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Evaluating the Cognitive Consequences of Playing *Portal* for a Short Duration

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Abstract

Learning physics often requires overcoming common misconceptions based on naïve interpretations of observations in the everyday world. One proposed way to help learners build appropriate physics intuitions is to expose them to computer simulations in which motion is based on Newtonian principles. In addition, playing video games that require spatial processing may also facilitate the development of spatial skills that have been associated with learning in science, technology, engineering, and mathematics areas. Two studies were conducted to examine whether playing the first-person perspective puzzle game *Portal* causes improvements in physics intuitions and spatial cognition skills. In Experiment 1, college students played *Portal*, the two-dimensional puzzle game *Tetris*, or the anagram game *TextTwist* for 75 minutes. There were no significant differences on measures of naïve physics reasoning (selected from the Force Concept Inventory) or measures of spatial cognition (mental rotation and perspective taking). To determine whether *Portal* could influence formal physics learning, in Experiment 2 participants viewed a brief lesson on Newton's laws of motion after playing one of the three games for 1 hour. The groups did not differ on subsequent tests of physics learning. This study shows that *Portal* was not successful in priming intuitions about motion or spatial abilities related to physics learning.

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Objectives

The goal of the present set of studies is to examine whether playing an off-the-shelf puzzle game based on physics principles (i.e., *Portal*) can help players improve spatial skills required in physics, develop appropriate physics intuitions, and prepare them to learn physics concepts. *Portal* is a first-person perspective, three-dimensional puzzle game in which the player must escape testing chambers by connecting areas of space by using two portals created by a portal gun. A screenshot of a testing chamber can be found in Figure 1. The first study examines whether playing *Portal* can improve spatial skills associated with success in kinematic problem solving as well as naïve reasoning about physics. The second study explores whether playing *Portal* can prepare students for learning a formal lesson on Newton's three laws of motion. Research examining the effects of playing an off-the-shelf computer game has been called *cognitive consequences* research and constitutes one of three major experimental methodologies for game research (Mayer, 2011, 2014). In short, the goal is to determine the cognitive consequences of playing *Portal* on (a) improving spatial skills related to learning in a STEM (science, technology, engineering, and mathematics) area, (b) developing physics intuitions about force and motion, and (c) learning physics concepts from a physics lesson.

Learning Physics With Simulations and Games

Learning physics can often be difficult because many learners already have misconceptions about how the physical world works. Mistakes are often made in relation to the incorrect theory of impetus, which is the belief that a moving object contains force and once this force dissipates the object will stop moving (McCloskey, 1983). This is in direct contrast to the first law of Newtonian physics, which states that a body in motion will stay in motion until acted upon by an external force. McCloskey, Washburn, and Felch (1983) found that even participants who had completed a course in physics would choose incorrect answers based on impetus theory. Teaching physics, therefore, often requires learners to go through a process of conceptual change in which they must recognize an anomaly between their own model and what they have observed, construct a new model that can account for what has been observed, and then use the new model to discover the correct solution (Mayer, 2008).

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

A way to encourage conceptual change is through predict–observe–explain methods in which the student makes predictions, observes the results, and then tries to explain what happened. However, Chinn and Malhotra (2002) show that often what is observed can be biased by preexisting incorrect intuitions. For example, when observing a heavy and a light rock being dropped at the same time, students who predict that the heavy rock will land first are more likely to perceive the heavy rock landing first although the two should fall at the same rate. In addition, students often have issues applying abstract formulas to everyday phenomena (White, 1993). One problem is that the real world can be overly complex with multiple forces acting simultaneously. However, simulations can be used as concrete models that can control for multiple factors and allow for students to make predictions, test them, and then try to explain the results.

To help teach the concepts of force and motion, White (1993) used a group of microworlds called "ThinkerTools" with sixth 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 with high school students taught using traditional methods, sixth 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.

White (1993) showed that a computer simulation could facilitate learning physics because of the controlled environment, but a related issue is whether a commercial video game could be used to help modify naïve intuitions about object motion. Some off-the-shelf video games have been developed to depict realistic movement based on Newtonian physics. In a study by Masson, Bub, and Lalonde (2011) participants completed six 1-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 they 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 and posttest asked students 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 completed a PowerPoint tutorial on physics after which they completed 13 tests problems based on the tutorial. Masson et al. (2011) found that students in the *Enigmo* group did not improve significantly more after viewing the tutorial compared with the *Railroad Tycoon 3* group.

