Can Playing Portal Affect Spatial Thinking and Increase Learning in a STEM Area?

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Abstract

Spatial skills have been associated with learning in STEM areas and some research has shown that playing video games could facilitate the development of spatial skills. This study examines whether playing a game that uses a realistic physics engine and places spatial demands on the players could facilitate learning a subsequent physics lesson. Fifty-eight participants viewed a brief lesson on Newton's laws of motion after either playing the puzzle game *Tetris* or the first-person perspective puzzle game *Portal*, which incorporates aspects of physics such as momentum. The groups did not differ on subsequent tests of learning outcomes involving physics, but the *Portal* group scored significantly higher on a perspective taking test (d = 0.57). This study shows that playing a commercial game that incorporates Newtonian physics does not prepare students to learn physics but does improve an important spatial cognition skill related to physics.

Keywords: video games; physics learning; spatial orientation

Objectives

The goal of this study is to examine whether playing an off-the-shelf first-person perspective puzzle game based on physics principles (i.e., *Portal*) can help prepare students to learn physics concepts and improve their spatial skills as measured by the perspective taking task. In the present study, students studied a brief lesson on Newton's laws of motion after spending an hour playing *Portal* or the puzzle game *Tetris*. Examining the effects of playing an off-the shelf computer game can be called *cognitive consequences* research and constitutes one of three major experimental methodologies for game research (Mayer, 2011). In short, the goal is to determine the cognitive consequences of playing *Portal* on (a) improving a spatial skill that is related to learning in physics and (b) enabling students to learn physics concepts on a subsequent physics lesson.

Learning Physics and Video Games

Learning physics can often be difficult because many learners already have misconceptions about how the physical world works. White (1993) argued that one of the problems with physics education is the top-down approach in which abstract formulas are taught first, which students later have trouble applying to every-day phenomenon. Instead White (1993) argued that physics should be taught using an approach in which students are presented with concrete versions of these models in the form of computer simulations. While the real world can be overly complex with multiple forces acting simultaneously, a simulation can control for these factors and allow for students to make predictions, then test them, and to try to explain the results. White (1993) used a group of microworlds called "ThinkerTools" with 6th graders. The curriculum was developed so that the initial microworlds had simple situations (no friction and only one dimension of motion) so that learners could develop intuitive knowledge before dealing with more sophisticated causal relationships. White (1993) found that, compared to high school students who were taught using traditional methods, 6th graders who received the "ThinkerTools" curriculum performed better on simple force and motion problems, better retained what they learned, and transferred what they learned to new contexts.

Similar to White's (1993) computer simulation, some off-the-shelf video games have been developed to depict realistic movement based on Newtonian physics and provide simplified environments to make game play easier. In a study by Masson, Bub, and Lalonde (2011) participants completed 6 one-hour game training sessions playing the video game *Enigmo* or the control game *Railroad Tycoon 3.* During *Enigmo* the player must alter the trajectories of falling droplets so that the drops land in target receptacles. The authors proposed that the *Enigmo* group would benefit from game play because the game gives repeated exposure to the movement of falling objects and this may benefit students by priming them to learn from formal physics instruction. The pretest/posttest consisted of a test of knowledge about the motion of objects with 15 items involving objects moving freely through space based on physics. Participants in the *Enigmo* group increased their ability to produce realistic trajectories but only in terms of the general parabolic shapes of those trajectories. After the posttest, participants then completed a PowerPoint tutorial on physics after which they completed 13 test problems based on the tutorial. Masson et al. (2011) found that students in the *Enigmo* group did not show a higher improvement after viewing the tutorial compared to the *Railroad Tycoon 3* group.

Masson et al. (2011) were not able to show that experience playing a game that uses realistic physics motion prepares students to benefit from direct instruction in physics, but video games may benefit science learning through improvements in visuospatial ability. Previous research has shown that playing video games such as first-person shooters (Feng, Spence, & Pratt, 2007), and spatial puzzle games (Okagaki & Frensch,1994; Subrahmanyam &,

