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ON THE EFFECT OF VIRTUAL REALITY ON STUDENT UNDERSTANDING OF AND INTEREST IN PHYSICS

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ON THE EFFECT OF VIRTUAL REALITY ON STUDENT UNDERSTANDING OF AND INTEREST IN PHYSICS

By

Isaac D. Crouch

A REPORT

Submitted in partial fulfillment of the requirements for the degree of

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This report has been approved in partial fulfillment of the requirements for the Degree of MASTER OF SCIENCE in Applied Science Education.

Department of Cognitive and Learning Sciences

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To my daughter Scarlett,

and the reality ahead.

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Abstract

This study investigated the effect that the video game Portal 2 had on students understanding of Newton's Laws and their attitudes towards learning science during a two-week afterschool program at a science museum. Using a pre/posttest and survey design, along with instructor observations, the results showed a statistically relevant increase in understanding of Newton's Laws ($p=.02<.05$) but did not measure a relevant change in attitude scores. The data and observations suggest that future research should pay attention to non-educational aspects of video games, be careful about the amount of time students spend in the game, and encourage positive relationships with game developers.

1. Introduction

1.1 Statement of Problem

In the current times of rapid technological advancement, an educator may become interested in technology's potential to transform the very nature of learning and may also pay attention future technologies with an eye towards their integration in the classroom. The works of prominent futurologists such as Ray Kurzweil, lead engineer of Google, and Kevin Kelley, one of the founders of Wired magazine, have reinforced the need for research in this regime, because their work reveals that across all areas of technological advancement the rate of growth is increasing exponentially. With new developments such as the internet and smartphones, this growth has paved the way for a society that functions much differently than the society of ten or twenty years past. Should the trend continue then the gap between the technological knowledge of educator and student will only widen.

The technological possibilities that will manifest in the near future as foretold by full-immersion virtual reality, radical and possibly endless life extension, and artificial general intelligence, just to name a few – could change our society at almost every level, education not excluded. While it is possible to predict some of these changes and whether they will impact society positively or negatively, it is impossible to predict them all. One does not have to read much history to point to examples of the negative consequences of technological growth, yet this does not mean we forsake technology and its positive benefits. A proactive approach must be taken when considering the application of new technologies. Kelly (2010) suggests five principles to guide the assessment of new technology – lots of anticipation, continual assessment, prioritization of risks, rapid correction of harm, and redirecting harmful technology to other areas of society instead of prohibition. The current state of video game technology anticipates full-immersion virtual reality, and exploring commercial video games in an educational context is the focus of this study.

To keep up with this rapid pace of growth, it is clear that educational researchers need to begin exploring the impact these technologies could have in our classrooms and on learning in general. All too often instructional designers quickly insert new technologies into our schools without much research to back up why we are doing so. This study will expand the body of research on using virtual reality in educational settings. In terms of Kelly's principles, this research is concerned with anticipating how new technologies will be used for learning, designing programs based on this anticipation, and honestly assessing the benefits and pitfalls so that the results can serve as a guide for future research and classroom applications.

1.2 Research Questions

The specific research questions addressed in this study are:

1. Can commercial video games applied in an educational setting increase student understanding of Newton's Laws?
2. Can commercial video games applied in an educational setting increase student interest towards learning science?

1.3 Science Content Addressed

The content of the program designed by this study covers a basic understanding of Newton's Laws, which are listed here.

1. An object at rest will remain at rest unless acted upon by an external force. An object in motion will remain in motion (same speed and direction) unless acted upon by an external force.
2. The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.
3. For every action (a force applied by one object on another) there is an equal and opposite reaction (the second object applies a force on the first that is equal in magnitude and opposite in direction).

The program assumes minimal to no prior knowledge with Newton's Laws. Through lecture and demonstrations, the lessons attempt to impart a basic understanding of and familiarity with the laws, along with addressing common misconceptions. For example, based on our experience on Earth it is natural to assume all objects eventually come to a rest position no matter what, however the First Law combats this assumption and replaces it with a deeper understanding of how gravity and friction are forces that change the motion of an object and without them (in deep space) an object would continue its motion in a straight line indefinitely. A discussion of the First and Second law also entails the concepts of velocity, acceleration, and mass, and how these are affected in response to forces. Finally, the concept of forces always coming in "equal and opposite" pairs is emphasized in discussion about the Third Law.

2. Literature Review

2.1 The Exponential Growth of Technological Progress

Before the invention of computers, technological progress followed what appeared to any reasonable observer as a linear growth trend. Linear growth is indeed what one would find before the knee of the exponential curve where the rate begins to increase rapidly. Many revolutionary technologies were invented throughout human history, yet for the most part their arrival was spaced out over long periods of time. These include the invention of human language, writing and mathematical notation, the printing press, the scientific method, and mass production of goods (Kelly 2010). According to Kurzweil (2006), the rate of technological growth is increasing exponentially and the current era takes place in the "knee" of the exponential curve, prompting reasonable conclusions about the continuation of rapid growth that we have experienced in recent years.

Kurzweil is a distinguished inventor, with many devices under his belt that we take for granted today such as flatbed scanners, speech-to-text software, and the first synthesizer to fool musicians into thinking it was a real instrument. He has lived through one of the most explosive growth periods in the history of technological progress – a period which began with the invention of the computer. During this time he has collected data across many areas of technology to document the rate at which this growth is occurring.

While the growth is occurring at different rates for different devices, all major integral components of computer technologies today show the exponential trend. The performance and speed of dynamic random access memory, transistors, microprocessors, hard drive storage, and the internet have shown a trend of exponential growth, while size and cost have shown exponential decay. There are broader societal measures of exponential growth that foretell that this trend is not likely to end anytime soon such as the amount of scientific research on key fields such as genetics and nanotechnology, the number of patents granted in the U.S., and information technology's share of the economy.

Unless one is convinced of a global economic collapse, imminent world-wide nuclear warfare, or an impending asteroid collision, it is reasonable to assume this trend will continue. By studying these trends regarding the state and function of various technologies, authors such as Kurzweil and Kelly have made predictions about how these technologies will evolve in the near future. Within a few decades they predict that artificial intelligence will be indistinguishable from human intelligence, even surpassing it and taking charge of its own evolution. Virtual reality will become increasingly realistic and immersive to the point which all of our senses can be replaced with virtual counterparts, blurring the lines between what is real and what is programmed. Recent technologies such as IBM's Watson, Google Glass, and the Oculus Rift headset give us a glimpse of what is to come. Additionally, advances in medicine and biological technology will increase human health and lifespan indefinitely.

Depending on your particular viewpoint, this incredible vision of tomorrow can sound wonderfully utopian or frighteningly dystopian. Not surprisingly these predictions are not without their criticisms. The basic assumption underlying them all is that the exponential trend will extend practically indefinitely and will not hit a “leveling off” period anytime soon. Of course the future is unknown, so the certainty of this assumption is ultimately unclear. Assuming computer intelligence does surpass that of humans, is there any way to stop them from subjugating us to their will just as we subjugate “lower forms” of intelligence to ours? Governments are already using new technologies to employ draconian surveillance policies such as those revealed by Edward Snowden (Appelbaum and Poitras 2013). It is not very reasonable or wise to think that governments will not continue to use evolving technologies for purposes that counteract democratic values.

While predicting the future is by definition informed guessing and thus must necessarily carry with it the possibility of inaccuracy, it does not take a futurist scholar to observe the impact of emerging technologies on our lives. The advancement in technological components discussed previously is responsible for the ubiquitous rise of cell phone usage and utility within the past decade. Children born today will come of age in a technological landscape that is vastly different from that of the past few decades, and even more so than before the arrival of the Internet. Many active teachers today began their career in this pre-Internet era. If educators are not a step ahead of the curve in developing the skills and knowledge needed to navigate through these technoscapes it will become increasingly difficult to understand and direct students learning.

2.2 Definition of Virtual Reality

> *Cyberspace. A consensual hallucination experienced daily by millions of legitimate operators, in every nation, by children being taught mathematical concepts….A graphic representation of data abstracted from the banks of every computer in the human system. Unthinkable complexity. Lines of light ranged in the nonspace of the mind, clusters and constellations of data. Like city lights, receding.*
>
> -From the book "Neuromancer" by William Gibson

Science fiction has always played the role in not only foretelling but also advancing our scientific and technological directions. Gibson's conceptualization predicts a complete virtual world, where users can plug in and become transported to a place where the normal limits of physical reality are totally nullified and quite literally anything is possible. Only the limits of the imagination provide the boundaries. According to Rheingold (1991), one way to view virtual reality is as a "magical window into other worlds, from molecules to minds". Imagine plugging into one of these worlds and being transported into the reality of atoms and molecules. One could grab on to them, bond them together, twist them around in three dimensions, and watch a chemical reaction evolve through time from all angles. Imagine watching a star explode from the inside out, seeing galaxies collide and witnessing the birth of the universe. With virtual reality these abstract worlds, previously only describable through words and crude diagrams, become as immersive as life itself. The potential for this type of immersion into virtual worlds for use in educational settings is quite compelling.

Obviously today's virtual reality applications have not reached a level of immersion capable of convincing all of our senses that we are not actually experiencing a program. However the use of one particular form of virtual reality, video games, has become pervasive in our lives and culture. In 2011, the Entertainment Software Association reported that 58% of Americans play video games (Association 2013). Anyone who has played a video game understands the high levels of user engagement that can be achieved. If this engagement could be harnessed for educational purposes, the potentials for learning are tremendous. Such is the focus of the current study.

Before examining virtual reality and video games further, a clarification of terms is needed. The experience provided by any virtual reality technology must have two characteristics – immersion and navigation (Rheingold 1991). Immersion refers the technology's ability to create the illusion of being in a simulated environment different than your waking life. The more immersive an environment is, the harder it is for the user to distinguish it from their normal sensory input. Navigation, on the other hand, refers to the ability of the user to move around within that environment and manipulate objects. Commercial video games certainly contain these qualities to varying extents, usually with the newest games offering the highest levels of either or both.

It has been suggested that a distinction is made between simulations and games used in educational settings (Young et al. 2012; Zahira Merchant et al. 2014). Both are designed to imitate some actual process or environment, and must allow opportunities for the player/student to test hypotheses and solve problems. However games differ from simulations in that they can impart the player with a sense of self-identity, and include goals, levels of achievement, and rewards as integral characteristics. Games can also progress through a narrative, but in order to be effective instructional tools these narratives must follow the contour of the learning context. In addition, Hew and Cheung (2013) have defined virtual worlds as three-dimensional immersive environments that have the illusion of 3D space, a visual representation of the user in the form of an avatar, and interactive tools for users to communicate with each other. To different extents these three somewhat overlapping distinctions have the qualities of immersion and navigation discussed above and thus can be categorized underneath the term *virtual reality*.