Masson et al. (2011) did not show that experience with a game that uses realistic physics motion prepares students to benefit from direct instruction in physics; however, 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, Newcombe, & Little, 2008) can increase spatial cognition skills such as mental rotation. Work by Kozhevnikov and coworkers has shown a relationship between spatial ability and physics problem solving (Kozhevnikov, Hegarty, & Mayer, 2002; Kozhevnikov, Motes, & Hegarty, 2007). A factor analysis conducted by Kozhevnikov et al. (2002) examining spatial ability tests and different types of kinematic problems found that spatial ability loaded on the same factor as two types of physics problems: 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 (a) more successful at integrating several motion parameters versus only considering one at a time, (b) able to interpret an object's motion based on kinematic graphs versus seeing the graphs as picture-like representations, and (c) able to understand 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) eye-tracking results also suggest that high spatial individuals actually visualize the movement of object by integrating motion components while low spatial individuals do not. Thus, there is evidence that certain spatial skills are related to success in STEM subjects.

Spatial Ability and STEM Learning

Sanchez (2012) showed that playing games can facilitate learning in science areas by priming visuospatial abilities such as mental rotation and visualization (as measured by the card rotation task and paper-folding task, respectively). After completing pretest measures of both spatial tasks, participants either played 25 minutes of the first-person shooter game, *Halo:Combat Evolved* or the word creation game *Word Whomp* before reading a lesson on plate tectonics. Participants did not significantly differ on prior knowledge in the subject area or pretest spatial skills. After playing the game, participants read a complex text about plate tectonics. They then wrote 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 showed 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 Case for Portal

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

Although they did not examine physics learning, Shute, Ventura, and Ke (2015) examined whether playing *Portal 2* for 8 hours could improve performance on cognitive skills as measured by composite measures for tasks dealing with problem solving (three measures), spatial cognition (three measures), and persistence (two measures) compared with the brain training game *Lumosity*. *Portal 2* participants showed significant improvements compared with the *Lumosity* participants for all three constructs. Teasing apart their spatial ability construct to look at performance changes across the three tasks, participants in the *Portal 2* training condition showed significant improvements on the Vandenberg and Kuse (1978) mental rotation task and a virtual spatial navigation task (Ventura, Shute, Wright, & Zhao, 2013). The participants, however, did not show significant improvements on the perspective taking task used to measure the spatial skill known as spatial orientation (Hegarty & Waller, 2004). Their results suggest that *Portal 2* may be a viable training method to increase spatial ability and therefore may facilitate learning in STEM areas that are related to spatial reasoning skills.

The previous research suggests that simulations can help learners understand physics concepts by controlling for all of the factors the learner must attend to; however, it is unclear if a commercial video game can be used similarly to encourage accurate thinking about physics thinking. In addition, some games have been linked to aspects of spatial ability which, in turn, are often linked with learning in STEM areas. No research to date has shown that playing an off-the-shelf video game can facilitate formal physics learning. Shute et al. (2015)'s work does suggest a connection between spatial skills and *Portal*; therefore, the present study examines whether playing *Portal* can facilitate learning about physics and spatial thinking.

Present Study

Similar to Sanchez's (2012) work with the game *Halo: Combat Evolved*, the present set of studies examines whether *Portal* could be used to prime spatial skills associated with physics learning. During *Portal*, the player must connect areas of space using two portals (orange and blue) created by a portal gun such that by entering one portal you will exit through the other regardless of how far away they are or one direction they are facing. Thus, playing *Portal* requires the participant to imagine what a room looks like from a different perspective. Placing the portals in order to solve puzzles within the game may, therefore, require the use of the spatial skill known as spatial orientation, or the ability to visualize what a spatial layout would look like from another perspective (Hegarty & Waller, 2004). Kozhevnikov et al. (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).While Shute et al. (2015) did not find a significant increase in performance on the spatial orientation task from playing 8 hours of *Portal 2* this may have been due to using an abbreviated version of the spatial orientation task which may not have included enough observations in order to detect a smaller effect. For their version of the task, the 12 items were divided into two sets of six for the pretest and the posttest. In addition, while the original task gives participants 5 minutes to complete as many of the 12 items as possible, Shute et al. (2015) gave their participants 3 minutes per item. Hegarty and Waller (2005) have argued that speed of processing can be important for teasing apart differences in spatial ability especially when dealing with simpler spatial relation tests. It is unclear whether the perspective taking task may have shown differences if students were given a shorter time limit in which to respond and if there were more items. To administer a complete 12-item test before and after game play, a second set of perspective taking items was developed for the current study.

The purpose of the first experiment is to examine whether a short exposure to playing *Portal* can increase spatial skills associated with physics problems solving as well as physics problems. While many video game training studies use longer durations ranging from 4 to 50 hours (Adams & Mayer, 2014), the present study focuses more on short-term benefits rather than extensive training for spatial ability. Recently Boot, Blakely, and Simons (2011) critiqued research in the field of cognitive consequences for not using active control groups or using control games that participants may not expect to cause increases in the desired measures. Therefore, both the two-dimensional (2D) puzzle game *Tetris* and the anagram game *TextTwist* were chosen as control conditions. *Tetris* has been found to increase performance on mental rotation under certain training regimens (Okagaki & Frensch, 1994; Terlecki et al., 2008) as well as closely mirroring the demands of 2D mental rotation tasks. Although Kozhevnikov et al. (2002) showed that mental rotation was not associated with kinematic problem solving (while spatial orientation was), Shute et al.'s (2015) work suggests that *Portal 2* may be effective at increasing mental rotation skills. Therefore, in addition to looking at spatial orientation with the perspective taking task, the first experiment also examines whether a short exposure to either *Tetris* or *Portal* can increase performance on a 2D mental rotation task.

