Exploring the Development of Spatial Skills in a Video Game

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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[7,10]. In addition, gender differences in spatial ability begin to emerge in early childhood[2]. Fortunately, research has found that spatial skills are malleable and transfer to different tasks [9].

I therefore focus on training students' spatial skills at an early age, before gender differences become a barrier to success in STEM for girls.

My approach utilizes educational video games to produce better learning gains than traditional instructional methods. Educational video games combine three popular learning principles: constructivist theory, which advocates learning by doing, learner-centered education, which emphasizes the diverse needs of individual learners, and scaffolding theory, which recommends progressive difficulty levels in learning. Certain video games, such as Super Mario and Tetris, are effective at training spatial skills in children[1], with the added benefit of increasing motivation and engagement as well[6].

However, not all videogames are effective at training spatial skills, and we do not know why. 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 [8]!

Project Goals

The goal of this project is to systematically determine which features of a video game contribute to spatial skill development in children. Off-the-shelf games like Lumosity and Portal 2 offer little control over specific game features. Thus, I will develop a video game from the ground up as part of an iterative design process whereby the game is repeatedly tested for spatial skill learning gains and then refined to enhance features that shown to be effective. The end product of my project will be a set of game features known to promote spatial skills and a complete game incorporating these skills which can be used to train children in the spatial skills needed to be successful in STEM majors and careers.

The Game

The game being used for this project, *Homeworld Bound,* is still under development, but several hours' worth of gameplay have already been completed by myself and a team of 7 other students. The game is a combination of an open world exploration game and a 3D construction game and is designed to teach two specific types of spatial reasoning skills identified in the research literature: *mental rotation* (imagining how objects would look after being rotated in a certain direction) and *spatial perception* (imagining how objects would look when viewed from a certain perspective) [3].

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, and Construction Mode, where the player builds items using the parts they have already found (Figure 1).

Increasingly difficult scenarios in both modes allow us to test the theory-driven game features we have developed. Exploration Mode consists of a series of navigational puzzles – mazes, bridges triggered by switches, cliff jumping, path memorization, and clue decoding. In Construction Mode, the player builds 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.

Project Plan

To determine how well *Homeworld Bound* is training spatial skills, I plan to launch a series of controlled

studies. During each study, children recruited from local elementary schools play the entire game, a certain subset of the game, or a control game for several hours. Pretests and post-tests of spatial skills using the Revised Purdue Spatial Relations Test: Rotations (PSVT:R) [11] and Guay's Visualization of Views Test [5] will be used to assess learning gains between conditions to determine what combinations of game features are most effective at training spatial skills.

Player behavior data from each mode will be used to make the game adaptive for each player. Data collected for Exploration Mode could include: routes taken, frequency of backtracking, and how their strategy evolves over time, while data collected for Construction Mode might include the sequence of part attachment, number of rotations per attachment attempt, and the number of failed attachment attempts.

We can compare the behaviors of high spatial skill and low spatial skill players to detect which gameplay strategies might be more or less effective for players with low spatial skills. Using machine learning algorithms, we can then teach our game to predict learning outcomes depending on players' past actions and strategies. I can then implement intelligent in-game assistance to guide players toward actions and strategies more likely to promote better learning outcomes.

After each study, I will revise the game to emphasize the effective game features and eliminate the ineffective ones.

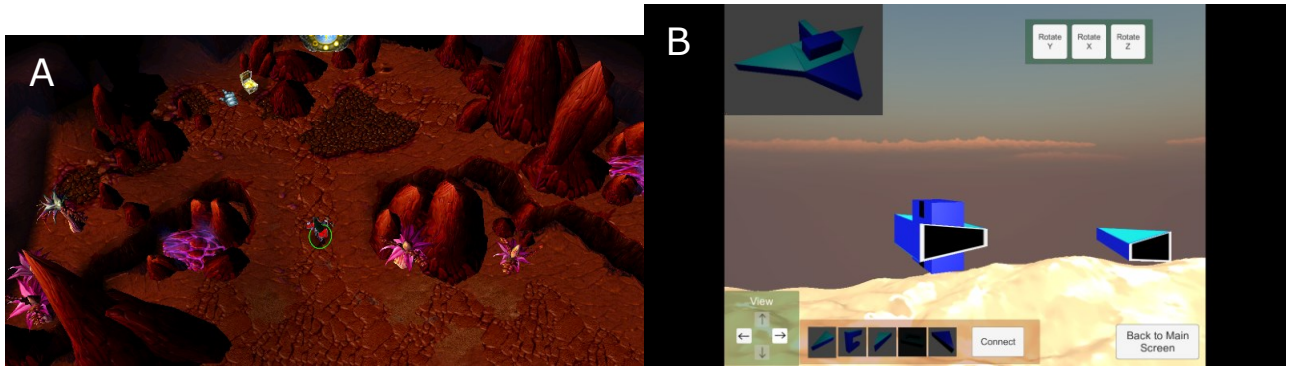

Figure 1: Screenshots of the two modes of the *Homeworld Bound* game. The player searches the game world for parts in Exploration Mode (A) and then transitions to Construction Mode (B) to build items using the parts they have collected.

Progress

My team conducted a pilot study of the game in October 2015 to fix bugs and enhance the gameplay experience. A total of 16 students at a local elementary school played the game for 1.5 hours while my proctoring assistants and I observed. We gained

several key insights into how to improve the game before launching our first controlled study and implemented them.

The following November, we launched our first controlled study at a different elementary school recruiting a total of 23 students. Each student took a pretest and post-test of spatial skills using the PSVT:R and Visualization of Views Test and was assigned to play either *Homeworld Bound* or a control game, *Little Alchemy* [4]. We are currently in the process of analyzing the results.

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