently underway and findings will be shared in the full proceedings.

Introduction

The U.S. has historically produced the world's top scientists and engineers, which has led to technological innovations that have been the primary driver of our economy. STEM innovations are responsible for over half of the economic growth in the U.S. over the past 50 years and have led to safer working conditions and increased wages for the entire workforce (Casey, 2012). The demand for the STEM workforce is expected to increase by 20% over the next decade making it one of the largest growth sectors in the U.S. Data from the U.S. Bureau of Labor and Statistics (BLS, 2014) project that occupations related to STEM will increase by 1 million jobs within the next decade (Vilorio, 2014). Therefore, we must ask how we maintain our technological leadership and train an expansive workforce by building STEM capacity, while increasing the quantity of workers with STEM related skills. Compounding the need for a thriving STEM workforce in the U.S. is today's global economy in which emerging countries are investing heavily in STEM education (NSB, 2012). This is creating an increasingly competitive environment for U.S. businesses.

A large body of research indicates that spatial ability is critical to success in STEM fields, and can predict success in STEM-related college courses (Sorby, Casey, Veurink, & Dulaney,2014; Sorby 2000). Further, a gap exists between boys' and girls' spatial abilities and skill development. Even when their academic grades are similar (Wang & Degol, 2013), spatial visualization skills are less developed in middle school girls than in boys (Ben-Chaim, Lappan, Houang, 1988; Maeda & Yoon, 2013; Sorby, 2009). Spatial ability varies greatly across contexts and learners (Hsi, Linn & Bell, 1997). As research has shown that girls routinely perform lower than boys (Hill, Corbett, & St. Rose, 2010; Hsi, et al., 1997; Hungwe, Sorby, Molzon, Charlesworth & Wang 2014; Maeda & Yoon, 2013, McGee, 1979), some researchers have investigated whether these differences are biological or environmental (Ben-Chaim et al., 1988; Newcombe, 2010), finding that these gender gaps can be remediated, even with abbreviated interventions (Hill et al., 2010; Hsi et al., 1997; Sorby, 2009).

A number of educational interventions and instructional strategies have been used to successfully improve visual spatial skills in students from middle school to college age (Ben-Chaim et al., 1988; Hungwe et al., 2014; Sorby & Baartmans, 2000). One type of intervention that holds particular promise are video games (Wouters, van Nimwegen, van Oostendorp, & van der Spek, 2013). Researchers have shown that playing digital games, especially first-person shooter-style games, can significantly impact students' spatial skills (Clark, Tanner-Smith & Killingsworth, 2016; Green & Bavelier, 2003 and 2007; Martin-Dorta et al., 2014; Nguyen & Rank, 2016; Sorby, 2009). Clark et al. (2016) theorized that this was due to the benefit of playing in an anthropomorphic, first person, environment, and that this syntonic perspective affects a variety of social, perceptual and cognitive tasks (Clark et al., 2016). Little research has been conducted on the visual-spatial impact of other first-person games, like Minecraft, which engages players in positioning and moving blocks to create structures (Mojang, 2016). Minecraft also leverages collaborative game play. Collaborative play has been found to be generally more effective than individual play, with single-player competitive games being the least effective for learning gains (Clark et al., 2016; Wouters et al., 2013). Indeed, competitive play has been shown to increase the cognitive load on students, causing them to learn content less effectively (Nebel, Schneider, and Rey, 2015). Minecraft can be an openly collaborative game (Niemeyer & Gerber, 2015), with some versions, like MinecraftEdu, allowing the teacher to contain the collaboration to the classroom (Mojang, 2016). Our intervention will be designed for collaborative play.

Strengthening students' spatial intelligence can help develop confidence and content-specific self-efficacy. Since self-efficacy is one of the strongest indicators of motivation and performance, intervening early may have a significant impact on building STEM confidence among pre-adolescent students. Each design challenge will be appropriately scaffolded so that learners are provided, in a pedagogically sound manner, the instruction needed to support growth in each targeted spatial skill and increase self-efficacy.

Theoretical Framework: Spatial Ability

We have couched our investigation in the theoretical and empirical research relevant to spatial ability. Educational psychologists argue that spatial ability plays a central role in learning and creativity (Ganley, Vasilyeva, & Dulaney, 2014; Kell, Lubinski, Benbow & Steiger, 2013; Gardner, 1983, 1999, 2011; Tzuriel & Egozi, 2010). Widespread agreement exists that a developed spatial ability is a core component of intellectual ability (Thurstone, 1938), as well as a precondition needed for learning (Maeda & Yoon, 2012). Despite agreement on the critical nature of spatial ability, there are a broad range of operationalized definitions for spatial thinking. Some suggest that spatial ability is "the ability to generate, retain, retrieve and transform well-structured visual images" (Lohman 1996, p. 112); others argue that it is a diverse set of skills that involve generating and manipulating mental representations of objects (Ganley, Vasilyeva, & Dulaney, 2014; Kahle, 1983; Miller & Bertoline, 1991). Further complicating the dialogue about spatial ability are the diverse terms used to describe it. Whereas some researchers use terms like spatial ability and spatial skills (Sorby, 1999, 2000; Lohman, 1996), others use spatial visualization (Kahle, 1983; Linn & Peterson, 1985), and others spatial intelligence (Gardner, 1983, 1999, 2011). For our project, and because of common usage, we use the term spatial skills to frame our work. According to Sorby (1999), spatial abilities are what we are born with; they are innate. Skills, on the other hand, are things that can be learned. We hypothesize that our Minecraft-based intervention will improve spatial skills such as rotation and mental cutting. Although many theories exist for how adolescents develop spatial skills, researchers have found that sketching 3-dimensional objects, like the type of activities that engage a 3D environment like Minecraft, substantially assist development of spatial skills (McKim, 1980; Sorby & Baartmans, 1996; Sorby & Gorska, 1998; Field, 1994; Bowers & Evans, 1990).