Experiment 1

The goal of Experiment 1 is to determine whether short-term playing of *Portal* helps students improve spatial cognition skills and physics intuitions better than playing non-physics-related computer games.

Participants and Design

The participants were 112 (64 male, 48 female) undergraduate students from the University of California, Santa Barbara Psychological and Brain Sciences's subject pool. Ages ranged from 17 to 22 years of age with a mean age of 19.00 years ($SD = .13$). In a between-subjects design, 52 participants were assigned to the *Portal* condition, 28 participants were assigned to the *Tetris* condition, and 32 were assigned to the *TextTwist* condition.

To assure that participants were actively engaged during game play, any player that did not reach certain performance benchmarks was removed from the analysis. For *Portal*, it was important that players be exposed to all of the pertinent game elements such as using the portal gun to travel between the areas of the test chamber. To be included in the analysis, *Portal* players had to complete Chamber 12, which is the first level in which players have full use of both portals and have to solve problems involving gravity and momentum. Twelve *Portal* participants were excluded due to not completing Chamber 12, and two players were excluded for not getting beyond Level 5 in *Tetris*. No *TextTwist* participants were eliminated. In addition, eight participants (one *Portal*, three *Tetris*, and four *TextTwist*) were removed from the analysis due to scoring above or below 2.5 *SD* on one or more of the spatial tasks (pre or postgame). As a result, 39 participants remained in the *Portal* group, 23 remained in the *Tetris* groups, and 28 remained in the *TextTwist* group.

Materials

Questionnaire. The questionnaire asked for basic demographic information (e.g., gender, age), self-assessed spatial cognition skills, videogame experience, and physics experience to make sure these factors were balanced across the three game conditions. Time spent playing video games was assessed by the item "How much time per week do you typically play video games (excluding card games like Solitaire, Minesweeper and text games)?" with five response options: *I do not play video games*; *Less than 1 hour per week*; *1 to 5 hours per week*; *5 to 10 hours per week*, and *More than 10 hours per week*. Three items asked participants if they had played *Portal* or *Portal 2*, *Tetris*, or *TextTwist* before with the options *Yes* or *No*. Prior experience with physics was measured with a 3-item checklist that read "Please place a check mark next to the items that apply to you: ___I took a physics class in high school; ___ I took/am currently taking a physics class in college; ___ I know Newton's Three Laws of Motion."

Games. The target game used in this study was *Portal* (2007), a first-person perspective puzzle game. The narrative of the game involves the player taking on the role of a test subject, named Chell, who has woken up in a facility in which she 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 gun that 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, linking 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 they can traverse large horizontal distances. For example, a player can place the blue portal at the bottom of a pit and the orange portal on a vertical wall so that falling into the portal at the bottom of the pit will increase their momentum and they will exit the orange portal with enough speed to travel a certain horizontal distance (e.g., 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 test chambers (i.e., levels) in the game. In this experiment, participants were started on the 1st chamber of the game to get used to the game mechanics and then advanced to the 10th chamber since it is the first one that deals with momentum to solve the puzzle. The chamber also starts with GLaDOS discussing momentum in which she says that portals do not affect forward momentum giving the quote, "Speedy thing goes in, speedy thing comes out." 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 75 minutes of game play were up. *Portal* was chosen over *Portal 2* for this experiment due to the shorter play time and simpler game demands. *Portal* deals predominately with learning how to use the portal gun while *Portal 2* incorporates additional elements such as gels that can decrease friction.

The spatial control game used for this study was the puzzle game *Tetris*. During *Tetris*, the player must make lines of blocks using seven 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 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° 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. 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.

The nonspatial control game used for this study was *TextTwist*. During the game, participants are given six or seven letters such as "T, N, D, I, E, U." During the game, the player gains points by making words with a minimum of three letters (e.g., nut, diet) and receive more points for longer words or for finding words which use all of the available letters (e.g., united). Players are given a total of 2 minutes and 30 seconds to find as many words as possible and must find a word that uses all the letters in order to continue to the next round. This game was chosen because we wanted to have a control group that was active in a game environment while not engaged in an activity that required spatial thinking.

