

RELATIVE EFFECTIVENESS OF EDUCATIONAL VIDEO GAMES
IN THE SCIENCE CLASSROOM

by

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Erik Nickerson

June 2011

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ABSTRACT

Research has shown that educational video games are effective learning tools, but have not made a significant impact in the classroom. This gap could be a result of the design of the games, in that most educational video games imitate classroom style activities (such as answering multiple choice questions or memorizing flash cards) instead of using the computer's superior simulation capabilities to create a unique learning experience. This research project examined the difference between different styles of educational video games, as well as the overall effect of these games. Each different type of game helped students learn, though the games with more words created a stronger impression that learning actually happened.

INTRODUCTION AND BACKGROUND

Video games provide students an experience which is otherwise impossible to create in the classroom. That experience can form the foundation for a student to develop ideas of increasing complexity and abstraction, even if the experience originated in the digital world instead of the physical.

As an example, students new to physics often struggle with Newton's laws. How is it that an object can just keep going and never stop? How can a student imagine a frictionless environment, when in everyday experience things slow down and stop? Even ice rinks and hovercrafts exhibit some friction, so a student can only create a pure frictionless environment in the imagination.

Dock the Spaceship, a simple video game often found on physics teacher's websites, requires the player to maneuver a spaceship to dock gently with a space station. The game can be played with friction on or off. With friction on, most students find the task quite simple. The motion of the spaceship matches common everyday experience and thus seems logical. With friction off, the motion of the spaceship matches real space travel and the task becomes much harder. On the first few tries, the spaceships twirl through space out of control, ultimately abandoned by the students. After ten minutes or so, most students figure out how to maintain control and dock the ship, and all students have acquired a direct experience with a frictionless environment. After that, Newton's first law finally makes sense.



Figure 1. An example of *Dock the Spaceship*. The student must maneuver the spaceship into the space station dock at a sufficiently slow velocity. This is very difficult without friction!

I have used this and similar video games in my classroom several times over the years to help students better understand physics concepts. The action of the game teaches the concept. Yet most games billed as “educational” rely heavily on long written text and multiple choice questions to do the teaching, then they attach all those words to some sort of game structure which has no relation to the educational content. A commonly used classroom example is Powerpoint-based *Jeopardy!* Teachers add short answer questions to a pre-set *Jeopardy!* animation, then review for the test by playing the game. In a more complex version of the same idea, the player shoots enemies, but can only upgrade weapons by answering algebra problems.

These two approaches to games, a game like *Dock the Spaceship* that teaches through gameplay which I’ll call conceptual, and a game like *Jeopardy* that teaches with

words nestled in a game structure which I'll call literary, offer distinctly different approaches to learning. To explore further, I focused my action research project on educational video games.

Dr. Walter Woolbaugh served as advisor for this project. Dr. Charles McLaughlin served as reader. Steve Kerchner, Tommy Manning, Derek Segesdy, and Craig Larimer all helped with the games and the research at Fountain Valley School (FVS). Damian Baraty, FVS technology instructor, assisted in the implementation of the games and offered good advice. Cory Carlson, CJ Holloway, and Mike Strife of Flatirons Elementary have been enormously helpful both in incorporating games into their curriculum as well as reviewing the material for the fifth graders. Diane Nickerson helped with many of the editorial details of the paper.

Focus Question

How do different types of video games influence student comprehension of science?

Sub-Question 1: How do different types of game design patterns influence student sense of learning and motivation?

Sub-Question 2: How do different types of game design patterns impact student comprehension of the science concept?

Sub-Question 3: How do teachers perceive the effectiveness of the games on student comprehension?

CONCEPTUAL FRAMEWORK

Physics can be a notoriously challenging class, largely due to the foreign concepts that the new student must master. The motivational design and simulation capabilities of video games may help.

“Physics First” is a high school science sequence that begins with physics, moves to chemistry, and ends with biology, so that a student has experience with electricity before studying electron energy states and with acids before studying amino acids. Though the movement has grown significantly in the last decade, it faces a major hurdle. Algebra-based physics (mathematically simpler than the more accurate calculus-based physics) can be difficult even for academically successful seniors. For ninth-grade students, many of whom are in their first year of algebra, the introduction of math in addition to the abstract concepts of physics causes significant learning issues (O’Brian, & Thompson, 2009). Physics is difficult to explore without math, and even Paul Hewitt’s (1999) classic Conceptual Physics text introduces a significant number of equations and calculations.

Yet the main difficulty is not mathematical, but conceptual. Most ninth graders can isolate x in an equation, just as most seniors can take a derivative. But even mathematically talented students struggle with simple physics concepts, and spatial reasoning has been identified as one of the culprits (Lindgren, & Schwartz, 2009; Newcombe, 2010; Ramadas, 2009). Physics requires a significant use of what Mel Levine (2002) calls “spatial ordering” in the neurologically based schema he developed to assess learning difficulties. Most of the education that high school students get

requires significant ability in eight other areas of the Levine “Schools Attuned” system-- such as in temporal-sequential ordering, graphomotor functions, or expressive language skills-- but with the exception of geometry and some other science work, most students have very little practice in spatial reasoning through official school activities (except for notebook organization, if taught). Must students have more experience with spatial reasoning to properly understand physics? If so, how do they get that experience?

Cognitive scientists George Lakoff and Mark Johnson (1980; 1999), citing current research in cognitive science (as well as referencing John Dewey and Maurice Merleau-Ponty), claim that all of our abstract thought is rooted in the experience of our bodies. Lakoff and Johnson come from a background in linguistics and primarily explore the use of early experiences of the body to create metaphors for understanding a wide range of concepts developed later in life. The concept of body orientation leads to the idea of “in front of” and “behind,” which can later be used to describe situations without any physical body orientation such as, “He is *behind* the other students in the class (in his understanding of mathematics).” The experience of warmth while being held by parents as an infant leads to the expression “a *warm* smile,” even though the temperature has not changed. Experience with boxes and carrying tools leads to container expressions such as, “Her argument *carries* little weight.”

How does this relate to physics? Lakoff and Johnson (1980; 1999) argue that all of physics (as well as other sciences, mathematics, and everything else) emerges as a metaphor constructed on fundamental bodily experiences. Students with more experience of the type related to development of physics concepts should have a distinct advantage in physics class.

What would that experience look like? When developmental psychologist Jean Piaget (1954) explored the development of reality in a child, he saw the growth of the object concept, the space concept, and the time concept in young children. Thus our experience with space as children (and our development of abstract constructs that enable us to properly move) forms the foundation to later understand the abstract formulations of geometry. Our experience with pushing and pulling becomes force. Our experience with spatial orientations becomes mathematics. This largely unconscious physical foundation of abstract concepts explains my own classroom observations. In my classes, students who had a lot of experience playing with mechanical objects have always done better in physics, regardless of mathematical ability or gender. Every student I have had in AP physics who has worked as a bike mechanic earned a 5 (the highest) on the exam. But then students without that experience, who spent their time reading books, for example, are at a disadvantage. How do they catch up? In a time-restricted classroom, could a short video game replace the physical experience?

Note that Piaget looks at how the object, space, and time concepts are created, but does not claim that those concepts are the foundation of the construction of reality in the child. Modern cognitive science agrees. Time, for example, is generally talked about in metaphorical terms. “Time flies.” “You’re running out of time.” “Do you have time left?” In physics, Piaget’s concepts of object, space, and time become mass, distance, and time -- the first three fundamental measurements from which the rest of physics is built (kilograms, meters and seconds in SI units). This has implications for what the cognitive process is when one does science (if science is a metaphorical construct of the mind, how then does the scientific process also yield clear results in the external world?)

which are explored by Lakoff and Johnson (1980; 1999) and many other thinkers since before the birth of the scientific process, but the question here is: what does this mean for a physics student attempting to think and act like a scientist?

For those students with less experience in spatial reasoning, a physics class must offer opportunities to develop that physical experience. Hands-on work in the lab provides that experience and has traditionally been the only solution within the classroom. But what happens when the experience is not possible? What high school physics class can charter a space shuttle to experience friction-free environments and calculate orbit trajectories? Though a student might hold an atom in her hand, can she see how it oscillates more quickly when she rubs her palms together? How does a cash-strapped teacher make an electrostatics lab that won't accidentally electrocute any students?

Recent developments in technology provide a solution. Computer simulations have been shown to be even more effective than lab time in developing conceptual understanding (Perkins et al., 2004). One study compared two groups of students ($N=231$) studying electrical circuits (Finkelstein, Adams, Keller, Kohl, Perkins, Podolefsky and Reid (2005). One group learned about circuits using only a computer simulation. A second group learned using wires, bulbs, and batteries. The computer group outperformed the physical group in both a conceptual test and in a test putting together a physical circuit. In a simulation, a student *can* control an orbiting rocket, *can* excite a group of atoms, and *can* play safely with electric fields. The student can change variables and “mess things up” (what Scot Osterweil of the Education Arcade at MIT calls “the freedom to fail” (Klopfer, Osterweil, & Salen, 2009), giving at least a

reasonable illusion of real life. The level of embodiment of this experience is disputed. For example, educator Kenneth Wesson, featured speaker at the 2011 NSTA National Conference, wrote in a recent article:

Firsthand experiences wire and develop the brain. This is why computer simulations cannot substitute for real-world, real-time, firsthand learning experiences. The representations of objects and events should follow the experiences they represent . (Wesson, 2011, pg. 2)

However, as a secondary experience when a primary experience is unavailable, or as a student-controllable follow-up to a laboratory experience, computer simulations clearly offer a unique new tool for developing cognition.