Greenfield,1994; Terlecki et al., 2008) can increase different spatial cognition skills, such as mental rotation. Work by Kozhevnikov and colleagues has shown a relationship between spatial ability and physics problem solving (Kozhevnikov, Hegarty and Mayer, 2002; Kozhevnikov, Motes, and Hegarty, 2007). When looking at a factor analysis of spatial ability tests and different types of kinematic problems, Kozhevnikov, Hegarty, and Mayer (2002) found that spatial ability loaded on the same factor as problems which involved determining an object's trajectory based on combining two motion vectors and using a different frame of reference to determine the characteristics of an object's motion. In an additional study in which participants were classified as being either high or low spatial, students classified as having high spatial ability were: (1) more successful at integrating several motion parameters versus only considering one at a time; (2) could interpret a object's motion based on kinematic graphs versus seeing the graphs as picture-like representations; and (3) understood the connection between different representations of spatial problems versus using multiple uncoordinated representations of the same problem (Kozhevnikov et al. 2007). Kozhevnikov et al.'s (2007) results with eye movements also suggest that high spatials actually visualize the movement of objects based on integrating motion components while low spatial individuals do not. Thus, there is evidence that certain spatial skills are related to success in STEM subjects.

Sanchez (2012) showed that playing games can also have a benefit on learning in science areas through priming these visuospatial abilities. Participants either played 25 minutes of the first-person shooter game, *Halo: Combat Evolved* or the word anagram game *Word Whomp* before reading a lesson on plate tectonics. Participants did not significantly differ on prior knowledge in the subject area or spatial skills, as measured by the first section of both the card rotation task and the paper folding task. After playing the game participants then read a complex text about plate tectonics. They then completed an essay task in which they were asked to write a causal essay about "What caused Mt. St. Helens to erupt?" After the essay task they completed the second part of both the card rotations task and the paper-folding task. The results found that playing the action video game had a significant positive effect on essay quality and rotation task performance. Sanchez (2012) proposed that the first-person shooter game requires visuospatial skills that are important for learning in some science areas. The present study parallels Sanchez's methodology, but explores the domain of physics learning.

Current Study

In the fall of 2011, the game company Valve introduced an educational program called Learn With Portals, which proposed using their games *Portal* and *Portal 2* to help teach students critical-thinking skills and physics (http://www.learnwithportals.com/). The games, depicted in Figure 1, incorporate elements of physics, such as momentum, into a problem solving game. *Portal* is intended to benefit physics learning because it applies realistic physics principles into the game experience, therefore allowing the player to build experience with physics concepts in a controlled environment.

It is unclear whether *Portal* has any effect on spatial cognition skills similar to previous research with first-person shooters and *Tetris*. If *Portal* does facilitate cognitive ability development it could help students learn physics similar to Sanchez's (2012) work with plate tectonics. Playing *Portal* requires the participant to imagine what a room may look like from a different perspective. Placing the portals in order to solve the puzzles within the game may therefore require the use of the spatial skill known as spatial orientation or the ability to visualize what a different perspective may look like from another location (Hegarty & Waller, 2004). Kozhevnikov, Hegarty, and Mayer (2002) found that performance on a spatial orientation test correlated with performance on a kinematics questionnaire, which included items from the physics test known as the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992). In this study, *Tetris* is used as the control condition because although *Tetris* has been found to increase performance on mental rotation under certain training regimes (Okagaki & Frensch,1994; Terlecki et al., 2008), Kozhevnikov et al. (2002) showed that mental rotation was not associated with kinematic problem solving.

Therefore, the objective of this experiment is to: (1) determine whether playing *Portal* can increase performance on a spatial cognition task; (2) determine whether an hour's worth of playing *Portal* versus *Tetris* can increase learning from a subsequent lesson on physics; (3) determine whether there is a relationship between spatial cognition skills and performance on physics problem solving.

Participants and Design Participants were 63 (39 male, 24 female) students from the University of California, Santa Barbara. Ages ranged from 17-23 years old with a mean age of 19.03 (*SD* = 1.28). Participants received class credit for their participation. Thirty-four participants served in the *Portal* group and 29 served in the *Tetris* group.

Materials The pre-game paper-based materials consisted of a participant questionnaire and pretest. The participant questionnaire contained basic demographic items concerning the participant's gender, year in school, age, and also asked participants to rate their spatial cognition ability (i.e. being able to visualize objects or imagine rotating items) on a 5-point scale ranging from "Very Poor" to "Very Good". Participants were also asked how many hours they played video games, excluding card games and text based games, during a typical week ranging from "I do not play video games" to "More than 10 hours per week". Participants were also asked whether they had played *Portal* or *Tetris* before. To examine prior knowledge, participants were asked to indicate whether they had previously taken physics courses during high school or college, or if they were in the process of taking a physics course.