Research Questions

Although a variety of designs exist for building K-12 learners' spatial skills, one approach lacking substantial current research is that of using the Minecraft virtual 3D building system to develop those abilities. Therefore, this investigation was conducted to empirically measure how intentional spatial reasoning training using the Minecraft virtual 3D building system improves spatial intelligence of elementary learners. The ability to make spatial judgment and visualize has been shown to be a strong indicator of middle school students' future achievement in STEM-related courses. Spatial intelligence has also been shown to be one of the only areas in which females perform worse than males, with noticeable differences emerging in the middle school years. This spatial reasoning gap can potentially reinforce stereotypes about gender roles in certain male dominated fields such as engineering and computer science, thus exacerbating the lack of gender diversity in the STEM workforce. However, research has also shown that relatively short training exercises can close the spatial reasoning gap between males and females. As such, a portable, technology-based spatial training system that can be easily deployed in middle school can have a considerable impact in improving STEM achievement of all learners, but especially of female students.

Therefore, the intent of this investigation is to determine if inclusion of the Minecraft-based design challenges that target specific spatial skills differentially influence learners' spatial abilities compared to less targeted game play. In addition, data collection and analysis will focus on which design challenges most positively influence spatial skills, and how learning varies by gender. The researchers will use the following two research questions to guide the inquiry: Does a Minecraft-based intervention that targets specific spatial reasoning tasks improve elementary learners' spatial ability?

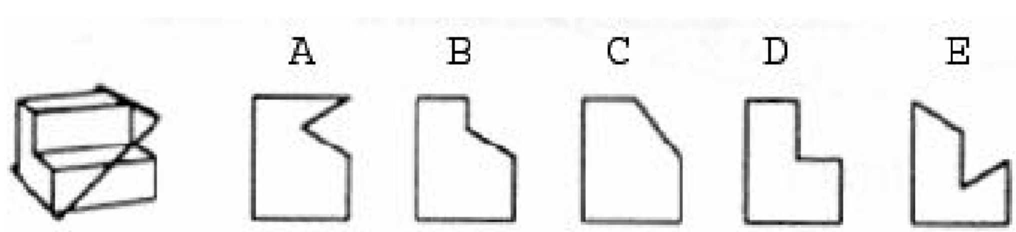
The Study

In the Fall of 2016 and early Spring of 2017, a land grant university located in the Northern Rocky Mountain region partnered with a local school to deliver a spatial-skills focused and Minecraft-based intervention to upper elementary learners. Upper elementary students were selected as the target learners for several key reasons. First, research indicates that middle school serves as a critical junction in students' STEM interests, especially in girls (Girl Scouts Research Institute, 2012; UMass Donahue Institute, 2011). Therefore, a spatial skills intervention designed for learners as they prepare to exit elementary school and enter middle school could leverage the development of the spatial skills and help grow interest and efficacy in STEM. Research also suggests that it is critical students become interested in STEM before they enter high school so they will then enroll in courses that will prepare them for STEM majors and careers. Secondly, research indicates that middle school is where the gap in spatial abilities tends to emerge in boys versus girls, with spatial skills typically less developed in middle school girls than they are in middle school boys (Ben-Chaim, Lappan, Houang, 1988; Maeda & Yoon, 2013; Sorby, 2009). And finally, the extent of valid and reliable instruments for measuring spatial skills in K-12 learners tends to be most appropriate for elementary age learners. By using upper elementary students as our target population, the most appropriate instruments will be available for measuring spatial skills growth.

Minecraft and Spatial Skills Intervention Overview

Participants will engage in a series of design challenges that each include an explicit task that addresses a design problem a STEM professional in that career might face in their day to day work. Each task will be designed to address a specific spatial skill. Each module will be tightly aligned to NGSS standards, cross-cutting concepts, and practices. Modules include: 1) Molecule Art Park, which will highlight careers in chemical engineering, and address the spatial skill of rotation; 2) Build A Bridge, which will highlight careers in civil engineering, and address the spatial skill of mental slicing; 3) Eclipses, which will highlight careers in astronomy, and address the 2D to 3D transformation spatial skill; and 4) Crash Reconstruction, which will highlight careers in physics, and address the spatial skill of perspective taking. Specific descriptions of one example design challenge follow in Table 1, including a Minecraft example.