2.3 Previous Applications of VR in Educational Settings

In medical settings, simulations have played a significant role in educating medical professionals, and sensibly so – it's generally not a good idea to put someone's health in the hands of a novice. While historically most of these simulations have been physical models of actual body parts that may or may not have computer representations, more recently virtual simulations are being used more frequently (Scalese et al. 2008). These range in levels of immersion from video-game like virtual worlds to surgical simulations encompassing the most dominant human senses of visuals, sound, and touch. This has allowed the medial field to educate new practitioners without the need for live patients, bypassing cost, availability, and ethical restrictions. It has also given the profession novel and more effective ways at assessing medical knowledge and competency. These technologies have been used in outreach initiatives for recruiting interested secondary school students into the medical profession (Tang et al. 2013). These students that participate in these programs report high levels of engagement, enjoyment, and assuredness regarding their desire to pursue a medical career. Other high-risk work environments such as airlines, militaries, and nuclear power plants have similarly benefited from virtual simulations.

In the classroom, the two-dimensional physics simulation program "Interactive Physics" utilized for K-12 teacher professional development was shown to increase not only the teacher's content knowledge but their ability to integrate this technology into actual lesson plans (Irwin 2012). Another computer simulation program "Real Time Relativity" has been shown to have a positive effect on student performance on exam questions, increase student confidence of their understanding of the concepts, and enhance their enjoyment of the subject (McGrath et al. 2010). The teaching of modern physics may benefit greatly from virtual reality since understanding many of the concepts requires a reconceptualization of common sense notions of reality.

In the subject of mathematics, Hwang and Hu (2011) studied how an Interactive Future Mathematics Classroom (IFMC) VR program can be used to promote fifth grade students understanding of geometry, proficiency with geometric problem solving, and familiarity with multiple representations of geometrical concepts. This system employed interactive geometrical manipulatives within a virtual environment that included a table where shapes could be added, stacked, removed, and moved around, "whiteboards" where students could write equations and notes, and a peer-chatting tool to communicate with other students. The chat tool allowed students to share alternative viewpoints and cooperate to solve problems. Two classes were used in the research, one as a control group and one using the IFMC program. They administered pre- and post-tests to evaluate prior knowledge of geometrical concepts and learning that was gained through the program. They found that students that were administered the interventions learned more about geometrical concepts and scored higher in problem-solving than the control group.

Also designed for mathematics education is the virtual environment CyberMath, which was developed specifically to investigate a number of key issues in virtual reality based education (Taxen and Naeve 2002). One is the effectiveness of free-choice learning that is normally found in VR educational programs (similar to what occurs in museums) as opposed to formal, directed instruction. Secondly the differing levels of immersion offer distinct advantages and disadvantages that have not been explored – high levels of engagement for full immersion environments vs. low cost and high availability of low-immersion desktop environments. How high levels of visual realism can either detract from or enhance learning, along with how to most effectively handle large amounts of users in collaboration can also be explored with the program. Unfortunately the designers of this program have not reported any outcomes of their studies at this time.

Chemistry is also a subject that requires geometrical visualization skills with the arrangements of atoms to form molecules. Z. Merchant et al. (2013) used the online virtual environment Second Life in order to explore it’s potential for enhancing spatial skills in the context of chemistry concepts. As a whole their study did not find that the program enhanced the spatial ability and chemistry achievement of their subjects - undergraduate college students in an introductory chemistry course. However they did show that students who had trouble manipulating two-dimensional objects performed much better in the three-dimensional environment. The study also showed no significant difference between male and female spatial abilities, challenging common-held views that males are superior in this area.

The usefulness of Second Life as a tool for learning has been explored within a graduate interdisciplinary communication course (Jarmon et al. 2009). This study used student journals, surveys, focus group discussions, and video recording analysis to probe how learning occurs in Second Life, the types of learning that occur, the transferability of the learning to real life, and student perceptions of the virtual world as beneficial to their learning. The study reported positive effects in each of these areas. The students reported that the virtual world offered them ways to test their ideas in a risk-free and playful setting, essentially allowing them to test their hypothesis without the cost and time drawback of doing so in the real world. While communication skills is not technically a science subject, it is a crucial skill that scientists and students who are learning to think as scientists need to have practice in and therefore these results still hold relevance to the current study.

Another study compared an undergraduate mass communications course taught in-person to an online course taught by the same instructor in the Second Life environment (Lester and King 2009). The traditional class included lectures, PowerPoints, video clips, and in-person submission of assignments. The online class included typed lecture notes, personalized avatars, digital whiteboards, video clips, and online assignment submission. Pre- and Post-tests were administered to gather information about student demographics, confidence levels towards computer literacy, student attitudes toward the course, and perceived knowledge of course content. Submitted assignments, discussion board responses, and exams were also used for measures. Overall the results of the study did not report any significant differences between the two courses. While the virtual world intervention did not seem to enhance learning for these students, it is important to note that it did not detract from it either.

The virtual world E-Junior is an underwater environment designed to emulate the Mediterranean Sea and teach students about basic natural science and ecology concepts (Wrzesien and Alcañiz Raya 2010). This was also a study that compared two classes with the same content and learning objectives, one using the virtual world and the other using traditional pedagogical methods. Both qualitative and quantitative data were collected. Pre- and Post-tests were administered to obtained background information and identify gains in conceptual knowledge of natural science and ecology. Additionally a post-test questionnaire containing both open and closed-ended questions was administered to measure student's attitudes and opinions toward the virtual world. The pretest identified that the students of both groups had similar background knowledge. The posttest results showed that both classes gained information from each respective instruction, yet the comparison of both showed no significant difference between the control group and intervention. While this seems to support the assertion that the virtual world did not have a positive effect on the learning of the students, the study suffered from a couple of major limitations that affected the direct comparison of the two classes. For example each class used a tutor, however the tutor in the intervention class was virtual. The difference in how these tutors interacted with the students is a confounding variable. Also the E-Junior program had to be administered to students in groups of four since the program only allowed four students at a time to participate. This is a major design difference in the classes that confounds the data as well. Lastly the students that were given the intervention reported higher levels of enjoyment, engagement, and willingness to participate in similar activities in the future.

2.4 Frameworks for Conceptualizing and Measuring Technology in Education

In order to assess the research questions put forth by this study, there needs to be a method by which to measure whether or not the technology integrated in the program has a positive impact on the dependent variables. What follows is a review of various frameworks designed towards this aim.

The RAT Framework

The RAT Framework was created as a means to examine and evaluate the various ways you can use technology in the classroom (Hughes et al. 2006). Inspired by research that identifies the difficulties encountered by both preservice and inservice teachers with integrating technology into lessons, the RAT framework holds potential as a tool for decision making when considering technological alternatives. Their methods involve examining technology’s impact on instructional methods, student learning, and curriculum goals. Following this analysis, the various functions of the technology are categorized as either replacement (R), amplification (A), or transformation (T).

The first categorization refers to the uses in which the technology replaces some aspect of non-technological instruction. The technology does not add to or change the instructional process in any way. For example, a teacher may use a word processor to have students underline and highlight key words; in this application the computer merely replaces the function of a worksheet that has the students underline and circle the same words. The second refers to the ways in which the technology amplifies instruction by increasing the efficiency and productivity of instructional methods, student learning, or curriculum goals. An example here is using a word processor to store and organize instructional materials. This is more effective than analog methods since the materials can more easily be sorted and modified for future uses. Lastly, technology can be used to fundamentally change, or transform, the classroom experience. In this case, the consideration of technology changes how and what students learn, the instructional materials the teacher uses, or even adds curriculum goals that were not previously present. The authors note that this will occur more frequently as we begin to see the unlimited potential of computers as a technological alternative rather than a “cold machine”. This particular statement was from 1997, and since that time the role of computers in our everyday lives have increased so tremendously that new teachers and students alike are already mentally prepared to view computers (and by extension the internet) in this way.

Usually any particular technology can serve multiple functions that may fall into different categories of the RAT framework. Similar to the word processing example listed above, the online tools provided by Google Docs replaces administrative tasks such as collecting and organizing assignments. In addition it also amplifies the efficiency of these tasks by doing away with physical copies – the document files are updated automatically so that revisions can immediately be seen by the instructor.

The RAT framework provides a system by which educators can more effectively consider how technology is integrated into their instruction. It does this by giving them three distinct categories that describe how the technology affects the instruction, allowing educators to make informed decisions on whether to use the technology in that particular way.

Technological Pedagogical Content Knowledge (TPACK)

Under this framework technology, pedagogy, and content knowledge are considered a complex interwoven matrix that must be navigated by teachers (Koehler and Mishra 2009). The authors recognize the challenges associated with teaching with technology – the differences in analog and digital technologies, lack of support of institutions, lack of teacher preparation due to rapid advancement of technological growth. They propose that there is no "one size fits all" approach to successful instruction. Instead, successful instruction results when an educator can fluidly traverse between the three areas as needed, and so requires teachers to develop knowledge of each individually along with how each relates and interacts with the others. As a theory it builds on the Shulman's pedagogical content knowledge (PCK), adding technology in to the mix. *Content Knowledge* refers to the knowledge of the specific subject being taught. *Pedagogical Knowledge* refers to the methods and practices of instruction applicable to any subject. Therefore Shulmans PCK was designed to address pedagogical practices that are applicable to specific content disciplines (Shulman 2008). It was proposed that thinking about content and pedagogy separately was inadequate to successfully teach diverse learners.

Adding technology into this framework introduces another level of complexity. Individually, *technology knowledge* refers to the understanding of technology as it can be used for information processing, communication, and problem solving, along with knowing when it is best to use any particular technology and when it is best to refrain. *Technological content knowledge* requires understanding how technology impacts a specific content area or discipline, and how that discipline in turn uses technology to advance itself and acquire more content knowledge. *Technological pedagogical knowledge* deals with how technology impacts teaching and learning, and how technology that was created for business or entertainment sectors can be repurposed for education.