The pretest asked participants to try to recall Newton's three laws of motion. Participants could receive a total of 6 points on this section, 2 points for each law if all of the elements were correct. For example, for the 1^{st} Law, the Law of Inertia, participants had to state both that a body in motion will stay in motion while a body at rest will stay at rest and that the object's state will not change unless acted upon by an external force. Excluding either the "at rest" or "in motion" element would result in the student only receiving one point for the 1^{st} law. The pretest also included 4 multiple-choice questions dealing with naïve physics. The first two were the cliff problem and the ball problem from McCloskey (1983). The cliff problem asks the learner to determine what path a person will take if they run at a constant rate of speed off the edge of a cliff. The correct answer to this problem is based on the 1^{st} law of motion, while some of the incorrect options are consistent with impetus theory or the idea that objects contain force that runs out. The ball problem asks the learner to determine where a heavy ball will land if you dropped the ball while running forward at a constant speed. The last two questions came from White's (1993) testing materials and asked participants about two balls falling from different heights. This question was used to examine the participant's understanding of gravity. Students received one point for each correct answer in this section. Overall, the pretest scores could range from 0 to 10.

The control game used for this study was the puzzle game *Tetris.* During *Tetris* the player must make lines of blocks using 6 different block shapes. Every time a line is completed the line disappears from the rectangular play area and the player receives points. The more lines that are completed at once, or the larger the combo, the higher the points the player receives. The player can press a button on the keyboard to rotate the blocks in increments of 90 degrees in order to best fit them into the available spots at the bottom. The block shapes fall from the top of the play area at a constant rate and as players gather more points the falling rate increases therefore increasing the level difficulty of the game. In the marathon mode version of the game, play continues until the player fills the rectangular play area with incomplete lines.

Figure 1: Sample screen shot from *Portal* game play. Chamber 13.

The target game used in this study was *Portal* (2007), a first-person perspective puzzle game. The narrative of the game is that you are a test subject named Chell that has woken up in a facility in which you must navigate through testing chambers using portals. The player is given advice and feedback from a computer named GLaDOS who promises cake upon the completion of the testing regimen. During the game the player acquires the use of a portal gun, which shoots two portals, a blue and an orange one, which are linked to the left and right mouse buttons respectively. The two portals can be fired on specific surfaces during the game and can link those two locations so that when you enter one portal you will exit the other. The game sometimes requires the participant to make use of momentum so that the player can traverse large horizontal distances. To do this a player can place one portal at the bottom of a pit and another on a vertical wall so that falling into the portal at the bottom of the pit will increase their momentum using gravity and they will exit the opposite portal with enough speed to travel horizontally over pits and other obstacles (Chamber 10 of the game requires this solution). Solutions become progressively harder as the chambers continue requiring the use of more and more portals. There are a total of 19 levels/chambers in the game. In this experiment, participants started on the 10^{th} chamber of the game since it is the first one that deals with momentum to solve the puzzle. The chamber also starts with GLaDOS explaining momentum, in which she states that portals do not affect forward momentum. She also informs the player that momentum is a function of mass and velocity. Participants were encouraged to get as far through the chambers as possible until the hour of game play was over.

The physics lesson consisted of an 18-slide presentation on Newton's three laws of motion and the law of conservation of momentum. The presentation also addressed the incorrect impetus theory and how it is a common misconception in physics. The lesson included the basic rules along with examples for each of the laws such as a canon recoiling after firing a cannonball for Newton's 3^{rd} law or "for every action this is an equal and opposite reaction."

There were four paper-based posttests: a retention test, a shorten, adapted version of the Force Concept Inventory (FCI) (Hestenes, Wells, & Swackhamer, 1992; Hestenes & Halloun, 1995), a *Portal* based scenario test, and a spatial orientation test. The retention test asked the participant to recall the three laws of motion. This question was used to determine whether there were basic recall differences between the two groups. Once again, students could receive a total of 6 points for this section, 2 points for each law with all of the components correctly defined.

The adapted version of the FCI consisted of 24 multiple-choice items. Only items dealing with the first three laws were included since the short physics lesson only dealt with these topics. This test was chosen because many of the items deal with the movement of objects and often includes items that could be answered incorrectly based on impetus theory instead of using Newtonian physics. The learner must apply what he or she knows about the three laws and momentum in order to select the correct answer. For example, one item asks participants to imagine that a bowling ball had been dropped out of the cargo bay of an airliner traveling horizontally and the participant must pick the correct path that the ball will fall from the plane to the ground below. There was only one correct answer for each item with a total of 24 possible points.