Spatial cognition tests. Hegarty and Waller's (2004) perspective taking or spatial orientation test was used to determine whether playing *Portal* affected the spatial cognition skill of perspective taking. During the task, participants are given an array of objects such as a house, a cat, a tree, and so forth. 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 the third object. Below the array, participants are given a circle in which the first direction (e.g., cat facing the flower) is given and they must then draw a line indicating the direction of the third object. Participants are given 5 minutes to complete as many items as possible with a total of 12 possible items. For this experiment, the task was scored by looking at the average angular deviation from the correct response measured from the shortest distance either clockwise or counterclockwise. In addition, in order to account for strategy differences such as participants taking more time to attempt fewer items, a 90° error was added for each item that was not attempted. Hegarty and Waller (2004) showed that this task measures the spatial ability known as spatial orientation. While spatial orientation is highly correlated with mental rotation, there is a disassociation between the two suggesting they are two separate abilities.

To develop the second array of objects, used for the pretest, the original array of objects was flipped along the vertical axis and all of the objects were replaced with objects of the same general size and shape. The order of the items was also reversed. Figure 2 includes sample problems given during the instructions for the task across the two versions.

The card rotation test was a 2D mental rotation test from Educational Testing Services (Ekstrom, French, & Harmon, 1976). A target 2D figure was

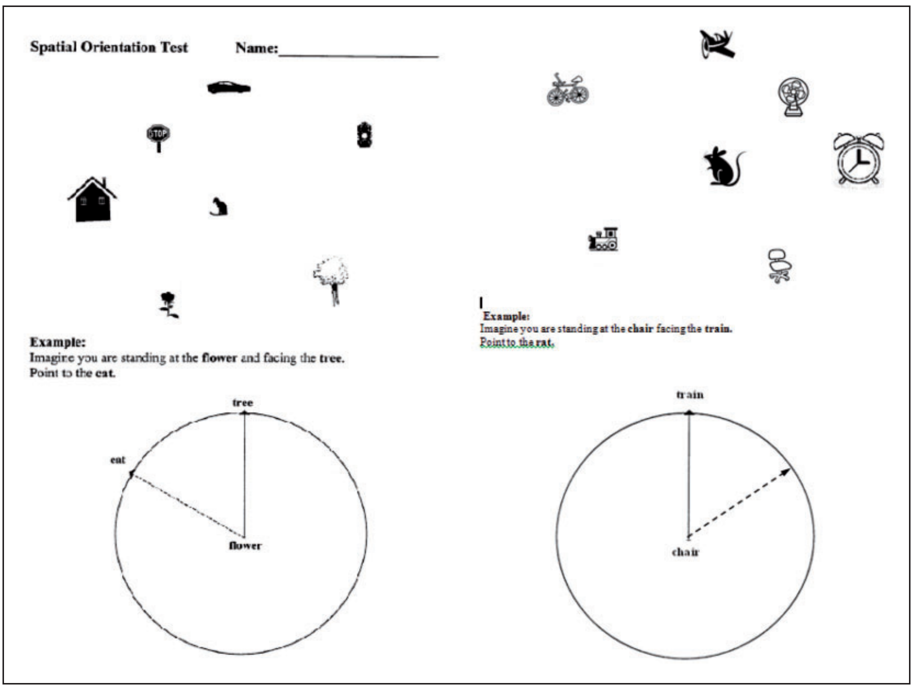

Figure 2. Sample item from the instructions for the spatial orientation test (Hegarty & Waller, 2004). The instructions for the original can be found on the left while the instructions for the new version can be found on the right.

displayed on the left side of each row of the test, followed by eight test figures. Participants were asked to determine which figures were rotated versions of the target figure and which were mirror-reversed rotated versions. The pretest was preceded by an instruction sheet that told participants to indicate “S” for “same” if a test figure could be rotated to match the target figure, and “D” for “different” if the test figure could not be rotated to match the target figure. The instruction sheet also included two practice rows and told participants that their final score would be the total correct minus the total incorrect, in order to discourage guessing. The pretest and posttest versions of the card rotation test each included 10 rows, for a total of 80 same or different judgments for different figures per test. Participants were given 3 minutes on each test to make as many judgments as they could.

Physics testing materials. To test naïve reasoning about motion, a subset of 123 items from the FCI (Hestenes & Halloun, 1995; Hestenes et al., 1992) was used. These items focus on the movement of objects in relation to Newton’s three laws of motion. For example, students were asked to imagine what path a cannon ball would take if it was fired off the side of the cliff or what path a hockey puck would take if it was already moving to the right and received a kick forward. In addition, 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 which is used to solve some of the problems during *Portal*. Participants were awarded one point for each item for a total of 12 possible points.

Apparatus. All games were run on Dell computers containing ATI Radeon HD 2600 XT video cards with 17-in. color monitors, and all the testing materials, including the perspective taking task, were given using paper and pencil.