Video games can take simulations one step further. To be effective, simulations need a carefully structured activity to accompany the simulation time. A video game primarily differs from a simulation in its use of an inherent structure to clearly define the goals of the activity (shoot all the bad guys, solve the puzzle, or get the electron through the circuit). Many video games also follow established psychological techniques to motivate the player to partake in and finish the game. The story of the game incites questions in the player's mind that can only be answered by playing the game (How can the hero shoot all the bad guys when the bad guys are too fast? How can I solve the puzzle? How can the electron move through the circuit when the other electrons are so energetic?) Unlike a book, which Socrates mocked for its inability to answer or ask a question (Plato, *Protagoras*, 1956), video games can actually talk back.

In his book *What Video Games Have to Teach Us About Learning and Literacy* (2008), as well as in other books and articles about the same topic, linguistics professor James Paul Gee argues that commercial video games use educational techniques superior to most of the educational techniques currently used in the classroom. In a game such as *World of Warcraft* (WOW) or *Halo*, an experienced player has developed a deep content knowledge of the game and its environment. For example, in the WOW sub-game *The Defense of the Ancients* (DOTA), a good player has memorized the characteristics of about sixty different characters, each of which has about twenty different traits, and each of which can possess up to about a hundred different items to help in battle. Each character changes traits as it evolves within a game, and how a character behaves when it battles other characters is different *for every character*. That's about 150 million unique relationships, of which a deep knowledge provides a major advantage when playing the game. And yet, people play. They join online groups to build their knowledge. They buy thick books full of technical detail that only makes sense after months of playing. They spend forty hours a week or more practicing. One hundred and fifty million unique relationships are far more than are typically investigated within the entire high school science canon of biology, chemistry, and physics combined, so it is not surprising that expertise in DOTA requires years of dedicated playing. How game companies manage to teach this level of knowledge is the focus of Gee's research. One of several ingredients he identifies is the embodied thought of cognitive science mentioned above. The technical detail of a thick book about how to play DOTA only makes sense after some experience playing. Gee says, "The problem with the texts associated with video games – the instruction booklets, walkthroughs, and strategy guides – is that they do not make a

lot of sense unless one has already experienced and lived in the world for a while” (Gee, 2008, p. 98). Most schools, argues Gee, have this backward. The schools teach the vocabulary and techniques of a subject before the student has any experience with the subject. The expectation is that the student can read carefully and take good notes and in this way, through memorization, careful repetition, and flipping back and forth between pages to make connections between definitions in the text, come to at least a partial understanding of the subject, with the details to be filled in, maybe, by later experience. Gee (2008) notes that this would also be possible with a detailed technical manual of a video game. One could, theoretically, piece together all the traits and characteristics of *DOTA*’s Kardel Sharpeye by taking careful notes. But then “it’s all ‘just words,’ words the ‘good’ students can repeat on tests and the ‘bad’ ones can’t” (Gee, 2008, p. 99). Gee (and Wesson (2011), and Lakoff and Johnson (1980; 1999), and many other cognitive scientists) argues that no learning is taking place at all.

Throughout his book, Gee compares learning a video game to the process of learning science. He uses science because the science classroom, in particular the lab and the ability of a student to try on the identity of being a scientist, comes the closest to following the path set out by cognitive science (and stands furthest removed from the push to test and drill in other subjects). In learning both games and science, the student can have the experience of probing and refining ideas about what works and what doesn’t. Gee’s examination is extensive, but the important concept here is that because a student can probe and experiment within a game, receive immediate feedback, and immerse themselves in the story of the game, a game can provide an experience closer to “embodied thought” better than anything except a physical experience.

Gee (2008) does not examine educational video games, nor does he argue that video games should be used in the classroom (though he doesn't argue against it). Gee only looks at the techniques the gaming companies use to educate players. Can a video game be used to teach academic content, and, more importantly, would the use of a video game be more effective than other techniques in teaching that content?

Video games of any sort have been repeatedly demonstrated to be effective educational tools (Annetta, 2008; Annetta, Cheng, & Holmes, 2010; Annetta, Murray, Laird, Bohr, & Park, 2006; Bottino, Ferlino, Ott, & Tavella, 2007). For example, Goodman, Bradley, Paras, Williamson, & Bizzochi, (2006) tested hockey players (n=130) about concussion knowledge using questions about concussion symptoms in a game environment. The players answered questions to prevent a hockey puck from sliding into the net. The group that played the game did better on the post-activity test than a similar group that learned the same material by more traditional means. Rosser et al. (2007) found a correlation between performance in *Halo*, a 3D shooting game, and facility with new surgical techniques involving remote manipulation of a tool. Since both the game and the surgery have only the 3D visualization in common, this result suggests that playing *Halo* improves 3D visualization abilities. Sports-related video games have become a major training tool for even elite athletes, as dramatically evidenced by a pro running back who ran out the clock in a close NFL game by running sideways in front of the end zone before stepping across to score (Suellentrop, 2010). After the game he admitted he learned the move from *Madden Football*, a game that "all the players play." The spatial ordering of field position required in team sports is closely allied with the

spatial ordering required in geometry or physics, according to Mel Levine's neurological schema.

So, games can teach. Games can teach a lot of detail quite well. Games can be used effectively in an educational setting. But there seems to be an inherent difference between learning the details of a Kardel Sharpeye spell to quickly use in battle and memorizing the answer to a concussion question to avoid being scored on. The first looks like the probing that occurs in a science lab or guided simulation, in that the content is learned within a rich context in which the content can be usefully applied. The second is a familiar type of educational game model – the player goes about some sort of activity, then encounters a multiple choice question related to a school topic, but unrelated to the story of the game, except that the player must answer the question in order to continue playing. Looking at Gee's analysis, the second type seems more similar to thumbing through a textbook without any real context.

Dr. Ruben Puentadura's Substitution, Augmentation, Modification, Redefinition (SAMR) model more clearly defines the differences between the games (Puentadura, 2010). Puentadura (2010) developed the model to describe the effects of technology in general, but also applied it more specifically to educational video games. Games that *substitute* or *augment*, the S and the A of the model, take typical classroom activities and put them into a game. Puentadura describes a "good" example of a substitutive game as a first person shooter (in which the player moves around a virtual environment shooting things) in which progress is frequently interrupted by algebra questions. If the player answers the question correctly, he gets some sort of upgrade that helps him play better.

Puentadura states that there are good and bad examples of the games at each level, but does not comment on the relative educational benefits of each.

Moving up the scale, games that *modify* or *redefine*, the M and the R of the model, introduce a subject in a way that cannot be done in a typical classroom. For example, *Dock the Spaceship*, mentioned in the introduction, requires the player to maneuver a spaceship to dock gently with a space station. The student can develop an intuitive feel for Newton's laws through playing the game, even if the game never mentions Newton, mechanics, or even friction. This sort of experience redefines how the subject can be taught. Note that this game also teaches by creating an embodied experience. Words, definitions and content are not yet necessary. Those come later, after the experience.

This discussion of video games in the classroom would not be complete without mentioning "flow," a psychological term introduced in Mihaly Csikszentmihalyi's *Flow: the Psychology of Optimal Experience* (1990). Csikszentmihalyi's evaluation of people's experience throughout the day and various activities led to a description of "flow" states. That is, there are certain common traits amongst people and activities when a person is performing at their best and most attentive. Designing games around Csikszentmihalyi's psychological parameters has led to increasingly "addictive" as well as soothing games. Many of the aspects of the flow state match the aspects inherent in a good learning environment (in addition to cognitive science, Gee also frequently references Csikszentmihalyi in describing how commercial games ease a player into the complexities of the game). The challenge must be difficult enough to be interesting but not so difficult as to be beyond the player's or student's skills. The participant feels a

sense of intrinsic motivation to complete the task. The participant becomes fully focused and loses any sense of self while engaged in the activity. The goal of the activity is clear. Since these conditions are reflected in a quality learning environment, they will be used here to assess how effective the games are.

So video games of all types have been shown to effectively teach. All abstract concepts are rooted in embodied thought, and carefully designed simulations may be more effective than physical experience. Many “educational” games teach using disembodied thought, but can also be constructed so as to teach by creating embodied experiences. So the question is: how necessary is embodied thought in an educational video game?

METHODOLOGY

Demographics

The treatments took place at two schools.

Fountain Valley School (FVS) is a private boarding school near Colorado Springs. Two hundred and fifty students attend the school in grades 9 to 12. Of those, sixty percent board at the school. Fountain Valley has a diverse international population, with at least a quarter of the students speaking English as a second language or growing up overseas. In a typical year, about thirty different countries are represented from all continents except Antarctica. The school is academically rigorous and relatively expensive, but over half of the students receive financial aid.

Flatirons Elementary school is a K-5 public school in Boulder, Colorado. The majority of the students are white and affluent, but a significant minority belong to a different ethnic group or class. The school is renowned as a good school, and local realtors tout Flatirons Elementary as a selling point. About 360 students attend the school.

About one hundred sixty different students participated in the study in three distinct groups: FVS underclassmen, FVS upperclassmen, and Flatirons fifth graders.

Of the eighty-five (85) FVS underclassmen, most were in ninth grade and 14 or 15 years old. In addition to the United States, students came from Russia, Kenya, Tibet, Korea, Taiwan, Poland and Canada. At least eight of these students were English language learners. Some of the American students had grown up overseas in Saudi Arabia, Mexico, Venezuela, and Japan. The majority of the students were white and affluent. However, forty percent have significant financial help (from the school, ARAMCO, or programs like ABC), and about half of the students are racially mixed or not white. Since the school is private and selective, the students as a whole have above average academic skills.

Of the nineteen (19) FVS upperclassmen in two AP Physics classes, all were in 11th or 12th grade and had significant academic ability. Nine of the students held a passport from another country, including Mexico, Canada, Korea, and Taiwan. About half of the students were white, and the other half were Asian, Black, or Hispanic. Some had millions in their trust funds, while others worked a part time job to help with expenses. Most notably, only three of the students were female.

Of the fifty (50) Flatirons fifth graders, about sixty percent were white, with the remaining forty percent claiming a diverse range of ethnicities. The school is located in a wealthy neighborhood and parents tend to be very involved. Some students come to the school from other districts.