The scenario test contained two questions about scenarios taken straight from the *Portal* game and asked participants to determine whether the law of conversation of momentum had been violated. In one example, the direction of the individual changes (from traveling vertically to horizontally) while in the other the direction is kept constant (vertical to vertical). Participants are asked to justify their answers and must have the correct explanation to receive full marks on the two items with one point for correctly selecting whether the law had been violated or not and one point for justifying their reason, for example, explaining how momentum is a vector (speed and direction). The total score could range from 0 to 4.

To determine whether playing *Portal* affected the spatial skill known as spatial orientation, Hegarty and Waller's (2004) Perspective Taking/Spatial Orientation Test was used. During this task participants are given an array of 7objects including a house, a cat, a tree, etc. For each question, participants are asked to imagine that they are standing at one object facing the direction of another. They are then asked to "point" to the direction of a third object. To respond, below the picture array, participants are given a circle in which the first direction (i.e. cat facing the flower) is given and they must then draw a line indicating which direction the third object is relative to the other two. Participants are given 5 minutes to complete as many items as possible with a total of 12 possible items. Hegarty and Waller (2004) showed that the spatial ability known as spatial orientation is highly correlated with mental rotation but there is a disassociation between the two, suggesting two separate abilities.

Apparatus Both games were run on Dell computers with 17 inch color monitors, with ATI Radeon HD 2600 XT video cards. The lesson was also administered using the computers. All the testing materials, including the spatial orientation task, were given using paper and pencil.

Procedure Participants were randomly assigned to groups and tested in individual cubicles. Upon entering the lab participants were seated at separate computer cubicles. Participants were first asked to fill out the participant questionnaire sheet and the pretest, at their own pace. Participants were then informed that they were going to play their respective game for an hour followed by a lesson on physics, a posttest, and the spatial orientation task. Each cubicle also had instructions for how to play the participant's particular game. Participants in the *Tetris* condition played on "marathon" mode in which the game becomes progressively harder as the player acquires points. For *Tetris* the experimenters recorded the scores and level reached for each of the completed games. At the end of the hour, the *Portal* group had their game progress saved, which was later accessed by the experimenter to determine how many chambers the participant had completed.

Next, the physics lesson was initiated on the participant's computer. Participants were told that they had a minimum of 8 minutes to review the physics lesson and could have more time if they wished. Upon completing the lesson the participants were given a packet including the retention test, FCI items, and the *Portal* scenario questions and told that they had as much time as they wanted to answer the questions. After turning in the packet, participants were then given the spatial orientation test. They had 5 minutes to complete as many items as possible.

Results

For the analysis, only participants who were actively engaged during game play were included. The reasoning behind this decision is that only active participants who had *Portal* full exposure to all the elements within the game were of interest. Therefore participants were excluded from the analysis if they did not get past Chamber 11 while playing *Portal* or if they did not get beyond level 5 in *Tetris.* Using these criteria, 4 Portal participants and 2 Tetris participants were removed from the analysis, leaving 30 participants in the Portal group and 28 in the Tetris group.

The two groups did not differ significantly in the proportion of males and females, $X^2(1, N = 58) = .009$, $p = .92$, the proportion of individuals who were familiar with the game *Portal*, $X^2(1, N = 58) = 1.62$, $p = .20$, and the proportion of individuals who were familiar with the game *Tetris*, $X^2(1, N = 58) = .283$, $p = .595$. The participants also did not differ on their self-ratings of spatial cognition ability, $t(56) = -.431$, $p = .67$, and reported hours of video game playing, $t(56) = .037$, $p = .97$. There was no significant difference on pretest performance, $t(56) = -1.15$, $p = .26$, or prior knowledge with physics, $t(56) = .82$, $p = .42$.

Does playing *Portal* improve students' spatial cognition? The perspective taking task was scored so that any item in which the participant was within 15 degrees of the correct angle was scored as correct and awarded 1 point while anything beyond 15 degrees and items that were not attempted were not awarded any points. Participants in the *Portal* condition significantly outperformed participants in the *Tetris* condition on the spatial orientation test, $t(55) = -2.12$, $p = .04$, $d = 0.57$. This is the major new positive finding in the study.

Table 1: Means and standard deviations for all posttest measures.