Procedure. The experiment took place in a laboratory with up to five participants per session, with each participant seated in a separate cubicle. Participants were randomly assigned to a condition by session and received class credit for participating in the experiment.[1] Participants were asked to sign a consent form and fill out the demographic questionnaire upon arriving at the lab. After completing the questionnaire, participants were given instructions for the pretest perspective taking test. For the perspective taking task, they were given 5 minutes to complete as many of the 12 items as possible. Participants were then given the instruction sheet for the card rotation test, including approximately 30 seconds to work on the sample questions on the sheet. They were then given 3 minutes to complete as many items as possible. Participants were then told what game they would be playing and were given an instruction sheet for that game. Participants in the *Portal* condition started at the beginning of the game for 15 minutes to help orient them to the game environment and basic movement controls. After 15 minutes, *Portal* players were advanced to Level 10 and given another 60 minutes to play. This chamber was chosen as a starting point since this is the first testing chamber that deals with momentum and starts with the voice of the computer GLaDOS telling the player that momentum is conserved between portals. For the *Tetris* and *TextTwist* conditions, participants were given 75 minutes of playtime. *Tetris* players had their scores recorded by the experimenter and were told to start a new game when each game ended. Participants in the *TextTwist* condition were told to start new games when the previous game ended (the *TextTwist* system saved their scores automatically).

Upon completing the game play session, participants took the posttest perspective taking test (5 minutes) and card rotation test (3 minutes). Finally, they received the shortened FCI, with no set time limit.

Results and Summary

Are the Groups Equivalent on Basic Characteristics?

To determine whether the groups are equivalent on basic demographic characteristics, analyses of variance (ANOVAs) were conducted on the questionnaire data showing no significant differences among the three groups on time spent playing video games per week, $F(2, 87) = 1.42$, $p = .25$, or physics experience, $F(2, 87) = 2.63$, $p = .08$. A chi-square test showed no significant differences among the groups on proportion of men and women, $\chi^2(N = 90) = 2.59$, $p = .28$, or prior exposure to *Portal*, $\chi^2(N = 90) = 1.02$, $p = .60$, *Tetris*, $\chi^2(N = 90) = 0.28$, $p = .87$, or *TextTwist*, $\chi^2(N = 90) = 0.48$, $p = .79$. Overall, we conclude that the groups were not different on basic characteristics.

Does Playing Portal *Affect Spatial Reasoning?*

Table 1 shows the means and standard deviations for each group on the pregame and postgame perspective taking test and card rotation test. A repeated measures ANOVA looking at performance increases between the pretest and posttest showed a significant main effect of testing time for both the card rotation task, $F(1, 87) = 7.72$, $p = .01$, $\eta^2 = .08$, and the perspective taking task, $F(1, 87) = 8.90$, $p = .004$, $\eta^2 = .09$. There was no significant main effect for condition on either of the tasks. In addition, for the critical game condition $\times$ Testing time interaction, there was no significant interaction for either the card rotations task, $F(2, 87) = .54$, $p = .54$, $\eta^2 = .01$, or perspective taking task, $F(2, 95) = .37$, $p = .70$, $\eta^2 = .01$. Therefore, playing *Portal* did not have a significant effect on either spatial cognition task compared with the control games.

Table 1. Experiment 1: Performance on Pregame and Postgame Tests.

Measure	Game group (*N*)		
	Portal (39) *M* (*SD*)	*Tetris* (23) *M* (*SD*)	*TextTwist* (38) *M* (*SD*)
Pregame perspective taking (angular error)	23.48 (12.95)	24.55 (14.66)	27.36 (15.85)
Postgame perspective taking (angular error)	19.35 (11.34)	18.41 (9.21)	24.48 (15.88)
Pregame card rotation (correct–incorrect)	54.69 (13.35)	53.91 (17.22)	54.68 (12.45)
Postgame card rotation (correct–incorrect)	56.49 (11.68)	58.13 (10.46)	54.68 (12.45)
Force Concept Inventory, 12 item (number correct)	6.82 (2.85)	6.52 (2.73)	5.32 (2.55)

Does Playing Portal *Affect Physics Intuition?*

The bottom row of Table 1 shows the means and standard deviations for the three groups on the 12 items from the FCI. An ANOVA revealed no significant difference among the three gaming groups on FCI score, $F(2, 87) = 2.58$, $p = 0.08$, $\eta^2 = .06$. Playing *Portal* did not have a significant effect on physics intuition compared with a 2D spatial game or the anagram game.

Is Game Achievement Related to Spatial Skills and Physics Intuition?