To properly examine the effectiveness of video games in the classroom, I needed to look at several different aspects of effectiveness. First, do the games, regardless of style, actually have an impact? Second, where does that impact occur, i.e. in content learning, motivation, or in creating an embodied experience? Third, how does that impact change in different situations, such as between different levels of the SAMR (Substitution, Augmentation, Modification, Redefinition) model or different groups of students? Does a redefining game create an embodied experience that leads to richer understanding of the material than a substitutive game? Does a substitutive game still create a positive impact? Does an augmentative game truly augment classroom activities? Do only students of a certain age respond well, or can it work for several age groups?

To answer these questions I introduced six different games to one hundred sixty (160) different students in the 2009-2010 and 2010-2011 school years. Educational games that can be used in a classroom as part of a curriculum are scarce, and finding a game that can also fit the demands of this research project near impossible. So after a year of unsuccessful searching (during my MSSE courses EDCI 504 and 505 and the summer thereafter), I taught myself how to program. I designed and programmed all of the games listed here with the intention of fitting them into the framework of this research.

Treatments and Design

Heat

The first game, *Heat*, was designed to create an embodied experience of molecular motion for ninth grade conceptual physics students. Though the programming code of the current version no longer reflects this, the code of my original game relied heavily on Keith Peters engine for particle collision in *Actionscript 3.0 Animation* (2007). Teaching the kinetic motion of gasses had always been difficult. Students could memorize answers, but shaking marbles in a box or steel beads on a mechanical oscillator never seemed to give students a real feel for what the particles were doing. Answers on test questions always appeared memorized, and students did better on more physical units surrounding the topic such as Newtonian mechanics or heat transfer.

Heat puts the student in control of a single molecule of gas. The student must navigate across a box full of flying particles (a gas at the molecular level) without heating it up. There are two solutions. The student can attempt to dodge the other molecules, thus avoiding any collision. Or the student can maintain a slow speed so that should a collision occur, little kinetic energy will be transferred. In either case, the student “experiences” what happens at a molecular level in a gas.

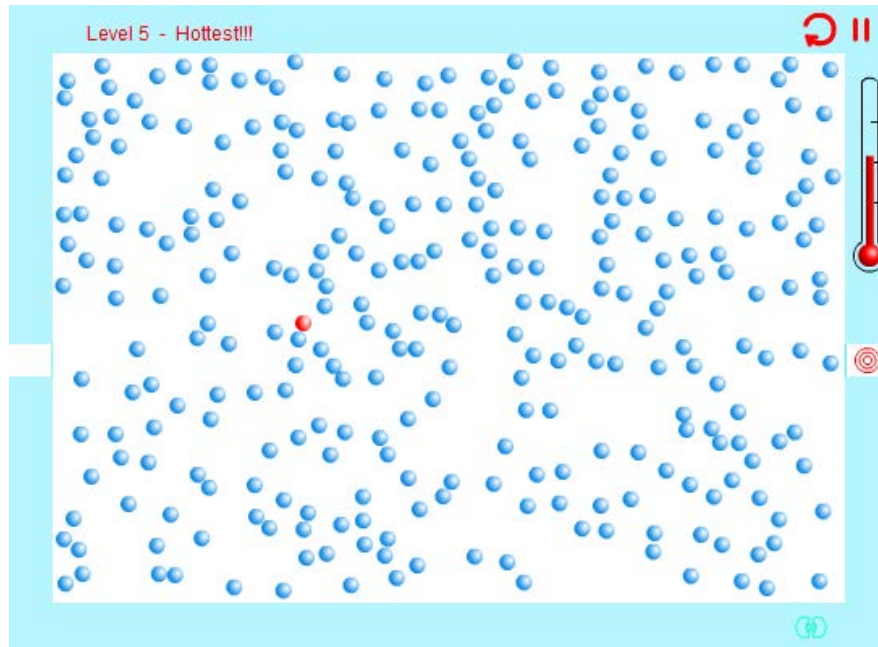


Figure 2. The *Heat* game. The player controls the red ball. The thermometer measures the kinetic energy of the blue balls.

The game was introduced to three classes of conceptual physics students ($n=35$) at the beginning of a unit on the kinetic theory of gasses. Students could play the game as homework, with no consequences for not playing. The next day, students filled out a brief survey and answered some questions about the kinetic theory of gasses. I interviewed several students about the experience (as well as asking some general questions of the class as a whole). Two weeks later, I gave a test on several topics and included two questions specifically about the kinetic theory of gasses. Though not a solid comparison due to differences of students and years, I could also draw some comparisons between the results of this year and the results from the same unit in the previous nine years. One year later, I re-interviewed three students about the game.

AP Mechanics C Review

The AP Review game has fifteen levels. Each level introduces a problem such as, “What must be the initial velocity of the cannonball in order to hit the target?” When the student enters a solution, the cannon fires and the student discovers whether or not they were correct. Because players tend to guess in this situation rather than solve, I installed several mechanisms to force a real solution. After every attempt, one or more parameters of the problem changed. If a player answered incorrectly five times in a row, they were pushed back to the previous level. This is an *augmentative* game, since the visual result of the solution augments the problem solving, but does not actually change the approach. Many of the problems could be created in the same way in the physical world. (Another game this class played involved problems with spaceships orbiting planets. Because that could not have been created in the normal classroom, it would be modifying or redefining on the SAMR scale.)



concussion risk

Choose an angle to shoot the ball onto the pad.

Muzzle velocity = 23 m/s

Angle in degrees =

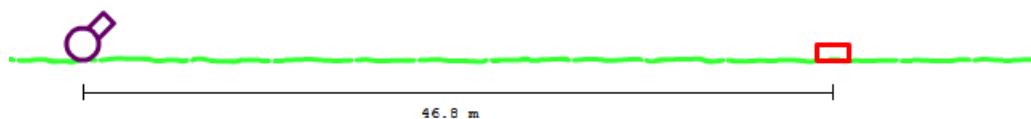


Figure 3. The ‘AP Review’ game. The player solves the problem, enters a value, then clicks the green button to see what happens.

In 2010, twelve 11th and 12th grade students played the game in the week before the AP exam. We played the game the entire week, but students missed an average of one or two classes during the week due to other AP tests. Only one student completed the game, after four days of effort. At the end of the week all students completed a survey. After the AP exam, I interviewed several students about the experience. I also interviewed two students one year later. Two teachers observed the class for about fifteen minutes each on two different days and gave me feedback about the class.

In 2011, seven 11th and 12th grade students played the game for several days in April to begin the review process. Most completed about five levels. All students completed a survey. I interviewed two students immediately after the last day. I also interviewed the teacher of the class.

Although students commented about how much they did or did not learn in the exercise, I have no significant for this game about how much students learned. Although the 2010 students did significantly better on the AP exam in this year than in previous years, we had made many other significant changes to the course (such as teaching just Mechanics C, cutting the course in half from full C, and applying stricter prerequisites for potential students), any of which could have had an outcome on the final scores.

Electrical Current -- Substitutive vs. Redefining

I used two video games to introduce electrical circuits to a conceptual physics class in April of 2010 ($N=35$) and again in April of 2011 ($N=50$). Students played two

games. In one game, students moved electrons around a circuit. In the other, they answered multiple-choice questions about circuits.

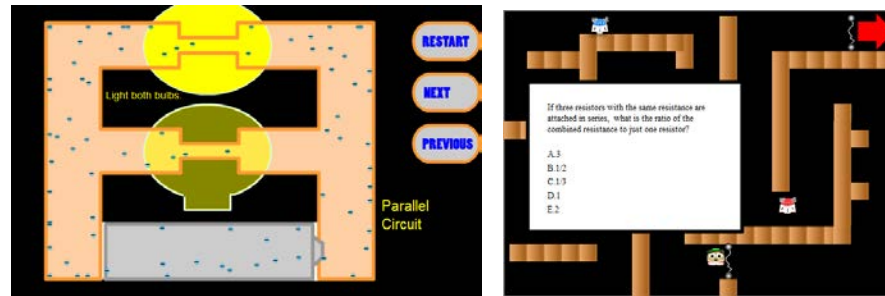


Figure 4. The electrical circuit games.

On the first day of 2010, students played one game for about 30 minutes, then took a quiz and completed a survey. On the second day, students played the other game, then took the same quiz and completed the same survey. Two classes played the literary game first while the third class played the conceptual game first. The quiz did not count as a grade. The surveys were anonymous. Two weeks later they took a test, and I recorded the test answers that related to the game. Another teacher observed one of the classes, and I interviewed him afterward. One year later, I interviewed three students about the game.

In 2011, the classes did one game as homework, then played the second in class. They completed quizzes and surveys as in 2010. Two classes played the literary game first and two classes played the conceptual game first. I interviewed two of the teachers and ten of the students afterward.

The survey used for this and the next treatment was adapted from EGame Flow (Fu, Su, & Yu, 2009), which itself was modeled on Csikszentmihalyi's psychology of flow. I removed questions that the authors themselves found problematic. I also removed questions that seemed irrelevant to my treatment or that other advisors had questioned. The remaining questions fit into eight categories of "flow" as outlined by Fu et. al.: concentration, goal clarity, feedback, challenge, autonomy, immersion, social interaction, and knowledge improvement. This pre-existing instrument helped with validity and reliability.

5th Grade Chemistry Substitutive vs. Redefining

To deepen the examination of the contrast between substitutive and redefining games, I introduced two games to two fifth grade classes (n=35) that were studying mixtures and solutions. One game, again, involved answering multiple choice questions specific to what the students had been studying. The second game allowed the students to manipulate any polar or ionic molecules by creating a strong electric charge with the mouse. The main challenge of the game is to evaporate all the water in order to crystallize the chemical. The chemicals matched the chemicals they would be using in the unit in class.