If all this is considered simultaneously as an all-encompassing idea, then what emerges is TPACK – technological pedagogical content knowledge. To effectively integrate technology into educational settings, teachers must be adept in each of these areas individually along with how they interact and affect one another. Often a change in one area requires a compensatory rethinking of other areas, such as how the Internet forced educators to rethink how to present and transmit content using impersonal web platforms. Moving forward it is clear that teachers who wish to successfully incorporate new technologies into their instruction can benefit from the conceptual framework of TPACK.

Technology Use In Science Instruction (TUSI)

The authors designed this framework with the goal of measuring how technology enhances the effectiveness of instruction along with alignment with scientific reform efforts (Campbell and Abd-Hamid 2012). Part of the motivation for this research is the need to measure technological knowledge as it relates to TPACK. In short, educators need a lens through which to conceptualize their adoption and use of technology in their lessons. They also need a way to measure the extent to which their technologically-infused instruction aligns with recent reform efforts. Specifically the authors are referring to two documents – *Science For All Americans* and the *National Science Education Standards*. To do this they relied on the five guidelines for ensuring that instruction, as altered by technology, aligns with these documents offered by Flick and Bell (2000):

1. Technology should be introduced in the context of science content.
2. Technology should address worthwhile science with appropriate pedagogy.
3. Technology instruction in science should take advantage of the unique features of technology.
4. Technology should make scientific views more accessible.

5. Technology instruction should develop students' understanding of the relationship between technology and science.

The researchers used a multi-stage approach for developing a set of assessment items to measure any particular use of technology in instruction. First they created an initial rough draft of the items by referencing the guidelines and standards documents listed above. Then they used feedback from four “national and international content experts… each holding a doctorate in science education” to revise the initial draft. Following these revisions they tested the items by teaching the system to six educators and having them apply the instrument to 25 videos of technologically-enhanced instruction. Finally they compared the ratings of each educator in order to establish the reliability of the items and used statistical analysis to condense similar items and increase the efficiency of the system.

As an appendix to the study the researchers provide the completed TUSI instrument and an accompanying observation guide. The instrument essentially consists of each of the five items listed above as main categories, with five or six items contained in each for an observer to rate the instruction on a scale from zero to five within the respective categories. The observation guide offers further explanation of each item and examples of a potential classroom implementation.

2.5 The State and Needs of Technology Education Research

As discussed above, there are certainly some studies that report promising results in regards to student motivation towards VR technologies and increases in understanding as a result of their use in the classroom. There has been some concern about the assumptions that researchers approach these studies with and the design of the studies themselves. Additionally a number of researchers have conducted meta-analyses of related research, identifying what has been accomplished so far and what the current needs are for the field. A discussion of both of these topics follows.

The effectiveness of the comparative approach to research design, where one class gets the technological intervention and the other receives traditional instruction with the same content, has been called into question (Kirkwood and Price 2013). Most studies using this research format report no significant differences between the intervention and control groups. Even if major differences are found, sufficient causal links would be hard to create between the intervention and the effects due to the complex nature of the classroom and the large amount of confounding variables. Since the research must attempt to keep the pedagogical components of each set of instruction constant for comparisons sake, the technology employed in the intervention cannot be explored to its full potential. Furthermore, it is unrealistic to expect the instruction to remain constant between groups since it is virtually impossible for a teacher not to change their instructional methods with the addition of new technological tools.

In their critique of technology education research, Kirkwood and Price (2013) also found that measures of student performance as a result of a technological interventions are hard to substantiate. Student and resource availability usually decides the intervention and assessment format rather than research ideals. It has also been found that the very format of assessments will affect the student learning outcomes, calling into question the usefulness of student performance on these assessments as a valid research tool. Lastly the authors found that educational researchers tend to associate positive scores on self-questionnaires and attitude scales with gains in learning. This is troublesome since this assumes that learning gains and positive attitudes are directly linked, which is not clear. Positive attitudes and even performance gains on assessments in a lesson with a technological intervention are not sufficient to conclude the causal link with the technology.

Williams (2011) conducted an analysis of research in three major technology education journals over a five year span (2006-2011). The amount of topics addressed in technology education is very broad in scope. He found that technology design, curriculum, literacy, and student thinking were the top four topics covered by research. While he found a wide range of other topics that are covered, some major examples of topics that were very low in frequency were information technology, mobile/online delivery of content, and learning styles, all of which suggest roadmaps for future research.

For an international perspective, Ritz and Martin (2012) obtained a panel of experts from outside the United States to identify the most pertinent needs for technology education. The authors systematically collected opinions and judgments on the topic, which were put through a four-step synthesis process to generate consensus among all the different members of the panel. In total they found seventeen major issues that need to be addressed through educational research. The issues that the current study will help to address, at least in part, are

- There is a need to understanding the nature of designing.
- There is insufficient understanding of learning that takes place through the technology curriculum.
- Abilities students develop through the study of technology education.
- Understanding the key knowledge and abilities that can be learned in technology programs.
- Pupil’s motivation towards technology.

Furthermore, Hew and Cheung (2013) conducted a review of articles related to virtual worlds in education and they found no research that pertained to commercial virtual worlds, such as *World of Warcraft* or *Portal 2*, the game that is the subject of this study.

2.6 Description of the Virtual World *Portal 2*

The popular video game "Portal" and its sequel "Portal 2", developed by the Valve Corporation, involve the player navigating through a giant network of connected rooms. Each room presents the player with a puzzle that must be solved in order to advance to the next room, and the player must use a "gun" that creates portals that the player can move himself or objects through. There are many other game elements that the player must employ to solve the puzzles such as dangerous turrets, blocks called “companion cubes”, buttons and switches, tractor beams, liquids that can be spread across the surfaces to make the player move faster or jump higher, laser beams and cubes that can redirect the beams, and panels called “faith plates” that launch the player through the air. The game engine is designed to follow Newton’s Laws and the resulting kinematics, which reveals the potential for using the game to teach these basic physics concepts.

The game is available for all popular video game consoles as well as for the PC. However in the PC version the developers included the *Portal 2 Puzzle Maker*, a tool that gives the player power to create their own maps and puzzles. The Puzzle Maker contains all of the elements available in the normal game and allows the player to create puzzles with a very simple graphical user interface. There is also a more complex editor available that allows more control over the puzzles, but has a much higher learning curve.

The developers also created an initiative specifically for educators called *Steam for Schools* in which lessons plans, free copies of the game, and other resources were made available for teachers. This program provided the initial inspiration for the current study. An “educational version” of the Puzzle Maker could also be obtained which allows the users to precisely control various physical quantities within the game, greatly expanding the games potential to teach science. The author of this study contacted Valve only to learn that *Steam for Schools* had been cancelled. With some persistence, copies of the game were acquired from Valve but they were unable to supply the classroom-friendly version of the game. Figures 1 and 2 show screenshots of what the game looks like while one is playing and editing puzzles, respectively.

Figure 1. In game screenshot of Portal 2 featuring the orange speed gel (left) companion cube (middle) and portal gun (bottom right).

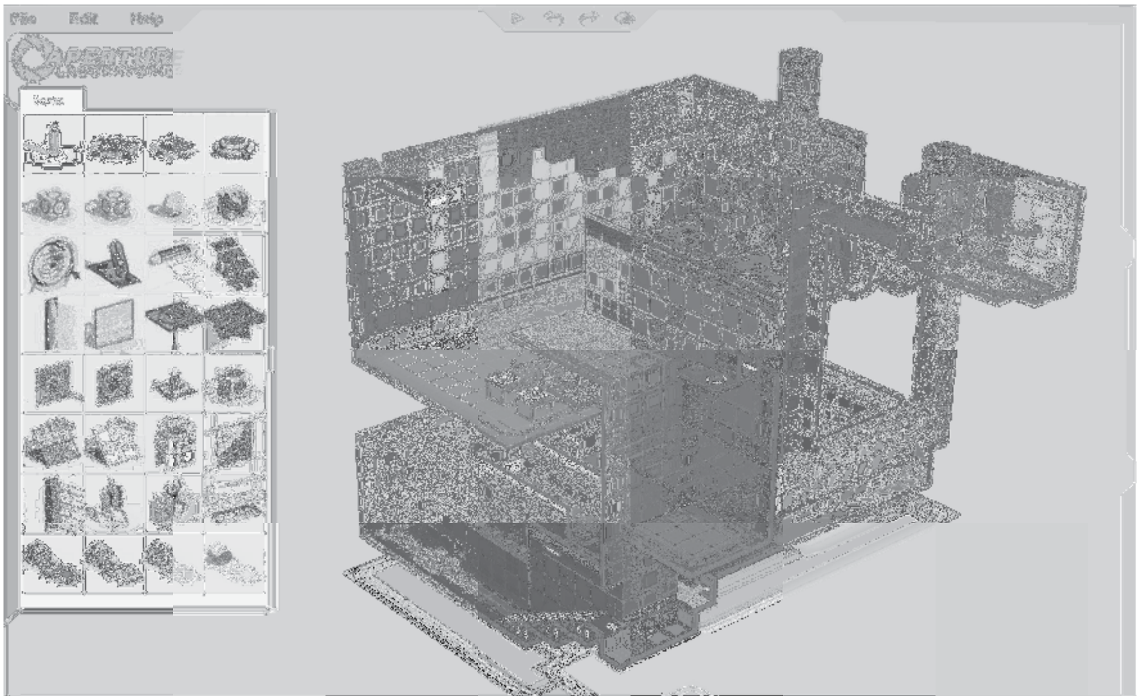

Figure 2. Screenshot of the Puzzle Maker. This is the puzzle the instructor created for the final challenge of the program in this study. The panel of all available items is featured on the left.

2.7 Instructional Techniques for Teaching Newton's Laws

Researchers have investigated ways of teaching Newton's Laws without the use of technology as well. Lee and Park (2013) studied the use of deductive reasoning to teach 11th grade students about how forces affect an objects motion. They observed that their methods had a positive effect on both the students' conceptual understanding and interest in the material; however they noted that the techniques they used were inadequate to teach students about the specific forces involved (they were only able to locate the direction, or absence, of the net force). Positive results have also been obtained when investigating student use of multiple forms of representations including visual, mathematical, and verbal (Mualem and Eylon 2010; Waldrip et al. 2012). Researchers have also investigated university students' conceptual understanding of Newton's Third Law using a method known as "Just-In-Time" teaching (Formica et al. 2010). This method utilizes the Internet in a three-step process in which students begin with a reading assignment accompanied by conceptual questions that are submitted online, followed by a discussion of the questions with the instructor informed by the students submissions, and ending with a group activity. The researchers observed that this method showed a greater increase in understanding than a control group.