Despite not causing significant increases in performance for either perspective taking or the card rotations task, Pearson correlations were run in order to determine if performance for either of the spatial games was associated with spatial ability or physics intuitions. *Portal* performance was not significantly correlated with performance on the perspective taking task on either the pretest, $r(40) = -.31$, $p = .06$, or the posttest, $r(39) = -.25$, $p = .12$. Participants who progressed through more testing chambers while playing *Portal* had marginally smaller angular error on the pregame perspective taking task ($p = .06$). *Portal* performance significantly correlated with performance on the shortened FCI, $r(39) = .35$, $p = .03$. For highest *Tetris* score, there were no significant correlations with any of the spatial cognition tasks for either the pretest or the posttest. *TextTwist* performance did not significantly correlate with any of the measures. Interestingly, performance on the FCI only correlated with performance on the perspective taking pretest $r(90) = -.24$, $p = .02$, and not posttest perspective taking scores, $r(90) = -.18$, $p = .10$. This suggests that student who did well when exposed to the new perspective taking task also did well on answering the 12 visually based physics problems. Performance on the FCI also significantly correlated with performance on the posttest for the card rotation task, $r(90) = .23$, $p_= .03$, but not the pretest, $r(90) = .15$, $p = .15$.

Summary

Overall, playing *Portal* did not have a significant effect on perspective taking, mental rotation, or physics intuitions compared with the control games. Thus, this study provides no evidence to support the idea that playing *Portal* over a short period improves spatial skills or physics intuitions related to learning physics. The results did show that performance on the FCI correlated with performance on the perspective taking task.

Experiment 2

The goal of Experiment 2 is to determine whether a short exposure playing *Portal* results in higher learning gains on a subsequent physics lesson compared with groups that play non-physics-related games. In Experiment 1, playing *Portal* did not increase intuitive physics knowledge; however, being exposed to the game environment may prepare students to learn formally from the lesson (similar to White, 1993, and Sanchez, 2012; unlike Masson et al., 2011). While Experiment 1 did not show a significant increase between pretest and posttest for the perspective taking task, the results showed that the perspective taking task was correlated with both higher *Portal* performance as well as performance on the FCI. Sanchez (2012) showed that playing a first-person shooter for only 25 minutes could prime spatial thinking and increase learning from a plate tectonics lesson. Therefore, Experiment 2 examines whether playing *Portal* for 1 hour can help prime students to think spatially when learning from a lesson on physics and Newton's laws of motion.

Method

Participants. Participants were 84 students (56 male, 28 female) from the University of California, Santa Barbara. Ages ranged from 17 to 23 years old with a mean age of 19.17 ($SD = 1.23$). Thirty-four participants served in the *Portal* group, 30 served in the *Tetris* group, and 26 served in the *Word Ruffle* group.

As with Experiment 1, participants were excluded from the analysis if they did not get past Chamber 12 while playing *Portal*, they did not get beyond Level 5 in *Tetris*, or if they scored above or below 2.5 *SD* on any of the measures. Using these criteria, five *Portal* participants, one *Tetris* participant, and two *Word Ruffle* participants were removed from the analysis, leaving 29 participants in the *Portal* group, 29 in the *Tetris* group, and 24 in the *Word Ruffle* group.

Materials

Questionnaire and pretest. The pregame paper-based materials consisted of a participant questionnaire and pretest. The same questionnaire was used as in Experiment 1.

The pretest asked participants to try to recall Newton's three laws of motion. Participants could receive a total of six points on this section, two points for each law if all of the elements were correct. For example for the first 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 first law. The pretest also included four 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 first law of motion while some of the incorrect options are consistent with impetus theory or the idea that there is a force that runs out over time. 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. Students received one point for each correct answer in this section. Overall, the pretest scores could range from 0 to 10.

Games. The same *Portal* and *Tetris* software from Experiment 1 were used in this experiment. *TextTwist* was replaced with *Word Ruffle*, a similar anagram game, due to having longer game rounds: 3 minutes instead of 2.5. *Word Ruffle* operates with the same rules as *TextTwist*, except that the target words in *Word Ruffle* are up to six, seven, or eight letters long.

Lesson. 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 third law or "for every action this is an equal and opposite reaction." The 18-slide lesson was self-paced.

Posttest materials. There were four paper-based posttests: retention test, application test, scenario test, and 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 six points for this section, two points for each law with all of the components correctly defined.

The application test was based on an adapted version of the FCI (Hestenes & Halloun, 1995; Hestenes et al., 1992) and consisted of 24 multiple-choice items. Only items dealing with the first three laws were included since the short lesson only dealt with these topics. This test was chosen because many of the items deal with the movement of objects and often include 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 image 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 follow 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 questions about two 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 or explaining how momentum is a vector (speed and direction). The total score could range from 0 to 4.

The perspective taking test was the original version of the Hegarty and Waller (2004) task used as the posttest version from Experiment 1.

Apparatus and Procedure

All of the apparatuses were the same as those used in Experiment 1.