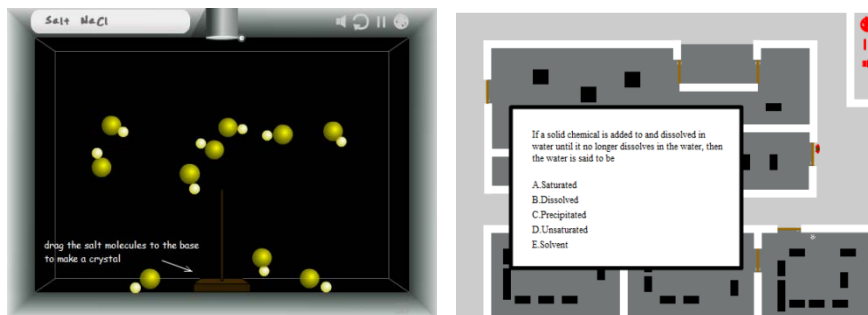


Figure 5. Mixture and Solutions games.

After each game, the students completed a survey and brief quiz. The survey for the fifth graders was simplified to be grade level appropriate. In addition, several students were interviewed afterward and the teachers provided feedback about their impressions of the games.

Research Design

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

Several different instruments contributed to the answers to each of the research questions. The variety of the instruments improved validity and reliability.

Table 1
Triangulation Matrix

Research Questions	Data Source 1	Data Source 2	Data Source 3
<i>Primary Question:</i> How do different types of video games influence student comprehension of science?	Student surveys	Student quiz and test results	Student interviews
<i>Sub-questions:</i> How do different types of game design patterns	Student surveys	Student interviews	Instructor and outside observer notes

influence the student's sense of learning and motivation?			
How do different types of game design patterns impact the student's comprehension of the science concept?	Post-game quizzes	Tests administered weeks later	Instructor and outside observer notes
How do teachers perceive the effectiveness of the games on student comprehension?	Instructor notes	Teacher interviews	

As mentioned before, most of the surveys were adapted from EGame Flow (Fu, Su, & Yu, 2009). The use of this established instrument backed by psychological research contributed to validity and reliability of the study and provided a clear format for evaluating student experiences with the games. The AP Review game survey was not adapted from EGameFlow, but was also designed to evaluate student experiences.

The student interviews provided an opportunity to triangulate the data collected in the surveys. In the interviews I was able to probe deeper into the trends that appeared in surveys.

My own notes and the observations from other teachers provided a contrast to the student's perceptions. A teacher sees the students in many different situations, and can evaluate student behavior during the games in contrast to student behavior during labs or lectures.

The quizzes and tests provided the best evaluation of actual student retention as a result of the games. The questions involved reading and writing, and as such may have favored learners who excel in reading and writing rather than in spatial logic. This could have biased the results toward the literary games. To counter this, students were allowed to draw answers to questions such as “Describe a series circuit.” However, a student with strong spatial reasoning skills but poor reading and writing skills may not have been able to properly demonstrate what they learned.

Despite the possible bias toward literary games, could a conceptual game still compete? Will the results show any difference at all, and do the games actually work in the classroom?

DATA AND ANALYSIS

I collected data for four different treatments: ninth grade kinetic theory of gasses (one game), twelfth grade AP Mechanics Review (one game), ninth grade circuits (two games), and fifth grade mixtures and solutions (two games). I will analyze the results for each section by data type.

Ninth Grade Kinetic Theory of Gasses

Teacher Notes

On the evening of the assignment, I supervised mandatory study hall, which was required for all freshmen. Many students took advantage of the opportunity to play a

game during study hall, though at the end of the study hall, everyone immediately left to do other things. No one got “sucked in” to the game.

As I stood in front of the class on the following day and asked about and reviewed the game, the student response was muted. Some nodded their heads to say they enjoyed it. A few said it was “frustrating,” and most sat silently. My class is usually a bit louder, so the quiet response was unusual.

In class in the days that followed, any potentially positive effects of the game were invisible. I reviewed the relevance of the game for about five minutes. One of the brighter students in one class asked, “So the balls are like what happens in a gas when it heats up?” No one else asked any questions.

So I continued with activities as I had in previous years. I introduced the kinetic theory of gasses and did physical demonstrations such as shaking marbles in a box and vibrating a square of metal beads on a mechanical oscillator. No one brought up the game again in class. A day later, we moved on to pressure and buoyancy.

I had been eagerly making notes during this process. *Heat* was, after all, the first game I had ever made. I had introduced a few video games before, but I always had to explain how they related, or which aspect of the games to focus on. *Heat* was designed to specifically fit the topic and the class. The idea was that *Heat* would give the students a direct experience of what it felt like to be a particle in a gas, an experience otherwise unattainable in real life. After experiencing the conditions of the particle, they would all just “get it.” But the muted class response certainly was not supporting my ambitions. Even in student interviews, the most enthusiastic students simply talked about “having

fun” and “getting addicted,” which flattered the game but not the learning objective. So after a couple pages of notes that mostly say “Nothing is happening,” I wrote, as my last entry, “Oh well.” That meant, “It didn’t work at all. It’s useless. It’s no good for the classroom after all. That was a lot of work for nothing. Time to look elsewhere for the key to turning a bunch of ninth graders into physics geniuses in only a few hours of class.”

Survey

The survey was administered at the beginning of the class following the homework assignment. It was intentionally anonymous so that students could freely tell me how much they played and not worry about getting the question about “What happens when the gas heats up?” right or wrong.

Although 38 students were in the class at the time, only 31 surveys were completed. The question “How long did you play the game?” is the best indication of actual student participation. About 8 (eight) (26%) students marked 1 or 2, indicating little or no time playing the game. Twelve students marked 3, indicating an average time, presumably 15 to 20 minutes. Eleven students marked 4 or 5 (or, with emphasis, made a 6), indicating a playing time of 30 minutes to more than an hour.

I divided the surveys into three groups to judge the effect on knowledge development. Specifically, did the amount of time spent playing influence the student’s answer to the question “Why would the green ball ‘heat up’ the gas every time it collides with a red ball?” Although the groups that played longer did slightly better on this question than the group that played the least, the difference is not statistically significant.

Three members each from the middle and the longest playing groups correctly stated that the motion of the green ball can increase the velocity of the other balls, thus heating up the gas. Only one student from the least-playing group correctly answered the question. However, this does not necessarily indicate a difference. With only eight students in the least-playing group, statistically there should have been two correct answerers (since there were three each in the groups of twelve). With this small of a group, the difference between one and two is statistically insignificant. Even if there were a slight difference, the difference could have been attributable to other factors, such as: students with better study habits were more likely to know the answer previously and to do the optional homework assignment of playing the game.

One correct answerer from the middle group stated “I started with only playing for fifteen minutes but then I finished my homework and started playing more.” Then, in answer to a later question, the student stated “I could not stop playing.” I left the student in the middle group since he or she marked 3 and the exact length could not be ascertained. Moving the student to the longer-playing group would have re-distributed the weights, but, again, the samples are quite small.

The three groups also showed similarities in answering the question with one of two misconceptions. Some students attributed the rise in temperature to friction in one way or another. This likely came from previous class work in which we looked at friction and how it works at the molecular level. The second misconception was somewhat subtle. Many students indicated that faster moving things are hotter. This could mean that the student correctly interprets heat as a change in kinetic energy at the molecular level. But it might also mean the student thinks that heat is still a distinct,

mysterious property that fast moving things simply have more of. Though such a misconception might be attributed to the loose way in which heat and energy are used in regular speech, it might also be attributable to the game. The ball collides, the thermometer rises. A student could easily retain a concept of heat as a mysterious property of the red ball that gets transferred with each collision.

Student enjoyment of the game was largely positive. Students rated the game a 3.6 out of 5 for enjoyment. Comments often expressed enjoyment of the game, such as “It was challenging and got harder,” “I liked the whole game! Trying to weave through green balls is fun!,” “It was amusing for ADHD-but-not-ADHD child.” Even negative comments from those who ranked it lower reflected issues that could be corrected, such as “I wish it were longer,” “Frustrating glitches,” “It’s frustrating because the ball doesn’t immediately change direction.”

Interviews

Within a few days of the assignment, I interviewed six students – three boys and three girls. The interviews were not completely random, as I sought out students with different lengths of admitted playing time.

Based on in-class responses and the student interviews, I detected no significant gender issues. Though the most enthusiastic player was a boy, several girls were also quite enthusiastic. The female interviewee who was most enthusiastic turned the interview on me and asked a lot of questions about how the mechanism of the kinetic theory of gasses works. The most enthusiastic boy interviewee, on the other hand, was more interested in the glitches and bugs in the game (he found all of them), but didn’t

fully understand the concept, nor did he show any particular passion for understanding the concept. This may have only been a temporary inability to express himself, as he clearly understood the concept on the subsequent test.

One girl expressed some frustration with the game. She played a lot, she said, but couldn't understand how to play it. She got a lot of help from a few other students, usually in the Campus Center where students would hang out. She is a very good student overall. On the circuits game in the second semester, she became very competitive and emotional, and was quite frustrated that she could not play as well as other students. However, when asked if she wanted to stop, she absolutely refused. I think the frustration expressed in the interview was genuine, but had a positive side, i.e. that she was pushed to learn something new. She wanted to do very well but could not improve as easily as she usually could.

All in all, the interviews confirmed my suspicions from the classroom. The students mostly enjoyed the game, but could not yet express any knowledge gained, if it existed at all. Granted, I expected nothing more. I had not taught them the requisite vocabulary to speak about the process, and the game did teach in an unfamiliar way. But I had thought there might be some glimpse of a deeper, more intuitive access to knowledge.

Test

One month later I gave the final exam for the semester. The test covered a wide range of topics in addition to the kinetic theory of gasses. One particular question asked, "Question # 47 : At the molecular level, what happens when something heats up?" Based

only on my nine prior years of experience, I guessed that this would be a particularly difficult question for the students, probably in the top third of difficulty in questions.