Researchers have also developed a way to assess content knowledge of forces in the well-known Force Concept Inventory or "FCI" (Hestenes et al. 1992). The FCI was created to help teachers identify student misconceptions in regards to forces and determine the effectiveness of their instruction. Mualem and Eylon (2010) employed the FCI in their study to measure the impact of instructional techniques emphasizing visual representations to teach about forces. An overall increase in FCI scores for their sample of ninth grade students provided evidence for the techniques' effectiveness. At the university level the FCI has been used to compare a traditional mechanical curriculum to an experimental one, although the researchers identified limitations in the FCI when used to justify curriculum reform (Caballero et al. 2012). While the FCI has been used primarily in high school and university settings, educators have expressed desire to simplify the language of the test items in order to be suitable for younger students. Preliminary investigation suggests that a simplified version of the FCI can produce similar results when given to eleventh and twelfth grade students, however more research and item development is needed to prove its effectiveness on younger students (Osborn Popp and Jackson 2009).

In a study consisting of 100 college students enrolled in a course on electricity and magnetism, the reliability of the FCI was investigated (Lasry et al. 2011). While receiving no instruction on forces, the students took the test twice with the second testing trailing the first by one week. The study found that the overall score of the test was indeed a reliable measure of the content knowledge, however when the individual questions were examined the responses tended to fluctuate significantly. Since individual questions were found to be unreliable, this indicates that the FCI is most useful as a coherent whole.

3. Methods

3.1 Students and Facilities

The intervention program in this study is administered to eight students who are all members of the partnering institution – The Greensboro Science Center. The researcher in this study gained part-time employment with the science center in the fall of 2013, at which time they agreed to provide the facilities for the program and offer it to members of the organization. Since members receive free admission to the facility, the program was restricted to members-only in order to avoid complications with payment or additional paperwork and supervision that would arise through offering a limited admission to non-members. Additionally, since the students' parents would be members as well, they would be free to enter and exit as they please.

Through an online registration form, a pool of potential participants was collected. The form required participants to clarify their former experience with computers and videogames, their experience with the particular game used in the program, and their mathematics background. The researcher selected eight participants with a variety of previous experiences with video games and Portal 2, but who also had acquired basic algebra skills. This was to ensure that the students were prepared to understand mathematical manipulations of Newton's Laws.

The facility has a number of computer labs available for use. Two of the labs are also used for LEGO robotics classes; these were not chosen because of the potential for students to be distracted by the LEGOs in the room. The third room was selected because it contained very little distractions. The room already contained five desktop computers, and three more laptop computers were brought in so that there was a one to one ratio with the students. Each laptop computer had an external mouse (an essential add-on for computer gaming), and all computers had a set of headphones.

The program was conducted in six after-school sessions over a two-week period – two Thursday sessions lasting for an hour and a half each and two Saturday sessions lasting four hours, giving the program a total of fourteen hours contact time. The sessions were spaced out in this way because the researcher wanted to ensure that attendance rates would be high, something that did not seem likely with daily sessions. Participants were made aware that the program was part of a graduate research study both on the flyer for the program and the registration form, with the hope that this would help to ensure high attendance rates as well. Participants were informed that their names would not be used in the final report of the study using consent forms delivered to both the parents and the students, returned to the researcher, and signed before the start of the program. The program flyer and consent forms are included in Appendix D. The intervention was delivered between May 6th and May 17th of 2014, and was taught by the author.

3.2 Goals and Objectives

The goal of the intervention program is to impart a general understanding of how objects move in response to forces to the students through an exploration of Newton's Laws in the Portal 2. An additional and equally important goal is to enhance student attitudes towards learning science and considering a scientific career. The program is designed to address the following items in the *North Carolina Essential Standards* (2011):

> **Phys 1.2.3 -** Explain forces using Newton's laws of motion as well as the universal law of gravitation.
>
> **Phys 1.2.4 -** Explain the effects of forces (including weight, normal, tension and friction) on objects.

During the course the students are instructed how to play the video game and how to build their own puzzles within the game using the Puzzle Maker. Through lectures and in-class demonstrations, they are introduced to the basic concepts of Newton's Laws. They are engaged in three main activities designed to achieve the goals stated above. For each of Newton's Laws, they are tasked with designing their own puzzle. Besides conforming to the basic rules for puzzles in the video game, an additional requirement is added to the activity: at some point within the puzzle, the law has to be demonstrated. Then the students present the puzzle to their classmates, explaining to each other how their puzzle demonstrated the law. Afterwards they are allowed to try out each other's puzzles.

3.3 Program Overview

During the first day of the program the students are welcomed to the program and introduced to the instructor and each other via a team-building game. Before beginning any instruction they are administered an attitude survey and a pre-test on Newton's Laws. The remainder of the period consists of an introduction to the game mechanics of Portal 2 and the Puzzle Maker, and a free play session where they start playing the storyline of the videogame. As the player progresses through the game, a built-in tutorial teaches them the various controls and nuances of the game.

In the second day students continue to play the storyline to keep learning the controls and getting an idea of how to solve puzzles. They also start experimenting freely in the puzzle maker in order to get used to the software. Finally, an attention-grabbing lecture on Newton's First Law is given by the teacher using the egg-drop demo as its centerpiece. An egg is placed atop a cardboard tube on a pie tin, which is itself placed atop a glass of water. Students are invited to attempt knocking the tin out from beneath the egg so that the egg falls directly downwards into the water without shattering. Afterwards the instructor discusses the forces involved and introduces the First Law as a way to understand the demo. Students are also asked to identify examples of the law in everyday life, such as flying off a skateboard or bike after hitting an obstacle and pushing a bottle of ketchup in order to get the last drops out.

The third day of the program is on a Saturday which is the first long session (four hours). During this session the students continue solving puzzles in-game and learning how to build their own puzzles. The instructor then performs a lecture clarifying what is meant by “a change in motion” in the First Law, using the egg drop demo and orbiting satellites as examples and introducing the concepts of velocity and acceleration. The distinction between “force” and “net force” is also discussed. Finally, they begin the first puzzle challenge – to design a puzzle that demonstrated Newton’s First Law. After they complete their puzzles they are given time to play each other’s puzzles and attempt to pinpoint where the law was demonstrated in the puzzle. This day ends with the students sharing each other’s puzzles with the instructor and the rest of the class, discussing the successful (or unsuccessful) application of the law.

During the fourth day of the program the students begin with a period of free playtime before gathering for a lecture on Newton’s Second Law. The previous material covered for the First is used as a bridge to the Second. With the First Law, the students discovered that a net force is required to accelerate an object, and now they learn that the

Second Law provides a way to figure out exactly how much an object is accelerated in response to a given net force and how mass can affect the motion as well. Common forces such as applied forces, gravity, air resistance, and friction are mentioned as potential "culprits" for changes in motion. They are then given the second puzzle challenge – to design a puzzle demonstrating the Second Law. After the puzzles are complete they play each other's puzzles and discuss with the instructor.

On fifth day of the program the students are again given a period of free playtime before transitioning to a lecture, this time on Newton's Third Law. To demonstrate the law the classic fan cart demo is used. The students were asked "If a sailboat is stranded at sea with no wind, can the seamen attach a fan to the boat to make the boat move forward?" The demo simulates this situation with a rolling cart that has both a fan and a metal plate attached to serve as a sail. With the plate attached the cart is still; only by removing the plate can motion be achieved. To help students understand the demo, the instructor begins a discussion of rockets where students come to understand the pair of forces involved in rocket flight – the force of the rocket on the air and the equal and opposite force of the air on the rocket. Students then compare this to the cart's lack of motion, seeing that the sail must also play a role. The sail also pushes against the air as the cart tries to move, and the air pushes back on the sail; since the sail is connected to the cart this balances out the force of the air on the fan and halts the motion. The instructor then finishes the lecture by soliciting examples of the Third Law from students and discussing. The students are then tasked with the third puzzle challenge which is similar to the first two.

On the final day, another four-hour long session, the students are given an hour and a half to solve a puzzle created by the instructor – one which demonstrated all three of the Newton's Laws in multiple ways. In this "Final Puzzle Challenge" they were tasked with identifying at least two instances of each law. Afterwards they are allowed to challenge each other to solve the puzzles they created. Finally they're given both the attitude post-survey and the exact same test on Newton's Laws that they took the first day.

3.4 Data Collection

This study utilizes a mixed-method concurrent convergent design in which both quantitative and qualitative data collection methods were used simultaneously as appropriate (McMillan 2004). Following similar studies in educational technology research, surveys that include Likert-type rating scales are employed to collect data regarding student attitudes towards learning about science (Wrzesien and Alcaniz Raya 2010; Hwang and Hu 2013; Jarmon et al. 2009). The surveys are given at the very beginning of the first session of the program and the very end of the final session, and can be found in Appendix C. The majority of the survey items are exactly the same on both surveys and had students rate their level of agreement to standard attitude statements ("I like learning about science", for example). The items that differ are those that didn't need to be asked again such as pre-survey items that gathered information on frequency of video game and computer use prior to the program, and two items that asked students to identify whether they believed this program had an impact on their desire to learn physics and if they would take another course like it. Two open-ended items on the post-survey asks the students what their favorite part of the program was and prompts them to add any additional comments they may have. Both of these are also not included on the first survey.

To measure the student's understanding of motion, forces, and Newton's Laws, and whether or not the Portal 2 program had an effect on understanding, criterion-referenced tests are administered at the beginning and end of the program. These tests can be viewed in Appendix A and include both true/false and open-ended items addressing the content covered in the program. While a standardized test such as the FCI is preferable for research purposes, the items on the conceptual test used in this study are not adapted from it for two reasons. As found by Osborn Popp and Jackson (2009), the language of the FCI is not suitable for the age group of the students that participated (middle school). Additionally Lasry et al. (2011) showed that while the FCI was reliable on the whole, individual questions were not (such as a subset of questions that only dealt with Newton's Laws). Therefore items on the test are either created by the instructor or adapted from a lower-level conceptual physics textbook (Hewitt 2002). Items 1, 2, and 7 address Newton's First Law; 3,4, and 8 address the Second; 5,6,and 9 address the Third.

