STEM education is immensely important to the future of our country; the Department of Labor reports that of the 20 fastest growing jobs in the nation, 15 require significant STEM education[1]. We are unprepared; a 2012 assessment of 15 year olds’ academic progress in 34 countries by the Organization for Economic Co-operation and Development (OECD) found that the United States ranked below average in math (27th) and science (20th). Even worse, this performance has not changed over the past few years, despite the fact that the United States spends more money per student than most other countries[2]. And the lack of women in STEM fields is still a problem[3]. I propose a new approach that harnesses the educational power of video games to teach students the skills they need to succeed in STEM careers.

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[5,6]. In addition, gender differences in spatial ability begin to emerge in early childhood[7]. Fortunately, research has found that spatial skills are malleable and transfer to different tasks [8]. 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. Video games also increase motivation and engagement[9] and can be played outside of school as a leisure activity, freeing up the school day for more activities. Certain commercial games, such as Super Mario and Tetris, have been shown to improve spatial skills in children [10].

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 in players. On the other hand, one of the most well-known brain-training games, Lumosity, was developed by neuroscientists to improve a variety of cognitive skills in players, but this game has been shown to have no effect on any of these cognitive skills [11]! Another problem is that most studies on training spatial skills with video games focus on adults, not children. My research addresses both problems by answering the question: What design features in a videogame contribute to the development of spatial reasoning skills in children?

Previous research in spatial skill training using video games has used only closed-source, commercial games that cannot be easily modified to isolate and test specific features. Thus, I have developed my own game over the course of 9 months by myself and my team of 6 undergraduate programmers and visual designers. The premise of the game is that the player is stranded on an alien planet after their spaceship crash lands. The player must explore the planet to find the missing parts of their rocket and rebuild it. The 2 central mechanics of the game, construction and exploration, are built around 2 major components of spatial reasoning: spatial perception (orienting oneself relative to nearby objects) and mental rotation (imagining how objects look as they move through space) [12]. I incorporate spatial perception in the game with open world exploration. The player navigates an environment looking for parts while receiving clues about where each part is. The clues require players to keep track of where they have been already, where they are relative to landmarks, and what direction they are facing. I incorporate mental rotation in the game’s construction aspect. Once they collect the necessary parts, players construct pieces of their rocket by moving, rotating, and connecting parts in 3D similar to LEGO construction. The process requires the player to use mental rotation to plan their construction.
The structure of my game allows it to be separated into two modes: Construction and Exploration. Each mode can also be broken down into levels. I will take advantage of this separability to isolate specific game elements and test their ability to train spatial skills relative to a “control” game that does not include spatial elements. I have already conducted two pilot studies of the game: one at the Indianapolis Children's Museum and a second, more extensive study at Barkstall Elementary School. My plan for future studies is divided into three phases.

Phase I analyzes the effect of my entire game - both Construction and Exploration mode together - on spatial skills. I will run studies in November and December at two local elementary schools, King Elementary and University Primary, analyzing the effect of my game relative to the control on spatial skills after a few hours of gameplay. I measure spatial skill gains by giving participants a pretest and post-test of spatial skills. I use the Revised Purdue Spatial Visualizations Test for Rotation to measure mental rotation skills and Guay's Visualization of Views Test to measure spatial perception skills. Phase II, during Spring and Fall 2016, will similarly compare the two modes, Exploration and Construction. Phase III in Spring 2017 will compare specific levels within each mode. By the time I write my dissertation, I will have a list of specific video game features that are effective at training spatial skills in players and an open-source game that I will provide to other researchers and educators around the world for free as a testbed for future spatial reasoning training studies.

To help me realize my goals for this project, I have a wide net of support on campus. I have already recruited 6 undergraduates for game development and 2 Education graduate students to assist with study proctoring. In addition, I will have the guidance of Professors Wai-Tat Fu (Computer Science), Chad Lane (Educational Psychology), and Frances Wang (Psychology), who have experience in spatial reasoning research and educational games research with children. The College of Education is also supportive of this endeavor; my project received seed funding from the Illinois Learning Sciences Design Initiative (ILSDI) in September.

**Intellectual Merit**

My proposed research is novel in that it will provide specific, actionable insights about how to design video games that are effective at training spatial skills for children. I have completed a pilot study already and will be completing Phase I this semester, and I have a team of 8 undergraduates and graduate students helping me develop the game and proctor my research studies. Several professors spanning the disciplines of computer science, education, and psychology, are available to mentor me throughout this project. I have a clear plan of action and have already demonstrated my ability to follow through with preliminary studies.

**Broader Impacts**

My proposed project will have a transformative impact on society. The results of my research will help children, especially girls, succeed in STEM early on, before the gender gap in spatial skills and STEM majors emerges. I will be paving the way for the next generation to reduce the gender gap in STEM and succeed in a wide variety of STEM disciplines that are critical for our competitiveness in today’s global economy.

References