Participants were randomly assigned to groups and tested in individual cubicles. Participants received class credit for their participation. 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 rate. 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 played their respective game for an hour. Participants in the *Tetris* condition played on "marathon" mode in which the game become progressively harder as the player acquires points. In the *Portal* condition, participants were started on the 10th level or chamber of the game. 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. Participants in the *Word Ruffle* group were told to start a new game whenever they failed to successfully accumulate enough points to progress to the next level (due to the *Word Ruffle* software not automatically collecting scores and the lack of performance issues in Experiment 1, no performance data were collected for participants in the *Word Ruffle* condition).

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, application test, and scenario test 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 perspective taking test. They had 5 minutes to complete as many items as possible.

Results and Summary

Do the Groups Differ on Basic Characteristics?

The three groups did not differ significantly in the proportion of men and women, $\chi^2(2, N=82)=.32$, $p=.85$, the proportion of individuals who were familiar with the game *Portal*, $\chi^2(2, N=82)=2.16$, $p=.34$, and the proportion of individuals who were familiar with the game *Tetris*, $\chi^2(2, N=82)=.03$, $p=.99$. The participants also did not differ on and reported hours of video game playing, $F(2, 79)=.14$, $p=.87$. There was no significant difference on pretest performance, $F(2, 79)=1.29$, $p=.28$, or prior knowledge with physics, $F(2, 79)=.99$, $p=.38$. We conclude that the groups did not differ on basic characteristics. Due to game performance being correlated with performance on the perspective taking task and the FCI, it was also important that the three conditions did not differ in terms of spatial ability. Performance on the perspective taking task was not significantly different among the three condition $F(2, 78)=.02$, $p=.98$, $\eta^2=.001$.[2]

Does Playing Portal Help Students Learn Physics?

Table 2 shows the mean (and standard deviation) of the three groups on each of the four tests. There were no significant differences on recall of the three laws of motion in the retention test, $F(2, 79)=.02$, $p=.98$, $\eta^2=.001$, applying what they learned to answer multiple choice for the application test, $F(2, 79)=.05$, $p=.96$, $\eta^2=.001$; or answering questions involving conservation of momentum through portal on the scenario test, $F(2, 79)=1.07$, $p=.36$, $\eta^2=.03$ Therefore, there was no evidence that playing *Portal* facilitated learning about the laws of motion.

Is Game Achievement Related to Spatial Skills and Physics Intuition?

There were no significant correlations between any of the testing measures and *Portal* game performance. This was true for both the full 24-item test ($p=.33$) and for the same 12 items used in Experiment 1 ($p=.23$). In addition, *Portal* performance did not significantly correlate with performance on the perspective

Table 2. Experiment 2: Performance on Pregame and Postgame Tests.

	Game group (*N*)		
Measure	*Portal* (29) *M* (*SD*)	*Tetris* (29) *M* (*SD*)	*Word Ruffle* (24) *M* (*SD*)
Pregame Newton's laws	2.17 (1.73)	1.72 (1.79)	1.58 (1.56)
Pregame physics intuition	3.14 (1.27)	3.03 (.98)	2.67 (1.09)
Perspective taking (angular error)	20.68 (12.46)	21.27 (9.62)	21.17 (10.44)
Postgame Newton's laws	5.34 (1.40)	5.41 (1.05)	5.37 (1.20)
Force Concept Inventory, 24 item	13.31 (5.29)	13.03 (4.63)	12.87 (6.20)
Portal Application Task	1.83 (1.49)	1.38 (1.40)	1.92 (1.50)

taking task, $r(29) = -.28$, $p = .15$. In addition, there were no significant correlations between *Tetris* game performance and any of the posttest measures or the perspective taking task.

Perspective taking scores significantly correlated with performance on the 24-item FCI, $r(81) = -.28$, $p = .01$. Participants who scored higher on the FCI also had smaller angular errors on the perspective taking task. This was predominately driven by performance on the visually based 12 items used in Experiment 1, $r(81) = -.32$, $p = .004$, while there was no significant correlation with performance on the other 12 items, $r(81) = -.15$, $p = .17$. Looking specifically at the problems related to kinematics, there was a significant correlation between perspective taking average angular error and FCI, $r(82) = -.26$, $p = .02$.

Summary

The results show that playing *Portal* for 1 hour does not prepare students to learn physics from a lesson. The results did show that there were significant correlations between kinematic problem solving and the perspective taking task, similar to results from Kozhevnikov et al. (2002).

General Discussion

Empirical Contributions

Playing *Portal* did not facilitate physics learning either with or without formal instruction. The findings from Experiment 1 contrast with results from Masson et al.'s (2011) first Experiment 1 in which playing *Enigmo* facilitated intuitive learning about the motion of falling objects, specifically problems that closely matched game play. This may have been due to *Portal* not closely matching the knowledge examined in our posttest, although many of the items dealt with the path of falling objects. Unlike Shute et al.'s (2015) long-term training study and some of the research on *Tetris*, neither *Tetris* nor *Portal* caused any short-term benefits for performance on our mental rotation task. Previous research by Nelson and Strachan (2009) showed strategy differences after playing *Portal* on a speed or accuracy task; however, there were no significant differences on either of the spatial tasks between the three game conditions for Experiment 1. Lastly, while Kozhevnikov et al. (2002) found a relationship between kinematics problem solving and perspective taking task, performance on the FCI only significantly correlated with performance on the pretest perspective taking task and not the posttest in Experiment 1.