If the program has a positive effect on the students understanding, then the post-test scores should show an increase from the pre-test. The instructor assigns each student a grade based on how well their test corresponds to a point-based answer key. The pre-test also serves as a way for the instructor to gauge what prior knowledge the students have on the subject material; this is important since the researcher has no former experience with the students.

According to McMillan (2004), subjects tend to respond in similar ways on differing questions on questionnaires and tests regardless of educational interventions and will sometimes even outright lie on these forms. Due to these limitations, observational methods are employed in this study in addition to surveys and questionnaires. The instructor of the program records observations on how the students are responding to the programs as they are happening in order to gauge how their interest may be piqued and if they are in fact learning the material. In order to facilitate these observations, the instructor records them in a set of journals for each day of the program. Following each session, the instructor also reviews these observations and writes an overall reflection in the same document that summarizes daily events, incorporates the observations, and analyzes his own thinking in an attempt to contextualize any inferences that were made. This is necessary since an unbiased, third-party observer is not able to accompany the researcher in the program.

4. Results

4.1 Pre/Post Test Scores

The conceptual test given at both the beginning and the end of the program revealed an average increase in scores. The test consisted of six true/false questions graded at one point each, and three open-ended questions graded at two points each (one point for providing a correct explanation and one for mentioned the correct law), for a total of twelve points. The scores were then converted to a percentage. None of the test scores decreased in the post-test, three students did not show an increase, and the remaining five students showed varied levels of increase. The raw data is included in Appendix A and the mean test scores, effect size, t-test values, and p-value is shown in Table 1.

Table 1. Pre- and Post- Test scores for Newton's Laws conceptual test.

	Mean	SD	ES	t_{obs}	t_{crit}	p
Pretest	41.67	12.60	1.07	3.05	2.36	$.02 < .05$
Posttest	55.21	13.32				

The pretest and posttests can also be looked at on a question-by-question basis. The number of total points missed for the questions involving the first law decreased from 15 to 10, the second law decreased from 12.5 to 11, and third law remained constant.

4.2 Survey Data

The students completed an attitude survey on the first day of the program and on the final day as well. The first two questions only appeared on the pre-survey and asked students to indicate how often they use computers and play video games. All students responded that they use their computers and play video games daily. Half the students use computers multiple times per day and six out of the eight students play video games multiple times per day as well.

The survey contained 9 questions targeting student interest in science, physics, and perception of the program. Table 2 summarizes the results. Two of the eight questions (3 and 6) showed a large positive effect size, two others showed no effect (1 and 5), question 4 showed a large negative effect, two questions (2 and 7) showed a small negative effect, and the final two questions were only asked on the post-survey.

Table 2. Pre- and Post-survey results.

Survey Statement	Pre-Survey		Post-Survey				
	Mean	SD	Mean	SD	ES	t_{obs}*	p**
1. I like learning about science.	4.13	0.35	4.13	0.35	0	0.00	1.00
2. I like learning about physics.	4.13	0.64	4.00	0.00	-0.20	-0.55	0.60
3. I like figuring out how things move.	3.88	0.64	4.25	0.71	0.59	1.00	0.35
4. I will enjoy [enjoyed] using Portal 2 in this course.	4.88	0.35	4.50	0.76	-1.06	-1.16	0.28
5. I am considering a career in science.	3.63	0.92	3.63	0.52	0	0.00	1.00
6. I like solving problems.	4.38	0.52	4.75	0.46	0.72	2.05	0.08
7. I like performing scientific experiments.	4.69	0.52	4.50	0.53	-0.24	-1.00	0.35
8. If there is another opportunity to take a course that uses Portal 2, I will take it.	-	-	4.50	0.76	-	-	-
9. How inspired are you to learn more about physics as a result of this program?	-	-	3.63	0.74	-	-	-

*Observed t-values are compared to a critical t-value of 2.36 (α=0.05, df=7)
**P-values are calculated at a 95% confidence level.

The post-survey also included 3 open ended questions. The first question was "What was your favorite part about this program and why?" Most of the students commented that they really enjoyed designing and playing each other's' puzzles.

> *"I liked creating my own puzzles and playing other people's puzzles."*
>
> *"I enjoyed playing each others puzzles because I could see what other people were doing and thinking about"*
>
> *"I really liked having the chance to play through the game on story mode, but i also really liked creating my own puzzles and trying to get them to work."*
>
> *"My favorite part was using the chamber builder and using the tests myself. It was fun doing things that involved testing."*
>
> *"My favorite part was creating the puzzles. I found that the most fun because I could make what I wanted with few limits restricting me."*
>
> *"I really liked having the chance to play through the game on story mode, but i also really liked creating my own puzzles and trying to get them to work."*

The second open ended question prompted the students to provide any additional comments about how Portal 2 was used in the program. This provided the students to express any lingering thoughts they had that were not specifically targeted in the survey questions.

> *"I really liked how intuitive the game was and it really helped me understand more about newton's laws"*
>
> *"maybe a little less computer time?? as someone who has trouble looking a bright screens for a long time it was really stressful on my eyes to keep looking at the computer the whole time"*
>
> *"I think that Portal 2 was a great choice for this program and it has taught me more about physics."*

"I think Portal 2 was the best choice to teach us about physics."

"it was fun"

The last question asked "How could this program be improved?"

"I think it was fine."

"If we had used the more advanced puzzle creator"

"maybe a little more social interaction, as of right now it's just a bunch of kids sitting in a room playing video games like none of us are there"

"I think the program could be more interactive with science experiments in the game."

"Make it last longer"

"You could have more experiments and a bigger class"

"more interactive"

Figure 3 displays the frequency of common words and phrases provided by the students in their open-ended responses on the survey.

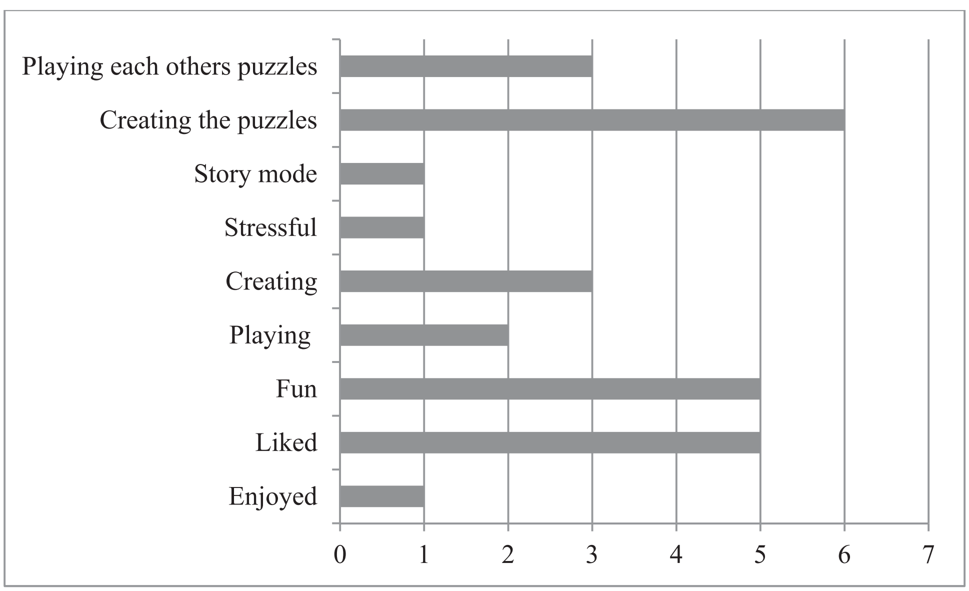

Figure 3. Common phrase frequency chart.

4.3 Instructor Observations

The most salient theme that resonates throughout the instructor's journal is the inherent interest in and experience with video games that was already present in the students. Most of the students were already aware of the Oculus Rift and the Omni Treadmill, two recent technological advances in virtual reality that the instructor talked about on the first day of the program. When one student was filling out the pre-survey, they noted that "several times a day" was not adequate to describe how much they use computers. Several students had already played the video game and jumped right in to the Puzzle Maker software. One student even had some experience with the software and was able to tell the instructor about an aspect of the program that he was not aware of.

There was also a large degree of enthusiasm from the parents. On multiple occasions the instructor spoke to parents and they thanked him for doing something that sparked their child's interest and would help them understand science at the same time. One parent even "practiced" the video game at home with his child. Another parent relayed how much their homeschooled child looked forward to coming to the program.

The observations also reveal that while the students were inherently interested in the video game, they were also prone to distractions from within the video game itself. While the Steam program has a family mode that can be activated to prevent the student from accessing the online store, the mode still allows them to access the community servers where other maps can be downloaded for Portal 2. The instructor noticed one student regularly became off-task on one of these community maps. After assigning the first task – designing a map to demonstrate Newton's First Law – the student ignored the instructions and played the community map. The instructor decided to wait to see if he would switch over to the task within the next ten minutes, but intervened after he realized that wasn't going to happen. This same student was also observed to be simultaneously watching something on his smartphone while designing puzzles. Another student became off-task after he became invested in one of his maps so much that he ignored instructions to work on the next task.

The observations also highlight technical issues associated with the video game. One student lost one of his maps demonstrating Newton's Third Law after a technical glitch crashed the entire program while trying to load the map. Fortunately this was the only technical issue that prevented a student from moving forward in the program. Another issue that deserves attention is the inability of the game to prevent access from users not in the program. The students were playing each other's maps by publishing them to the Steam workshop and downloading them. However these published maps were also accessible to other Steam users, and one user ended up playing a student's map and leaving a rude comment about how easy the puzzle was.

The students were always very eager to play the video game and design puzzles, and for the most part they all seemed highly engaged with the game while playing and designing. When this was happening the room fell completely silent, prompting the instructor to comment in the journals how more activities should have been planned that involved the students interacting with each other. However there was only one instance where the instructor observed direct evidence of boredom. This was when the only female in the program made a comment in the description of one of her puzzles that she was “bored staring at a screen” and “knew what she was doing”.

4.4 Examples of Student Thinking from In-Class Assignments

The puzzles students created to demonstrate Newton’s Laws can perhaps provide a glimpse of their understanding of the laws. For example, for the first assignment a number of students used tractor beams and faith plates (launch pads) to demonstrate the first law. Typically, either the player or a cube was launched or dropped from some height, and the resulting motion was altered by a wall or tractor beam providing an external force. The students were also given a handout to complete that prompted them to explain how their puzzle used the given law. Some students did not given clear or full explanations, but those that did make statements that demonstrated some understanding of the law.