What actually happened blew me away. On the test overall, students averaged 85%, but there was a significant amount of extra credit as well as some multiple choice. So the average for the main portion of the test was closer to 80%, and the average for free-response questions about 78%. On this particular free response question, which I expected to be difficult, students scored 90%. Furthermore, two of the students who completely missed the question were still learning English. One of those students later explained that she had not understood the question. If I exclude their two scores, the average on the question leaps to 96% (n=35). The hard question had become one of the easiest on the test.

But that's not all. What really blew me away, and forever changed my perception of teaching, was the personality and description of the responses. For example: "Molecules start getting hyper. They move around and don't stop if the heat is up." "The molecules move faster and bump into each other." "It starts to vibrate. Everything then gets heated up and the molecules go crazy and bounce off each other. " "The molecules start moving faster like in Heat when the green dot touched a bunch of red dots they all started zooming around." From the enthusiastic boy player interviewed above: "It begins to move very rapidly bumping into other molecules heating and expanding continuously." From a girl who confessed to playing the game in her free time, and who scored a 70% overall on the exam, 63% on free response: "When something heats up the molecules in the heated up thing are moving faster and faster, rocketing around and wishing there were

more space.” That is to say, this girl did poorly in areas taught by traditional methods, but well on thermodynamics questions.

Over a third of the class gave correct responses that were clearly inspired by the heat game and distinctly not memorized. They had, to my perception, developed a gut feel for the kinetic theory of gasses. Though I had occasionally seen fresh, non-memorized answers from students in the past, I had never seen so many on one question.

One Year Later

To check long term student retention, I interviewed three students one year later. All of the students remembered the game. All of the students could also explain the relation between the game and the kinetic theory of gasses. However, one student still held the misconception that the friction of the atoms rubbing against each other caused the heat.

Twelfth Grade AP Mechanics Review

Students in 2010 ($N=12$) played the AP Mechanics Review game during the entire week before the AP exam. In this way, students could miss class to take another AP exam, then return to physics and pick up the review in a somewhat self-paced manner. Some students spent only two classes on the game, while others spent five, depending on how many other AP classes they had.

Students in 2011 ($N=7$) played the AP Mechanics Review game for two and a half days in class to begin their review process.

No data relating to improved student ability was collected during the treatment. Eleven students in 2010 passed the AP exam with an average score of 4.4 out of 5. A twelfth student who only played the game for one day did not pass. However, many other factors could have contributed to the student performance improvement over previous years. Stiffer class prerequisites, a switch to just Mechanics C from full Physics B or C, and a smaller class size could have all contributed to higher scores.

Teacher Notes

During the classes, I made notes about the process. Students very quickly engaged with the problems. They were serious during game time, but then these were advanced students in the last week before the big test. Students often paired up to solve the problems, though some preferred to work alone. A couple of the problems in 2010 were slightly off (the cannonball consistently landed a few meters short of the target), and students enjoyed some pride at identifying the teacher's errors.

The problems were relatively difficult, and students had to work out the solutions on one or several pieces of paper. Combined with the desktop computers and the shortened desks of the computer lab, this made for awkward work spaces. No students shouted effusive praise at their teacher for making such a brilliant game, but when asked if they would like to do something else to review, everyone always refused. The game provided a fresh and novel approach to the same old problems.

One student attempted to guess his way through the game, and successfully made it to level 11 of 16 despite my anti-guessing obstacles.

In my notes, I painted a picture of student involvement that could have been interpreted as half-interested or even bored. Based on student comments in the surveys and interviews, the quiet attentiveness of the class during the process actually reflected focused attention or even “being in the zone,” i.e. being in the state of flow that Czikszentmihalyi describes.

Teacher Interview

In 2010 two teachers visited and observed the class for about ten minutes each. They both said the class was very focused, and one wondered if it would be possible to create a similar game for AP Chemistry.

In 2011 I did not teach the class so another teacher was in charge of the class for the entire process. I interviewed him for half an hour about both the AP classes and some of the conceptual classes that he taught. In his perception, the AP students enjoyed the game, but did not get as much out of it as the freshman did with their games. The AP students were smart and motivated, and would have done the problems even without the game to supply motivation. And though the visualization helped, the AP students had already developed a good sense for physics, whereas the ninth-graders had not and thus benefitted more from their games.

Survey

At the end of the week, the students filled out a brief survey. They rated the game a 4.4 out of 5 for it’s ability to help them learn physics. In the other categories they

rated the game at 4.7 or higher, indicating they enjoyed the problems in the game better than in a textbook and would recommend the game to other students.

One student gave the game a 2 for helping him learn physics, but stated “I didn’t really try but if I would have it would have helped a lot.”

The main advantage of the game over the textbook is that the situation of the problem and the answer are both dynamically displayed. All but two of the students pointed to this above all else in their comments: “The game allowed us to better visualize the results of entering certain values or answers and was a nice change from solving inanimate problems whose set-ups may not have been as readily apparent.” “The gratification of seeing the ball hit the target increased the motivation to solve the problem correctly.” “You could actually see what happened when you put different answers so I got a very good idea of what the general physics concepts were.” “Since the variables changed, it forced me to create generic/conceptual solutions over numeric approximations. It also made me work many steps ahead.” “Made review very enjoyable, able to see objects actually moving, visualize problems.” “It created a different approach, with interactive feedback – it made me want to get it” “It was a good intuitive way to view the physics involved.” “It is entertaining that I could keep trying questions without a big stress.”

Interviews

After the end of the exercise, I interviewed six students. Students were selected by availability and may not have been random. In response to the question, “Should I do

this with future classes?” the response of all was “Oh yeah” and everyone was very positive and enthusiastic about the game. It should be noted that I also did several digital labs with the 2010 class which were similar to single levels of the game. During those labs, students worked in groups to solve the animated problem. Some of the discussions included those labs.

One student was headed to MIT, where, he had been led to believe, much of the work would be oriented around solving animated problems in groups. He was looking forward to that, and enjoyed what he considered to be a preview. He said, “I wasn’t expecting this at all. I thought it was just going to be another *Jeopardy* game.” (Referring to Powerpoint-based *Jeopardy* games he had played in other classes.)

One student did express some frustration. Like the others, he enjoyed the game overall. But he was somewhat frustrated by “extra” challenges I had thrown in. Some of the problems were off (due to programmer measurement error) and he had found those. But some of his frustration also related to an earlier lab simulation of orbiting bodies in which the answer required mathematics and detail that went significantly beyond what was necessary for the AP exam. In an interview with this student one year later, he said that the game helped him visualize the problems, but did not necessarily add to his physics knowledge. He had already learned the physics in labs or problem sets. This student earned a 5 on the AP exam.

Another student with extensive interest in and knowledge of computer programming admitted that he tried to decompile the code to find the random variable that made each problem unique. He could not find it, so we spent part of the interview

looking at the code. This served to help his understanding of physics, as he could see how the mathematics translated into realistic motion on screen. This would suggest that much of first year physics could be taught through programming.

Ninth Grade Circuits

Eighty-five students in two successive years played two games relating to electrical circuits. After each game, they completed a survey and took a quiz.

The Survey

The students could select answers from 1 to 5 for each question, where 1 represents “strongly disagree” and 5 represents “strongly agree.” Occasionally a student wrote “0,” “6,” or a fraction such as “3.5.” I recorded these answers as “0,” “6,” or “3.5.”

Compiling, averaging, and sorting by category yields this comparison chart:

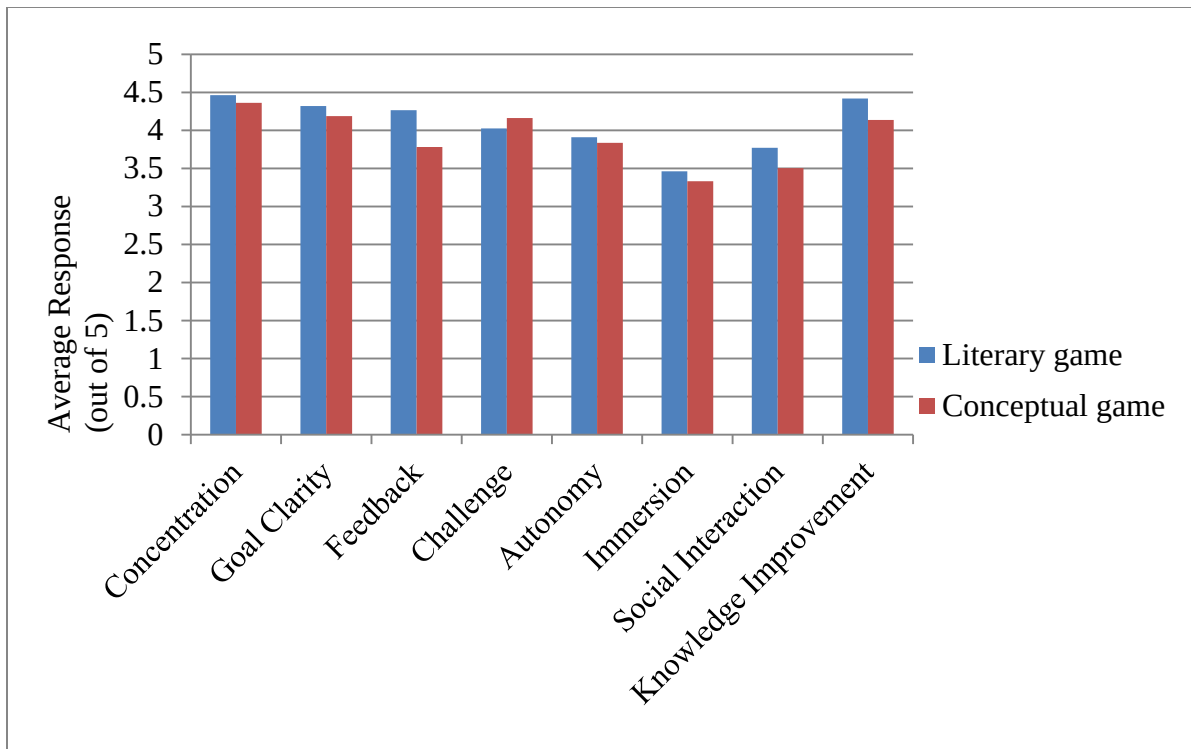


Figure 6. Ninth Grade Survey Results, (N=73).