Table 1. Examples of the Challenges, Possible Minecraft Designs, and Spatial Skills Instrument Items

Example Module - Build a Bridge (Spatial Skill: Mental Slicing)	
STEM Career: Civil Engineer	**Spatial Skill: Mental Slicing**
Civil engineers design solutions for everyday life. They design roads, buildings, bridges, and airports. Your challenge is to build a bridge over the gorge you see in front of you. Notice that one side of the gorge is rough rock, the other side is smooth. Make sure the bridge will be big enough and strong enough to carry many vehicles at once. Once you have built your bridge, create a sculpture of what the bridge would look like if you sliced it down the middle. People going over the bridge will be able to see this, and they will feel safer knowing your cross sectional design process.	
NGSS Alignment - *DCI: Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions. SP: Define a design problem that can be solved through the development of an object, tool, process, or system and includes multiple criteria and constraints, including scientific knowledge that may limit possible solutions. CC: All human activity draws on natural resources and has both short and long term consequences, positive as well as negative, for the health of people and the natural environment.*	
Minecraft Examples	
	
Sample Item from the Mental Cutting Test (MCT) (College Entrance Examination Board [CEEB], 1939)	
	

Minecraft was selected as the primary environment for intervention delivery for several key reasons. First, we intend to capitalize on the explosive interest in Minecraft around the globe, including new efforts to make Minecraft readily available, and safer, for classroom use (Thompson, 2016). Minecraft provides a learning platform that has a high probability for continued broad-scale development and use. Second, Minecraft allows us to align with new directions in recent gaming research in which focus has shifted to using non-action games, like Minecraft, can improve cognitive abilities such as spatial skills (Nguyen & Rank, 2016). Third, we intend to leverage the capacity for Minecraft to readily combine multiple modalities, including video, into a transmedia curriculum. And lastly, research suggests that 3D-based games like Minecraft can significantly influence learners' development of spatial skills (Sorby, 2009).

Methodology

For this investigation, learners (n = 60) from four different third and fourth grade classrooms will engage in a series of spatial skills interventions. Learners will be randomly assigned to either the control or treatment group, stratified by gender, whose experience will differ only in the actual Minecraft challenges they are given. For the treatment group, Minecraft challenges will target the four specific spatial skills outlined in Table 2. The control group will receive similar, but less spatially-complex tasks, not targeted at a specific spatial skill. For example, the treatment group might be tasked with building a sliced section of a bridge over a gorge. Conversely, the control group might be tasked with building just the bridge over the gap. Students will then complete a design challenge within the Minecraft learning environment relevant to that particular spatial skill. A pretest/posttest experimental design will be used to assess the effect of the treatment on both spatial skills and STEM interest. For each task, an instrument measuring the targeted spatial skill will be administered to learners both before and after the task to assess change in that particular spatial skill, as well as the STEM Semantics Survey to assess change in interest in STEM. Because changes in spatial skills can be detected even after brief interventions, a post-test immediately following the intervention should be sufficient to confirm any gains in spatial skills. Table 2 provides an overview of the spatial skills and STEM interest measurements that will be used.

Table 2. Instruments to use in Pre/Post capacity & Corresponding Skill/Construct Measured

Instrument	**Spatial Skill**
Purdue Spatial Visualization Tests: Visualization of Rotations (Maeda & Yoon, 2013**)**	Rotation
Mental Cutting Test (MCT) (College Entrance Examination Board [CEEB], 1939)	Mental Slicing
Perspective Taking Test for Children (Frick, Möhring, & Newcombe, 2014)	Perspective Taking
Diagrammatic Representation Test (Frick, A., & Newcombe, N. S., in press)	2d to 3d
STEM Semantics Survey (Tyler-Wood, Knezek, & Christensen, 2010)	STEM interest

Data will be entered and cleaned for analysis, and the entire research team will collaborate in data analysis. Specifically, data will be analyzed using analysis of covariance (ANCOVA) methods to test for significant differences between treatment groups on changes in spatial skills and STEM interest. Using pretest scores as a covariate, ANCOVA will allow us to determine the difference in post-test scores by treatment group controlling for pre-test scores, as well as whether pre-test scores differ significantly from post-test scores. ANCOVA methods are appropriate for testing differences between experimental groups on a continuous dependent variable where a single covariate has been identified to be controlled for, and random assignment has mitigated other confounding variables (Agresti & Finlay, 2009). Effect sizes will be calculated using Cohen's d for the ANCOVA to estimate the magnitude of the treatment effect. Unlike significance tests (e.g. T-tests), these indices are independent of sample size, and can be used to confirm the significant differences due to an overly strong observed effect of the Minecraft-based spatial skills intervention.

Preliminary Findings

Data collection is currently underway and findings will be shared in the full proceedings.

Preliminary Conclusions

Once data have been collected and analyzed, interpretation, conclusions, limitations, and implications for research and practice will be shared in the full proceedings.

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