> *“I used the faith plates to move the ball around the map. When the ball ran out of faith plates it stayed at rest. The player also was stopped by a plate after flying through the air”*
>
> *“The cube was at rest until the beam pushed it.”*
>
> *“I put and demonstrated what Newton’s First Law was in my puzzle by using a tractor beam to stop my motion, and I used a piston plate to act a force on the resting cube.”*
>
> *“Tractor beam moves a cube until stopped by a pressure plate.”*
>
> *“You get thrown into the air by the faith plate and stop when you hit the wall.”*
>
> *“The falling cubes.”*

> *"In my first puzzle I used N1L with faith plates. You would be walking normally until you walk on one and then it's force would send you flying."*

With their second law puzzles, the students primarily used what is called the speed gel to reduce friction, noting that this caused acceleration. As shown below, the students varied in terms of the level of detail used to describe the use of the gel. Some also used tractor beams to change the speed and direction of motion of a falling companion cube.

> *"I used the different gels to reduce friction and gravity. When the player ran and jump over the hole but when the speed and bounce gels were not present the friction stopped the player from speeding up."*
>
> *"When the beam carrying the cube is turned off gravity forces the cube to change velocity."*
>
> *"I used the gels to eliminate friction and produce a greater net force to overcome the force of gravity."*
>
> *"Speed gel causes acceleration"*
>
> *"The speed gel decreases the friction of the ground so you go faster."*
>
> *"In the second puzzle I used the speed gel to reduce the friction, therefore causing you to go faster."*
>
> *"Sliding cubes on the faith plates."*

For the third assignment the students were tasked with designing a puzzle that demonstrated Newton's Third Law. Most of the puzzles involve collisions between companion cubes and other game elements. The comments demonstrate an overall fundamental lack of understanding of the law, with no mention of force pairs either generally or in specific.

> *"The first part in this puzzle involves putting a cube on a faith plate. When you do this you have to bump into the cube in the middle of the two faith plates which exerts a force on you and the cube knowing the cube onto a button."*
>
> *"Once the beam releases the cube, the floor pushes against the cube as it slides then once it falls it will hit a wall that also pushes against the cube.*
>
> *"I used two portals to demonstrate that when you jump in one, the on you come out of has an equal but opposite net force."*
>
> *"One pressure plate causes another pressure plate to activate."*
>
> *"The sphere hits the turret, which causes both of them to move in opposite directions."*
>
> *"The ground is pushing up on you as you push on it until its gone, which is when you fall."*
>
> *"Cubes hit the turrets."*

Figures 4 through 6 display the frequencies of key words and phrases used by the students to describe the puzzles they created.

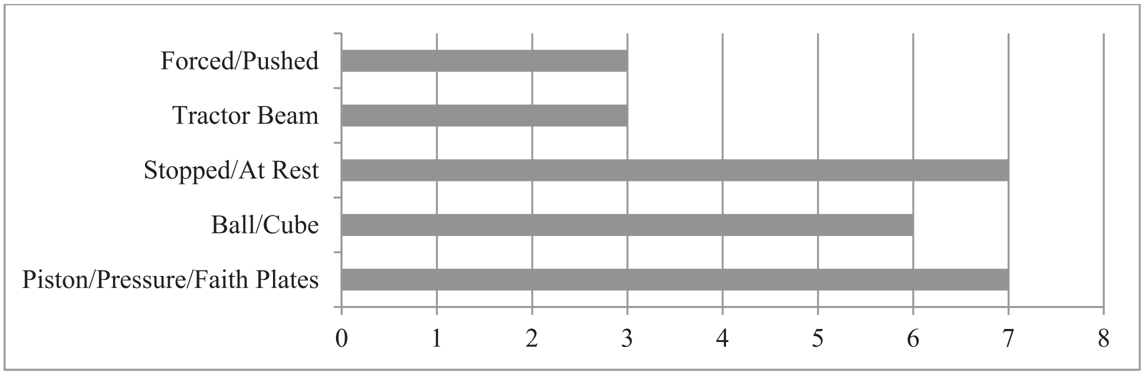

Figure 4. Frequency chart for key words and phrases used in the First Puzzle Challenge.

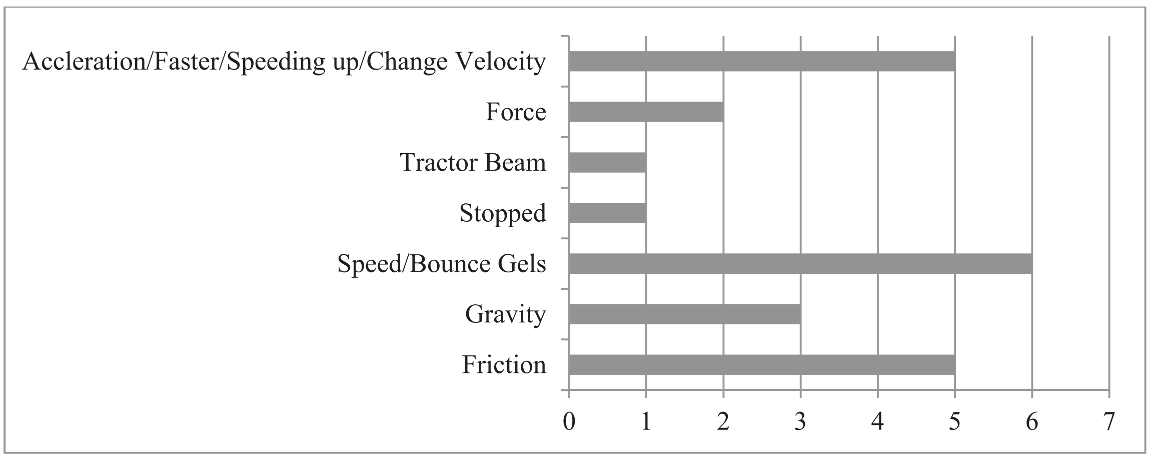

Figure 5. Frequency chart for key words and phrases used in the Second Puzzle Challenge.

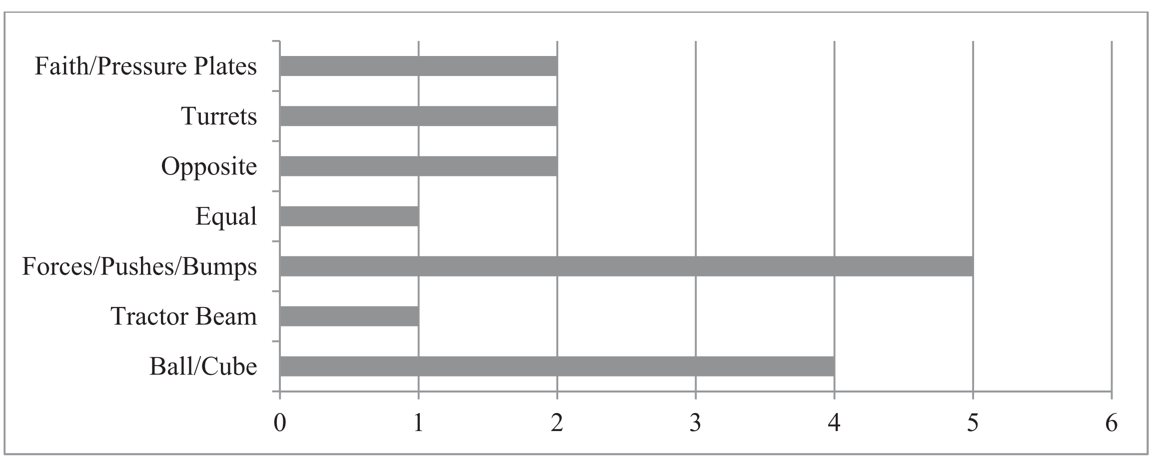

Figure 6. Frequency chart for key words and phrases used in the Third Puzzle Challenge.

5. Discussion & Conclusion

5.1 Analysis of Data on Student Understanding of Newton's Laws

Student understanding was measured primarily with the pre- and posttests, however the instructors' observations and examples of student work can also provide useful information. The tests did show an overall increase in scores and an appreciable effect size. This increase is statistically significant as the observed t-value of 3.05 is greater than the critical value of 2.36 and the p-value is less than 0.5 (95% confidence level). However it is unclear how much of this can be directly linked to the video game. Almost half of the students' scores did not increase at all, which is troubling from an educator's standpoint. This could be due to the variability in student background knowledge. The students came to the museum from a variety of grade levels and schools. Much more time would have been needed to identify all of the student's prior knowledge and bring them to the same level. For example one test question used the terms "direct" and "indirect" relationship, which are concepts that may not have been familiar to every student. Additionally, given that the tests involve true/false questions, the possibility of guessing cannot be completely ruled out. A final possibility for a confounding variable was the instructors own inexperience with teaching Newton's Laws. A more experienced teacher may have been able to elucidate the concepts more clearly and perhaps accommodate the students varying levels of prior knowledge more effectively.

The data can be analyzed from the perspective of each law, beginning with the first. On the tests, the first law showed the most gain in understanding in terms of how many students answered the questions correctly on the posttest compared to the pretest. In some ways, this law could be considered the simplest of the three which could in part explain the data. For the most part, the puzzles created by the students accurately demonstrated the law by either changing the direction or speed of a companion cube (or ball) in motion and describing the force that was responsible (usually a tractor beam or a wall/floor – see Figure 4). In the final puzzle challenge the student responses show varying levels of understanding, sometimes identifying the force correctly, others hinting at what may be a good understanding of the law even if the student could not articulate it completely. This all at least represents a basic understanding of the law, presumably attained through their application of it in the video game.

The data from the second law is somewhat contradicting. The game did not specifically lend itself to a comparative analysis of the law since there was not an easy way for the students to vary the force, mass, and accelerations of objects. Most of their explanations for their puzzles simply stated that the speed gel reduced friction, but rarely did students elucidate that in terms of the law. Figure 5 shows that most students identified the gels as the agents of change, recognized the forces of friction and gravity as responsible, and commented that acceleration was the result even if they did use the exact word ("speeding up", "faster", "changing velocity"). Every student answered the open-ended question on the post-test correctly, representing an overall gain. The question involved what would happen to the acceleration of an object if the force was tripled. This was a concept that we went over twice in the program during instructor lectures. It is more likely that the "perfect score" for the question was due to the lecture rather than the video game. On the other hand, one of the true/false statements actually showed an increase in the number of students that missed it. The statement was essentially the second law, with the words “direct” and “indirect” reversed. The second law was explicitly stated multiple times in the course, so this data was likely due to the students’ unfamiliarity with direct and indirect relationships.