This chart implies a greater sense of flow for the literary game. The conceptual game only rivaled the literary game in areas of challenge and autonomy. Because the conceptual game had an unfamiliar type of game play, many students found it more challenging. The literary game provided the very familiar task of navigating a maze while staying away from bad guys. In answer to questions relating to autonomy such as, “I feel a sense of control over the game,” the games essentially tied. In all other categories, the literary game was favored.

For a more accurate statistical analysis, I checked the P-value for each category to determine how likely each difference represents an actual difference. Each question was

treated as a new sample, such that thirty three students answering three questions in a single category yields 99 results. Due to such a small difference between the games, the “Autonomy” category would show this particular difference about 80% of the time, indicating no significant change from random statistical fluctuations. The remaining categories would only reach such a difference due to random fluctuations less than 1% of the time, strongly suggesting that the differences are real.

Students generally gave both games high marks, which may or may not have reflected high praise. Some students tend to give high marks anyway, just to “be nice.” A second survey of a more standard classroom activity such as completing a worksheet would have clarified the significance of high marks.

The Quiz

I created a rubric for grading the quizzes, then graded each quiz without knowing which game the student had just played to avoid as much as possible the effect of any personal bias. The quiz score averages for all classes and each individual class are:

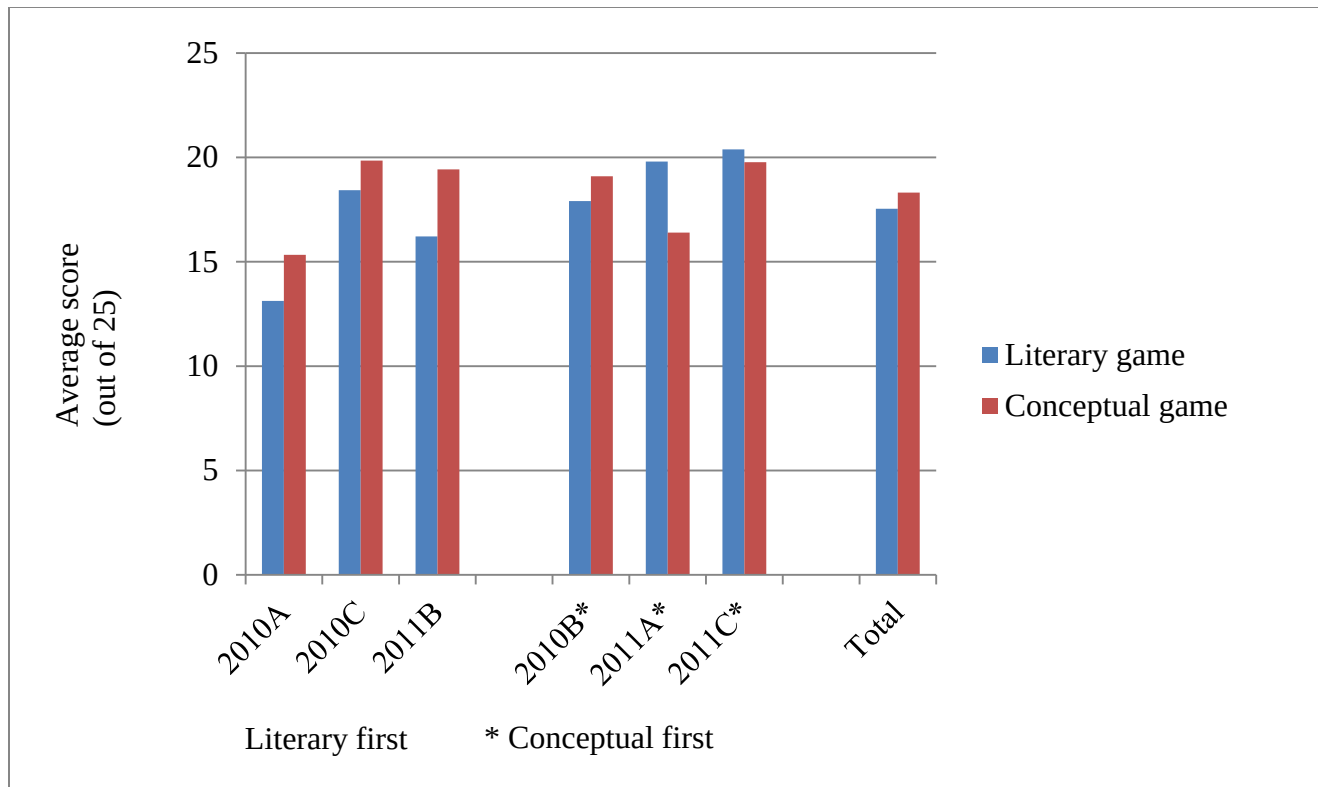


Figure 7. Ninth Grade Quiz Results, (N=73).

Each “Block” is a class. In every class but one, students scored higher after playing the second game, whether conceptual or literary. This makes sense, since those students would have more experience with the topic, regardless of how the information was presented. One anomaly stands out. One class in 2010 played the conceptual game first, and then scored lower on the second quiz the next day. Students were asked to not study in between and were repeatedly told that their scores would not count and would only be shown to others anonymously. Whether or not this anomalous class is included, the scores on the quizzes as a whole were slightly higher after the conceptual game.

The graph points clearly toward the superiority of the conceptual game, but how meaningful is a one or two point difference? If it is assumed that the data fits a standard normal curve, the p-value suggests that such a difference could occur due to statistical fluctuations alone about 23% of the time, suggesting that the difference is significant. For the “reversed” E block alone, statistical fluctuations could cause the difference about 47% of the time, which still slightly favors the hypothesis that the difference was a result of the game. At the very least, the difference for E block did not favor the literary game. So the conceptual type of game teaches the concepts better, even though the evaluative quiz would appear to favor a “literary” test of knowledge.

While grading the quizzes, I came across a shocking outlier. One student scored a 7 on the quiz after the literary game, but after the conceptual game the next day scored a stunning 23. This student had never scored that high on any test or quiz, and I graded this quiz harder than others (since it had no effect on grades). This particular student was at risk of failing numerous classes, and at the end of the year did fail several. She struggled with simply writing answers, any answers, and worked five days a week with a learning specialist. She was by far the weakest student in my class, and a low C on any assignment was a point of celebration for her. Though she *may* have cheated, I find that unlikely based on her character and the relatively low importance of the quiz. Her answers looked like this:

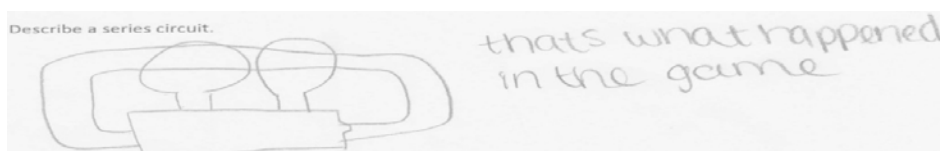


Figure 8: Student sample answer.

Which mirrors the game:

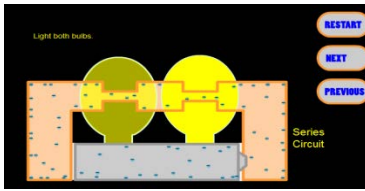


Figure 9: Circuit game comparison.

To explore further, I made a list of eleven students who, based on my in-class observations over the year, seemed to favor spatial thinking over literary thinking. They all did better on assignments that required visual or constructive thinking than on assignments that required writing or reading. The list includes some of my best and some of my worst students, but all tend to favor spatial reasoning. Their individual quiz scores, sorted by their general performance in the class, are:

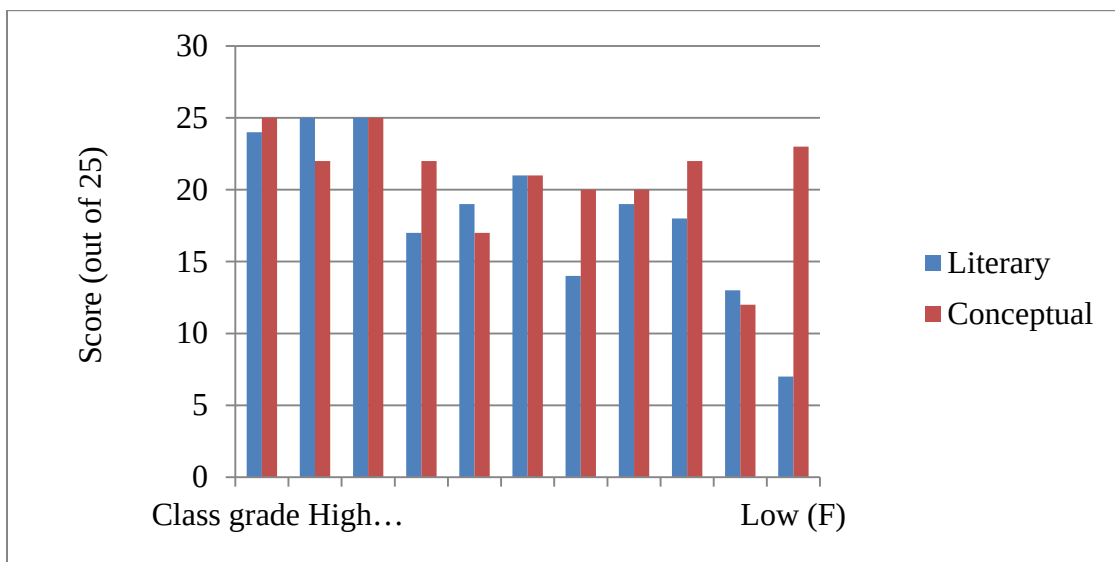


Figure 10. Spatial thinkers by student. (N=11)

The high changes toward the right side suggests that some types of learners would greatly benefit from the right type of video game. A student who is particularly adept at spatial thinking could achieve greater improvement from a video game than a student more adept at reading and writing. Video games may even be a better medium than books for certain students. The left side shows less change, but I suspect some may have had prior knowledge or learned more quickly from the first game. In any case, the small pool of data only suggests a potentially interesting trend without actually supporting any firm conclusion.