	Group			
	Portal	Tetris		
Measure	*M (SD)*	*M (SD)*	*p*	*d*
Retention	5.27 (1.44)	5.39 (1.06)	0.71	-0.09
FCI	13.07 (5.37)	12.75 (4.45)	0.81	0.06
Portal Scenerio	1.77 (1.50)	1.39 (1.42)	0.34	0.26
Spatial Orientation	7.07 (3.03)	5.52 (2.41)	0.04	0.57

Importantly, there was a significant positive correlation between performance on the adpated FCI (which measures physics intuitive knowledge) and performance on the spatial orientation test, $r(57) = .323$, $p = .014$. This finding suggests that spatial cognition skills such as spatial orientation may be related to success in physics learning.

Does playing *Portal* help students learn physics? Table 1 shows the means (and standard deviations) of the two groups on each of the four tests. There were no significant differences on recall of the three laws of motion in the retention test, $t(56) = .378$, $p = .71$; applying what they had learned to answer the FCI items, $t(56) = -.242$, $p = .81$; or answering questions involving conservation of momentum through portals on the scenario test, $t(56) = -.972$, $p = .34$. Therefore, there was no evidence that playing *Portal* facilitated learning about the laws of motion.

Discussion

On the negative side, playing *Portal* did not improve learning of physics content, paralleling the results of Masson et al.'s (2011) research with *Enigmo*. On the positive side, playing the first-person perspective puzzle game *Portal* for an hour resulted in higher performance on an important spatial cognition skill (i.e., spatial orientation) compared to playing the 2D puzzle game *Tetris*. In addition the results showed a significant correlation between performance on a measure of spatial cognition (i.e., the spatial orientation test) and a measure of physics knowledge (i.e., the adapted FCI), paralleling the results from Kozhevnikov et al. (2002) showing a connection between spatial skills and success in STEM learning.

This study provides evidence that spatial orientation is a learnable skill. Games such as *Portal*, which require participants to imagine taking different viewpoints, may facilitate the development of this skill. In contrast, a game like *Tetris* which can utilize mental rotation under certain circumstances, does not tax spatial orientation therefore causing no improvement. Overall, the results support the idea that training of spatial skills is domain specific, such that different kinds of computer games can promote different kinds of spatial skills rather than improving spatial cognition in general.

These findings support the idea that if educators want students to improve in spatial orientation skill, they can benefit from playing a first-person perspective puzzle game like *Portal*. Improving in this skill appears to be related to STEM learning, so in order to help students that might be struggling in areas such as physics, perhaps developing their spatial orientation skills could facilitate learning. Educational physics games could incorporate both direct instruction and spatial components to increase learning.

Limitations and Future Directions

One limitation for this study is the lack of a pretest measure for spatial orientation. None of the pretest or demographic measures showed any significant differences between the two testing groups; therefore random assignment should have balanced spatial ability between the two groups. The spatial orientation task only has one form with 12 items and dividing the task into 2 sections may have weakened the power of the measure. In the future, a second version of this test with an alternative array of objects could be used a pretest to determine spatial orientation ability before game play.

Although playing the off the shelf version of *Portal* for a brief period of time did not benefit students when learning physics, perhaps playing either for longer or playing chambers created to teach specific principles would result in higher learning gains. Our study found that there was a significant benefit on spatial orientation scores for playing *Portal* as well as a significant correlation between performance on the spatial orientation task and performance on the modified FCI. Perhaps with further game play participants could increase their spatial skills, therefore facilitating learning physics problems dealing with motion. Previous research with video games has shown that different cognitive skills can be improved by playing games (Green and Bavelier, 2003). While *Tetris* can improve mental rotation under some circumstances but not others (Terlecki, et al., 2008, Sims and Mayer, 2002) it is important to consider what skills are improved by a particular game and what skills are associated with success in a particular STEM area. For example, Sanchez (2012) found improvements in mental rotation and learning about plate tectonics from playing a first-person shooter but no improvement in the paper-folding task. Spatial orientation has been found to correlate with performance on kinematic tasks, therefore a game which trains these skills could help participants with solving these problems.

In addition, the game company Valve has released a tool in which players can create their own testing chambers with the *Portal 2* game software. Similar to White's (1993) highly controlled simulations, if the *Portal 2* software could be used to create lessons in which students build up prior knowledge through playing the game, then perhaps physics learning could be improved. One issue with *Portal* is that participants view the game from the first-person perspective so they are unable to see the falling trajectories of their game avatar caused by differences in momentum. Therefore, misconceptions about how objects fall can not be correctly addressed. By creating special testing chambers, other objects could be used to show how physics behaves in a controlled environment. Further research must be done to determine under what circumstances a lesson using the *Portal* game environment could facilitate learning and the development of spatial skills.

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