The data for the third law is not encouraging since the posttest showed no gain from the pretest. Prior to the program, most of the students were able to recognize that a baseball exerts a force on your arm when you exert a force on the baseball while throwing it. Unfortunately the third open-ended question on the posttest revealed that the program was unable to enhance this understanding with the “equal and opposite” clause of the law. Figure 6 reveals that the terms “equal” and “opposite” were barley present in their explanations of puzzles. Again it is unclear what role the video game had to play in this, since an inexperienced instructor could easily explain why the students did not learn.

It is important to note that some of the students at the very least believed that they learned about Newton’s Laws from the course. The comments left by the students on the second open-ended question of the post-survey show that at least three of them believed that Portal 2 taught them more about physics and Newton’s Laws.

5.2 Analysis of Data on Student Interest in Learning Science

All of the students that participated in the program entered the program with high levels of interest in computers, video games, technology, and science. This is not surprising given that only students that are interested in science and video games are going to sign up for a course that advertises exactly that. Therefore the very nature of the study was somewhat problematic from the beginning since it would be difficult to show an increase in student interest when high levels already exist.

It is also not surprising that the survey results do not show a clear gain in interest. The results show no increase in enjoyment derived from learning about science (question 1) or consideration of a career in science (question 5). The second shows a slight decrease in enjoyment derived from learning about physics, but a larger increase in enjoyment from figuring out how things move (kinematic physics). There was a decrease in the attitude scores regarding the students expectation of their enjoyment of using Portal 2 in the course (question 4), however the students responded favorably towards taking another course using Portal 2 (question 8). The data derived from the surveys are thus inconclusive. The slight deviations in the scores of the post from the pre could be explained by a host of other external factors – the lack of honesty, apathy towards the questions, mood shifts caused by the daily events of school and home life, and simply the normal shifts in mood that occurs during the teenage years. Since none of the observed t-values were greater than the critical t-value of 2.36, and none of the p-vales are below .05, this study is 95% confident that the survey results show no difference in the pre and post.

The inconclusiveness of the results is also highlighted by question 7 regarding scientific experiments. There was a slight decrease in their attitudes toward this question, however the question was written in an earlier stage of the development for the program when the instructor was planning on using a different version of the game where it would actually be possible to vary physical properties precisely and thus perform experiments. Since that version could not be obtained, no experiments were performed in the class. From a research standpoint there should not have been any change in this attitude score, yet there was. This exposes the natural variability of the data.

While the numerical scores are not revealing, student comments on the open-ended questions provide evidence of student engagement, and exactly what engaged them. There were high frequencies of words such as “fun”, “liked”, and “playing”. These words were usually associated with either playing each other’s puzzles or creating their own puzzles. Almost all of the students (six out of eight) commented that they enjoyed creating their own puzzles in the software. Only one student had a negative comment, using the term “stressful” to describe the monitor’s effect on the eyes after prolonged periods of play time. These periods of playtime might have taken a toll on more than one student’s engagement in another way, since half the students remarked that either a bigger class or more social interaction would have improved the program.

5.3 Limitations of Study & Recommendations for Future Research

The results of this study are essentially non-generalizable due to the small sample size involved of only eight students. Larger sample sizes such as those found in a normal classroom setting would certainly be needed in future research. This would also allow researchers to investigate a video games potential to transform knowledge and interest towards science for students that are not already interested in doing so. A normal classroom would also contain students who have similar background knowledge. Controlling this confounding variable would ensure both the lessons and the pre/posttests are on the right level and researchers could be more certain that their data is indeed revealing the effect of the video game.

A school setting would also lend itself more naturally to the inclusion of a control group in the study. Without a control group it is not possible to know with significant certainty whether or not the video game influenced the students learning. While the game was intended to be an opportunity for the students to apply their knowledge of Newton's Laws and thus increase their understanding, the students very well could have achieved the same scores simply by attending the instructor's lectures alone. Additionally, a standardized test instrument would help to ensure that the items measure the desired content knowledge. Without a widely accepted and scrutinized measurement tool such as the FCI, this study cannot assert in high confidence that correct answers on the conceptual test indicate knowledge of Newton's Laws.

The surveys themselves could also be more extensive. Multiple statements that are essentially the same but worded differently could pinpoint student attitudes more effectively, as compared to the singular statements included in this study. Additionally, future researchers with access to more students could field test their surveys on a smaller group of students and revise accordingly. They could also consult with educational psychologists or other experts that would be qualified to provide feedback on the statements.

A study of this nature would also benefit by gathering more varied sources of qualitative data directly from the students in order to provide more evidence of both student understanding and interest. Qualitative data sources could include having the students keep a journal, video or audio taped reactions from students after playing the game, discussion groups, or one-on-one interviews with the students by the instructor or an outside interviewer.

Finally, computer games are only the tip of the gaming iceberg in terms of the changing technological landscape. The reduction in price and increase in computing power of cell phones has resulted in more children playing games on them. If the Oculus Rift virtual reality headset follows this same trend, it might also eventually find its place in the classroom. Future research could move beyond desktop and laptop computers and investigate these emerging technologies. Of course it could also investigate different games such as the Universe Sandbox, a game that allows the player to build and alter solar systems. Educators could also investigate the potential of open-sourced software. In this study the video game software is considered “closed-source”, meaning that only the developers have access to the code. Using open-source games, where the code is accessible to anyone, could allow educators more control over how the game is used in that it could be designed specifically for teaching the desired concepts.

5.4 Educational Implications and Lessons Learned

While much more research needs to be done in order to further explore how to effectively use video games for teaching science, there are some lessons that can be extracted from the experience gained in this study. In the spirit of Kelly's insistence that future applications of technology need ample anticipation, what follows is a list of suggestions that is essentially anticipation for how video games should be used in educational settings.

1. Pay attention to non-educational aspects of the game.
2. Do not let the game become a replacement for the teacher.
3. Develop positive relationships with game developers.

Educators that attempt to use video games, especially commercial ones, need to be aware of the downsides. Although some commercial video games have educational components to them, the primary purpose of all video games is entertainment. Therefore educators need to spend ample time exploring the video game and considering how students might become distracted from the lesson, such as the access to community maps that distracted the student in this study.

It is also important to consider how much time the students are spending playing the game itself. Too much time in-game presents the risk of the game taking over for the instructor as the chief director of the students' mental activities. While it was necessary in this program to give students adequate time to learn the game and design their puzzles, perhaps more frequent breaks from being on the computer would have improved the students experience by giving them more time to interact with each other physically and share their learning.

On a final note, the cancellation of Valve's Steam for Schools program is an unfortunate step backwards in a partnership between the gaming company and educators. As educators seek to integrate emerging virtual reality technologies in to their classrooms, communication and cooperation with the game developers is a crucial component of success. We need to reach out and let the programmers know that their support is both desired and necessary. The educational version of the Puzzle Maker, which would essentially allow students to perform scientific experiments within the game itself, is a great example of how the support of the developers can vastly expand the applicability of the game into the classroom.

5.5 Conclusion

The major benefit of using commercial video games is that they can be quite fun and engaging for the students, and most of them are already playing them. Some students may even already have familiarity with the particular game and would jump at the opportunity to play it in school. As video game technology becomes more interactive and immersive in the future, the potential for learning and engagement will increase alongside the potential for distraction. The results of this study did not show large increases in student understanding and interest due to the application of the video game Portal 2, however methodological limitations render the exact effect of the video game difficult to identify. The primary contribution of this study is that it provides researchers and educators with a starting point for more extensive research and more effective integration of video games into the classroom.

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Appendix A – Conceptual Tests and Raw Data

Name ______________________ (Post)

Physics & Portals Concept Quiz

True/False Questions

_________ 1. It is the natural tendency of all objects to eventually come to a rest position.
_________ 2. If an object is at rest, then there are no forces acting upon the object.
_________ 3. The acceleration of an object is directly dependent upon its mass and inversely dependent upon its net force.
_________ 4. Accelerating objects are either slowing down or speeding up.
_________ 5. When you exert a force with your arm to throw something like a baseball, the object also exerts a force on your arm.
_________ 6. Forces exist by themselves, without any strongly linked counterparts.

Open-ended Questions

1. Why do you lurch forward in a bus that suddenly slows? Why do lurch backward when it picks up speed? What law applies here?

2. If the net force acting on a sliding block is somehow tripled, by how much does the acceleration increase?

3. Which is stronger, the force of Earth's gravity on the Moon, or the force of the Moon's gravity on Earth? Explain your answer.

Figure 7. The pre and posttest.

Table 3. Raw Data for Conceptual Pre and Posttests

	Pretest	Posttest	Difference
Student 1	41.67	58.33	16.67
Student 2	25.00	41.67	16.67
Student 3	33.33	58.33	25.00
Student 4	25.00	41.67	16.67
Student 5	50.00	50.00	0.00
Student 6	58.33	58.33	0.00
Student 7	50.00	83.33	33.33
Student 8	50.00	50.00	0.00
Mean	41.67	55.21	13.54
SD	12.60	13.32	12.55
SE	4.45	4.71	4.44

Appendix B – Student Worksheets

Name________________________________

Please explain in detail and in complete sentences how each of your puzzles incorporated Newton's Laws.

Puzzle/Law	Explanation
First Law	
Second Law	
Third Law	

Figure 8. Handout for students to explain how each law was utilized in their respective puzzle.

Name	How Newton's 3rd(2nd) Law Was Used in Puzzle
Student 1	
Student 2	
Student 3	
Student 4	
Student 5	
Student 6	
Student 7	
Student 8	

Figure 9. Handout given to students in order for them to explain how their peers used Newton's Laws while playing each other's puzzles**.** In the version given to students, their individual game alias' were used in place of "Student X".

Final Puzzle Challenge

Play through the puzzle "Newton's Three Flaws". Throughout this puzzle there are many ways that each of Newton's laws are demonstrated. Your task is to identify 6 – two of each law. Fill out the chart below as you go. Good luck!

Law	[illegible]
First	
First	
Second	
Second	
Third	
Third	

Figure 10. Handout given to students for the final puzzle challenge in order for them to identify and explain where each of Newton's Laws was used in the puzzle.