Test

Three weeks later the students in 2010 took a test about circuits. They did a significant amount of work with circuits in between. Students did well on the test, averaging about 88%, but only did slightly better on questions pertaining to circuits, averaging 90% on those questions. Several students did use drawings from the game. Overall, the difference was not as stunning as in the “Heat” game. (Per FVS policy, the average semester grade in any class should be 85%, and tests are engineered to come close to this average.)

Student Interviews

Several refrains were repeated throughout the interviews.

Students almost all found the maze game to be more fun, but also enjoyed the conceptual game. Either game was greatly preferred to studying with a textbook and worksheet. When pressed about whether the game was simply more fun or also more effective, every student said the game was a more effective learning tool. Several almost

apologized for this, saying, “I kind of learn in weird ways” or “I have learning issues,” in some way thinking that their preference for learning with the game was unusual. Yet every student, regardless of gender or relative enjoyment of books, preferred the games as a learning tool.

Several students referred in some way to “my generation,” as in, “these games are a much better way for my generation to learn things.” Though I have heard this said of the games from some teachers, I had never heard this from students. These responses were not prompted in any way.

Most students thought they learned more in the literary game, though most also thought they learned in the conceptual game. However, when asked what they learned, the results were evenly mixed. Many said that during the maze game they memorized the necessary answers and vocabulary. However, some students were not able to give specific answers or words that they had learned. Some identified aspects of electrical circuits that they had learned in the conceptual game. Others thought they learned something, but were unable to say what that was.

Many students talked about the games as if they were hands-on activities. When I asked one interviewee how it could be hands-on if it were in a screen, she said, “Well, it feels like it is hands-on.”

Teacher Interviews

Several teachers observed the class. I interviewed the 2011 teacher in depth.

Like other observers, he found student attention to be better than usual. Even energetic students focused their energy toward accomplishments within the game.

Contrary to the student perception of knowledge improvement, this teacher thought that both games contributed significantly to student learning. The conceptual game developed the student experience and intuition with the topic, whereas the literary game developed student vocabulary. He foresaw using the games as part of a progression. The students could start with the conceptual game, develop vocabulary with the literary, then move into the lab.

One Year Later

Four students from the 2010 trials were interviewed one year later. All remembered the games as well as the basic principles of circuits. As a comparison, I asked these students about a topic that was covered in another lab but not in a video game. All students also remembered the basics of that topic. Three of the four students felt that the games were equally as memorable as any hands-on activity. One student thought the labs and projects were more memorable, but the games still ranked far above any readings or worksheets.

Fifth Grade Mixtures and Solutions

Survey

Following each game, the students completed a survey. This survey was also adapted from eGameFlow, but further simplified to be appropriate for fifth-graders. Each

of the eight categories had two questions, with the exception of “Knowledge Improvement” which had four.

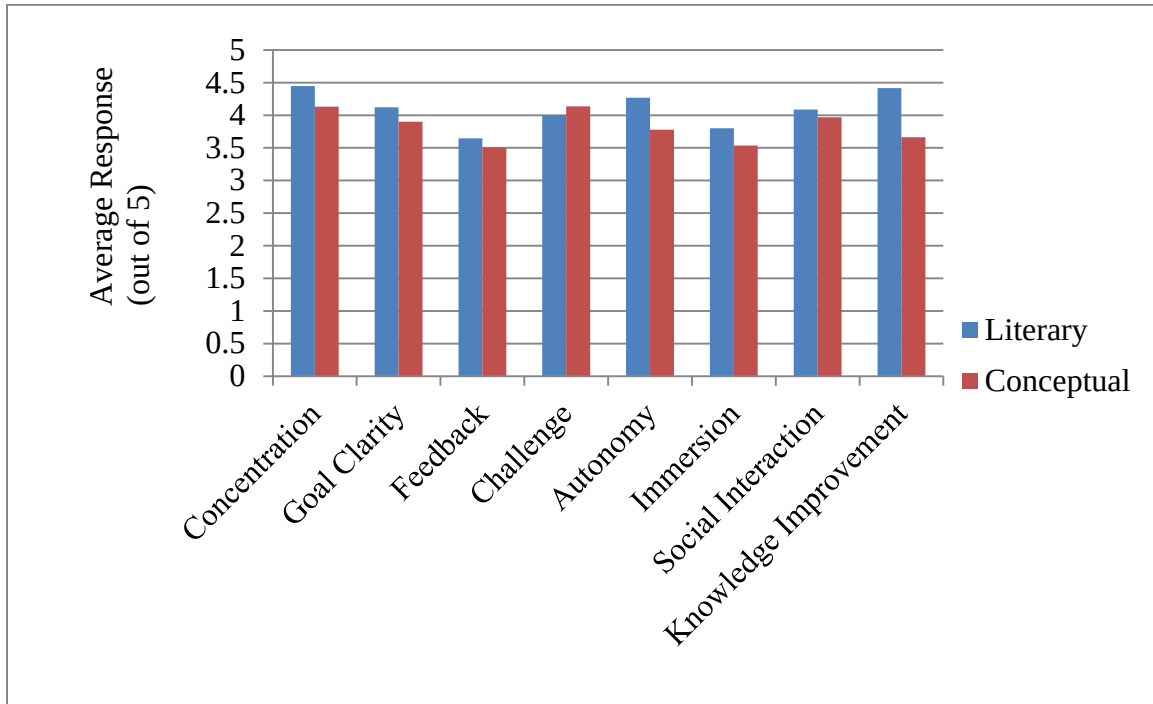


Figure 11: Fifth grade survey results, (N=35).

Literary beat conceptual in every category except challenge. This reflected my own observations of the class. Most students enjoyed the maze more, and found the more conceptual game a bit confusing and difficult. After running a p-test, the chances of these fluctuations here being the result of random statistical variations run from 20 percent to 40 percent. That is a pretty high likelihood. So although these results are similar to the results from the ninth-grade, the support is not as strong as in the ninth grade classes.

Quiz

As I had been curious about the odd results from the ninth-grade class, I deliberately made the questions for the fifth graders slanted toward the literary game. One of the questions regarding what happens when baking soda is dissolved in water came directly from the questions within the literary game. Only one of the three questions, “how does a salt crystal form?” could be said to be biased toward the conceptual game.

The quiz results suffered some implementation issues. The activity and the quiz were clearly labeled as voluntary on the sheet, in the introduction to the treatment, and in notes home to parents. For fifth graders, writing appears to be one of the least enjoyable tasks to do, especially when another video game or recess is waiting. Also, because both video games were played within a single lab period, many of the students resisted answering the same questions a second time, and instead wrote “same as before” or something similar. All this led to a reduced number of completed quizzes (about 75% of the surveys) and many duplicate answers among those completed answers.

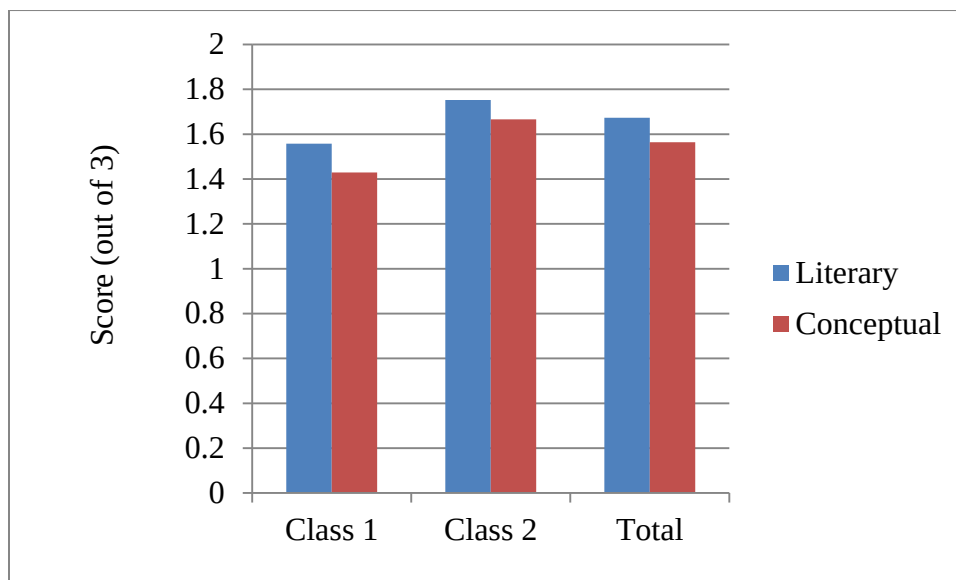


Figure 12: Fifth Grade Quiz Results, (N=35).

Given the conditions mentioned above, it is no surprise that the data is not particularly reliable. It does appear that the literary game was more successful at teaching the students what they needed to know for a written short answer assessment. As expected, the gap between the two games was largest for the question that directly quoted a multiple choice game from the literary maze game. For the question that seemed biased more to the conceptual game, there was no gap.

Yet even these small gaps lack certainty. For every one of the questions, as well as for the tests as a whole, there is about a 40% chance that the difference could have occurred due to random statistical fluctuations, according to the p-test. This assumes a normal distribution of the curve, but given the conditions mentioned above, the close equality of the scores is about right.

Notes

The first class started with the conceptual game. Students were very enthusiastic that they could play video games in school. There was a lot of energy in the room from the start, and students helped each other and gave each other tips or answers to problems. Though there was a lot of talking, the talk focused on the game.