Experiment 2 showed no significant benefit of playing *Portal* for learning from a lesson on physics and Newton's laws of motion. Unlike Sanchez's (2012) findings using a first-person shooter game and a plate tectonics lesson, *Portal* did not prime the critical spatial skills needed to improve learning from a physics lesson. These results also contrast with White's (1993) finding that experience in a physics-based world helped with later physics learning. These results are in line with Masson et al.'s (2011) finding that experience with a physics game did not help students learn from a lesson about force. In Experiment 2, we found a significant correlation between the perspective taking task and performance on the FCI, paralleling the results from Kozhevnikov et al. (2002). In Experiment 1, the lack of a significant correlation for the perspective taking posttest and the FCI may be due to participants relying on different strategies when faced with the task a second time. The significant correlation in Experiment 1 for the FCI and performance while playing *Portal* may have been due to some shared spatial strategies when encountering new material; however, any shared skills did not result in any improvement on the spatial tasks.

The results from this study suggest that not all games may prime the spatial thinking needed to prepare students to learn from STEM areas that are associated with spatial ability. While the research is still unclear in terms of which games can prime spatial thinking, previous research has shown that in order to prime transfer, the game must tax the same skills that are required for the cognitive task (Adams & Mayer, 2014). This suggests that a short exposure to *Portal* may not tax the same types of spatial skills required when thinking and learning physics. However, the field still lacks an understanding of what length of the exposure or training facilitate different cognitive skills. Therefore, it is unclear how *Portal* may affect physics learning over longer exposures. Shute et al. (2015) did show significant benefits on the Vandenberg and Kuse (1978) mental rotation task and their virtual spatial navigation assessment as well as an insight problem solving task after 8 hours of training. The lack of a significant effect of *Portal* on the perspective taking task in this study as well as Shute et al.'s (2015) lack of significant findings suggests that *Portal* may not tax the same skills required during a spatial orientation task.

Limitations and Future Directions

Previous research with video games has shown that various cognitive skills can be improved by playing games (Green & Bavelier, 2003). While *Tetris* can improve mental rotation under some circumstances but not others (Sims & Mayer, 2002; Terlecki et al., 2008) 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 a paper-folding task. Spatial orientation has been found to correlate with performance on kinematic tasks therefore a game that trains these skills should help participants with solving these problems. It was originally proposed that *Portal* may require the same underlying spatial orientation ability tested in the perspective taking task. However, performance between the two was only marginally related in Experiment 1. In addition to Shute et al.'s (2015) findings, there may be no relationship between the perspective taking task and *Portal*.

Recent commentary from Boot and coworkers (Boot et al., 2011, Boot, Simons, Stothart, & Stutts, 2013) has criticized the field of video game research investigating cognitive consequences, claiming that many of the findings may be placebo effects due to demand characteristics. Participants could believe that they should show improvement on a task because it appears similar to the play demands of the game. While our participants may have believed the they should show improvements on the perspective taking task and physics problem solving for *Portal*, as well as card rotation for *Tetris*, the data from Experiment 1 provided no evidence of any benefit. In addition, Boot et al. (2011, 2013) argue that reasonable comparisons should include games or conditions that are active. We choose to include both *Tetris* and an anagram game specifically to address this issue. While the strongest comparison is to look at a game with no connection to spatial ability (i.e., *Word Ruffle* or *TextTwist*), we also included *Tetris* to have a game that has also been studied with respect to spatial ability.

While *Portal* may not be able to facilitate learning in the short term, longer training regimens using the *Portal* environment may improve physics learning. Our sample size may also have not have been adequate enough to capture any significant differences between the three games after such a short training duration. Our intent was to model our design after Sanchez's (2012) study which only included 30 participants per group and had a training regimen which was half the duration of ours. However, the lack of significant results for our study were most likely not due to a lack of power considering the results from Experiment 1 were not in the predicted direction of *Portal* outperforming the other two game conditions.

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 cannot be correctly addressed. By creating special testing chambers for other objects, students could see how physics works in a control 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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Notes

1. Initially participants in the *Portal* condition were going to be compared with the control conditions combined as well as separately; therefore, additional *Portal* sessions were included. However, a cognitive analysis of the skills required for *Tetris* and *TextTwist* suggested that the two games were significantly different in terms of their cognitive demands; therefore, the control games were considered separately.
2. One participant in the *Tetris* group did not follow the task instructions and therefore was removed from the analysis.

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