Appendix C – Pre and Post Surveys

Edit this fo

Post-Questionnaire

* Required

Name *

I like learning about science. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

I like learning about physics. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

I like figuring out how things move. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

I like solving problems. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

I like performing scientific experiments. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

I am considering a career in science. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

I enjoyed using Portal 2 in this program. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	○	○	○	○	○

If there is another opportunity to take a course that uses Portal 2, I will take it. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
	○	○	○	○	○

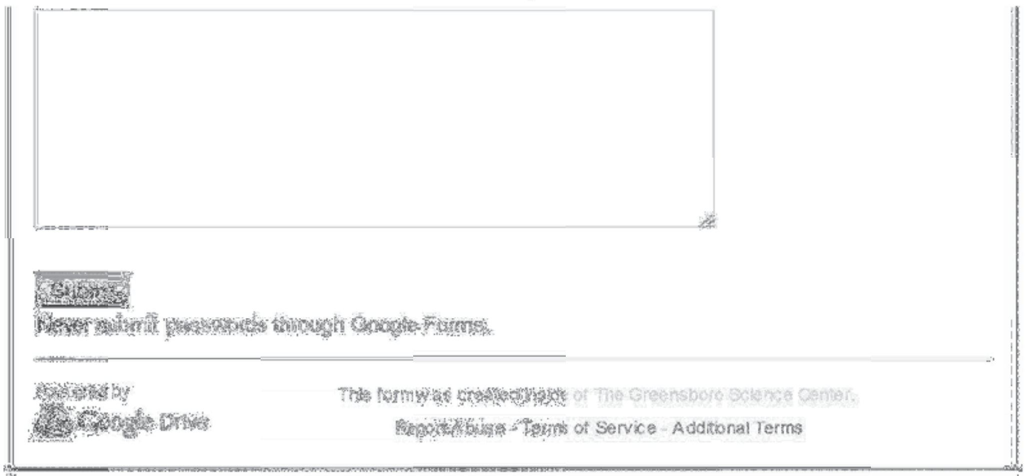
How inspired are you to learn more about physics as a result of this program? *

	Not at all	Slightly	Moderately	Very	Extremely
	○	○	○	○	○

What was your favorite part about this program?

How could this program be improved?

Please provide any additional comments about the use of Portal 2 in this program.


Submit
Never submit passwords through Google Forms.

Powered by
Google Drive

This form was created inside of The Greensboro Science Center.

Report Abuse - Terms of Service - Additional Terms

Figure 11. Postsurvey given to students. The presurvey was identical except for past-tense phrasing and it did not include the open-ended questions.

Appendix D – Permission Forms & Program Flyer

May 1, 2014

Dear Parent or Guardian:

I am an educational instructor at the Greensboro Science Center and graduate student in the *Cognitive and Learning Sciences Department* at Michigan Technological University. I am conducting a research project [redacted] study, children's responses will be reported as group results only.

Participation in this study is voluntary. Your decision whether or not to allow your child to participate will not affect the services normally provided to your child by the Greensboro Science Center. Your child's participation in this study will not lead to the loss of any benefits to which he or she is otherwise entitled. Even if you give your permission for your child to participate, your child is free to refuse to participate. If your child agrees to participate, he or she is free to end participation at any time. You and your child are not waiving any legal claims, rights, or remedies because of your child's participation in this research study.

Any information that is obtained in connection with this study and that can be identified with your child will remain confidential and will be disclosed only with your permission or as required by law. Confidentiality will be maintained by means of anonymity and complete discretion on the instructors' part. Your child's name will not be included in the results of the study and no one outside of the [redacted]

[redacted] (336) 288-3769 ext. 1399 [redacted] John Irwin, the faculty [redacted] he bottom portion and [redacted] py to Isaac Crouch at 4301 [redacted]

If you have any questions about your child's rights as a research subject, you may contact the Michigan Technological University Institutional Review Board (IRB) by mail at 1400 Townsend Drive, Houghton, MI 49931, by phone at (906) 487-2902, or by e-mail at irb@mtu.edu.

Sincerely,

Isaac Crouch
Educational Instructor, Greensboro Science Center
Graduate Candidate, Applied Science Education, Michigan Technological University

---

Please indicate whether or not you wish to allow your child to participate in this project by checking one of the statements below, signing your name and email a scanned copy to icrouch@greensboroscience.org or mail a physical copy to Isaac Crouch at 4301 Lawndale Drive, Greensboro, NC 27455. Sign both copies and keep one for your records.

_____ I grant permission for my child to participate in Isaac Crouch's study on the impact of videogames in science education.

> _____ I agree that my minor child may be photographed or videotaped by the Greensboro Science Center. With my signature, I understand and agree that photographic images and information that corresponds to the images may be released to the public and used in various digital and written communications and advertisements.
>
> _____ I do not wish for my child to be photographed or videotaped during this study.

_____ I do not grant permission for my child to participate in Isaac Crouch's study on the impact of videogames in science education.

____________________	____________________
Signature of Parent/Guardian	Printed Parent/Guardian Name
____________________	____________________
Printed Name of Child	Date

Figure 12. Parental permission form, including photography permission.

GREENSBORO SCIENCE CENTER

[illegible]

[illegible]

May 6-17, 2014 - Ages 13-16

1. My name is Isaac Crouch. I am from Michigan Technological University and the Greensboro Science Center.

2. We are asking you to take part in a research study because we are trying to learn more about how videogames can be used to both teach science and get students more excited about learning science.

3. If you agree to be in this study you will be learning how to play the videogame Portal 2, how to design your own puzzles with the games built-in map editor, and using the map editor to design and perform virtual science experiments.

4. There are no known risks associated with participation in this study.

5. Upon the completion of this study you may have an increased desire to learn science and an [illegible] how videogames can not only be used purely for fun but can actually make learning [illegible]. You may also learn scientific concepts that will give you an advantage in science classes that you take in school in the future.

6. [illegible] with your parents before you decide whether or not to participate. Your parents [illegible] permission for you to take part in this study. Even though your parents said "yes," [illegible] not to do this.

7. [illegible] to be in this study, you don't have to participate. Remember, being in this study is [illegible] will be upset if you don't want to participate or even if you change your mind [illegible] stop.

8. You can ask any questions that you have about the study. If you have a question later that you didn't think of now, you can call me at (336) 288-3769 ext. 1399, email me at icrouch@greensboroscience.org, or ask me next time.

9. Signing your name at the bottom means that you agree to be in this study. You and your parents will be given a copy of this form after you have signed it.

____
Signature of Subject

______________________________ _______________
Printed Name of Subject Date

DATE OF IRB APPROVAL:
IRBNet NUMBER:
IRB NUMBER:
PROJECT EXPIRATION DATE:

Page 1 of 1

Figure 13. Student assent form.

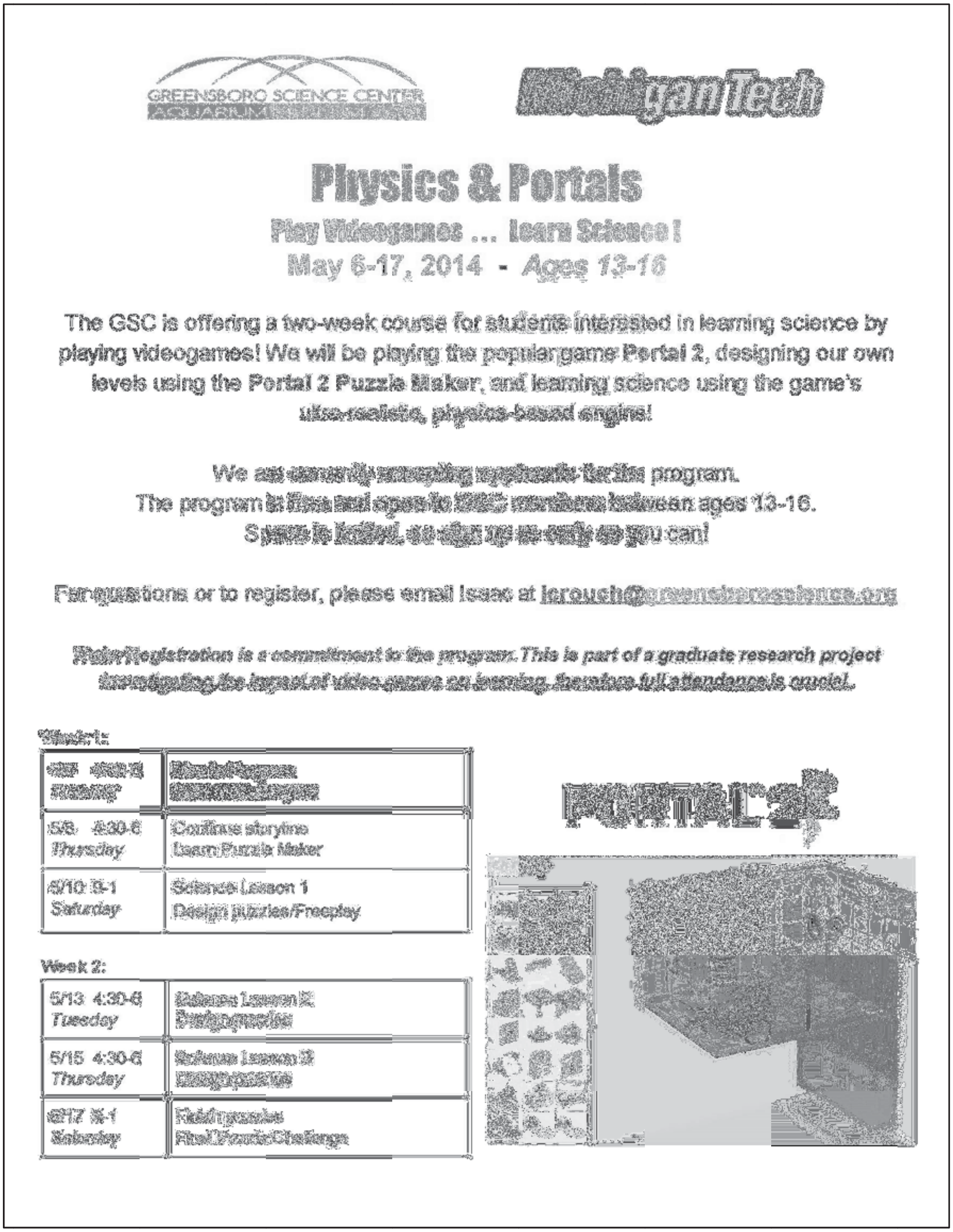


Figure 14. Program advertisement posted in and around the museum.