Near the end of the conceptual game, every single boy (n=10) had made it to two levels beyond where the furthest girl had made it to. This trend held for only the conceptual game, as boys and girls fared equally well on the literary game. The boys and girls sat on opposite sides from each other.

Students were more talkative during the second literary-style game, and winning the game before friends did became more important than helping for some.

The second group played the literary game first. They displayed a similar amount of energy. However, the gap between boys and girls was much less distinct during the conceptual game. This class also mixed genders in the seats they chose, at least more so than the first class. According to the teachers, this is a class-specific trait.

Student Interviews

I waited a week before conducting student interviews, in order to assess whether the students thought about the games during their lab work with mixtures and solutions. I interviewed 5 (five) students from each class.

The students unanimously stated that they preferred learning from the games instead of “sitting there and taking notes.” The questions I asked did not lead to this statement. Instead, students responded in this way when I asked “How did the games help you with the unit?” or “How did you like the games?”

Several students thought the conceptual game was harder and more confusing. “I didn’t really know what was going on,” said one girl. Yet they all praised both games and said both helped them learn.

When asked if they thought about the games again during class, four students thought about the words they had learned in the literary game during a lecture by the teacher. The teacher noted in his interview that the students seemed to pick up the

concept of saturation quite quickly and easily, and said this was likely due to the students' prior exposure from the game. However, he had not taught the unit before so he didn't have a prior basis.

One student did not mention the literary game at all, but instead mentioned making crystals in the conceptual game. He thought of the crystals and how the atoms fit together as the made mixtures of salt in water and citric acid in water. This student was a boy, and notably, he had some clear difficulty with speaking and expressing himself in words, indicating that he may have favored conceptual thinking.

Teacher Interviews

I interviewed two of the three teachers involved about their observations during the class and during the unit afterward.

The teacher of the first class, as mentioned above, did notice that the students seemed to pick up the concept very quickly after having played the game, though he did not have a prior experience to compare to. Both he and his co-teacher (who also observed the class) found the students to be incredibly focused during the exercise. He also said that the social interaction, of which there was a lot, was much more focused on the topic than it normally is during similar group work. Upon elaboration, he also noticed that the focus during the literary game tended to become more competitive, whereas during the conceptual game the students tended to help each other more. He expressed an interest in returning to the games at the end of the unit, to see how much better the students do at that time.

The teacher of the second class also found the class to be more focused than usual during the games. Most significantly, he found that several of the students referred back to the conceptual game during a classroom investigation into the dissolution of salt in water. It became a focal point that he as a teacher could use to help students “grasp” what was happening.

Data Notes

The data presented here has been condensed and sifted to present the most significant findings. Some redundant topics from interviews and notes have been left out simply because they did not add to the body of data already presented. However, I included all contradictory data as well as any information that was repeated across multiple sources.

INTERPRETATION AND CONCLUSION

How do teachers perceive the effectiveness of the games on student comprehension?

Despite my obvious bias toward the potential for using video games in the classroom, I was repeatedly overwhelmed by what actually happened in the classroom. For every game, the students expressed an impressive enthusiasm for playing, even when the game involved solving complex problems or had what I thought to be boring game play (over 90% of the interviews reflected this enthusiasm). This focus and enthusiasm on the part of the students was visible in my observations, in the surveys, in the interviews, and in the observations of other teachers.

Based only on my observations, it was not clear whether all that enthusiasm led to improved learning. During the treatment, every teacher who observed said “They are all focused and on task.” Several added, “I’m not sure what effect it is having.” But the teachers who taught the classes all stated that they thought the games had a very positive effect on student learning.

The fifth grade teachers both saw some effect in the days that followed, suspecting that the ease with which the students learned the topic could be attributed to the game. One of the teachers incorporated the game into a discussion about salt saturation after a student brought it up.

The conceptual physics teachers found the games to be quite useful. One proposed a staggered use of the games while introducing a topic, since the students seemed to learn in two different ways from the games. He suggested starting with the

conceptual game to give the students an experience, then transitioning to the literary game to give the students the vocabulary, then moving into the lab after that. He said he would do that for every topic if the games were available.

Personally, I was never convinced while observing classes that the students were learning. After the *Heat* game, I saw nothing surprising in class, but was astonished at how well students did on the test two weeks later.

I now know that the classroom silence in the aftermath of a video game is not due to a lack of thought, and that the ability to express what the student had experienced within the game comes with time. So I could be patient and wait. But would a teacher new to the experience react like I did and simply say, “Oh well,” never to try again?

How do different types of game design patterns impact student comprehension of the science concept?

Though I expected the transformative types of games (*Heat*, *Circuits*, *Crystals and Solutions*) to have a bigger effect on learning than the games that were merely substitutive (*AP Review* and the maze games), the data does not bear that out. Yes, students did better on quizzes after the circuit game than they did after the maze game, but the difference was small (18.3 versus 17.4 out of 25). Slightly different wording in the maze game questions, or a different structure to the conceptual game, could have shifted that result. And students experienced the opposite effect after the *Mixtures and Solutions* games.

Based on student interviews, the students gained something from each type of game. A couple questions about saturation stuck with the fifth graders, even though they had not been exposed to the word before. As one girl said, “I kept getting caught by Mr. Carlson (as a game character), so I got the same questions all the time, and I kind of memorized them.” This memorization meant that the word was familiar when the teacher used it in class, and the students could focus on the rest of what the teacher said.

The AP Review game would best be described as augmentative, since it augments the problems that could normally be solved in class, but goes beyond true substitution by giving animated responses. It does not fundamentally change how physics is taught. Yet here, too, the students valued that slight change in format. The animation motivated them to solve the problem and helped them visualize what was happening.

The conceptual games had the effect I designed them to have. I expected these games to give the students a deeper, intuitive sense of what it would be like to be an electron or a molecule. After experiencing that role, the student would find the abstract terminology easier to grasp. Success on the final exam after playing *Heat*, as well as some student responses to interviews and the lack of any negative results in other tests, lends credence to the effectiveness of this subconscious approach (as one student said in an interview “I really got to be the battery and feel what that was like”). The games do seem to have a greater influence on more visual students, as suggested by some trends during the circuit games and the reactions of some of the boys in the fifth grade.

How do different types of game design patterns influence the student’s sense of learning and motivation?

The majority of students in both the fifth and the ninth grades thought they were learning more when vocabulary or some sort of wordy descriptions were attached to the learning content. In interviews with the fifth graders, those who imagined the crystals game while working with crystals in class did not think of what they were doing as related to learning. The perception can be summed up as “words = learning.” Students could easily identify the learning that was happening in the maze games as well as in the AP Review game. These games taught in a familiar way. The other games did not teach in a familiar way, and the results were not immediately obvious in writing. On the survey immediately after the *Heat* game, most students couldn’t explain what happened when a gas heats up (only 6 of 35 students answered that question completely correctly on the survey). One month later, almost all of them could.

All of the games helped student motivation. The games offered a different approach which made class more exciting. But the structure of the games also contributed to motivation, even for generally unpalatable topics. Physics problems are usually considered unpleasant, but the AP students said the animation motivated them to complete the problems. Memorizing words may not be the highlight of a fifth grader’s day, but accidentally memorizing them from repeated repetition while running from their cloned teacher turned out to be okay. These games also had what Osterweil calls the “Freedom to Fail,” because if they missed the pad or got caught by the teacher, they could simply hit restart and try again.

How do different types of video games influence student comprehension of science?

As noted by the current physics teacher at FVS, all of the games work, but they serve different purposes. The substitutive literary games work well for developing the vocabulary for a topic. The augmentative problem solving games help students visualize physics problems as well as improving motivation. The redefining conceptual games give the students a hands-on type of experience, even if their hands are not actually manipulating anything. All of the games motivated the students. They really wanted to answer that question to open the door. They really wanted to light that light bulb. They really wanted to solve that problem and save the cannonball man. As one student gushed, “I’ve never had so much fun while learning.”

For me, that’s more than enough.

VALUE

The results of the final exam after the *Heat* game changed my life.

In the classroom and in my career as a teacher, I have always sought faster, easier, and more exciting ways to help students learn. My own experience in high school had been miserable. Though I received good grades, I never felt like I really learned anything. It was all “memorization and regurgitation” to me. As a teacher, I wanted to change all that. I always thought physics was the ideal subject to discover better teaching techniques because, to my mind, physics seemed to be the hardest subject for most students. So if I could find a secret to teach anyone physics, and thus change the experience of classroom life in high school so that no student would experience the lackluster experience that I did, then I could change the world ... or at least change the world for a few students.

In the responses on that final exam, I found what I was looking for (a third of the students got the question correct without memorizing the answer! It was real for them). However, the game itself took a significant amount of time to develop, and I still could not find many games by other designers that fit the conceptual teaching criteria I needed. So I have, for now, left the classroom to develop the tools I need to teach in the way I know I need to teach. I started www.olotolo.com to be a permanent freely-available repository for educational video games for the science classroom. To support this no-profit venture, I’m exploring several more profitable venues, such as developing educationally-inspired games that are also entertaining outside of the classroom.

Were I to step back into the classroom right now, I would do many things differently. Video games would be a much larger part of the curriculum – likely much more prominent than textbooks. But in my exploration of the subject I have come across many other technological innovations which would also change my classroom. For example, listening to Puentadura’s podcasts as well as podcasts from MIT’s open courseware, I realized that podcasts offer a significant improvement over lectures. In a podcast, I can always hit rewind if I space out for a moment. So I would put much of my lecture time on podcasts for students to review as homework, and save class time for labs, group work, and individual help. I would not be the first to do this, and my classes already had as little lecture time as I could manage, but it would still be a change for my class.

My research of the use of video games in the classroom has led me to discover some potential implications that could become important beyond my own classroom. By “video games” I mean all interactive multimedia content with self-paced activities and some sort of motivational goal. These game structures can be powerful learning tools, and one school in New York and three in Chicago have opened up recently using game-based curriculums that put the teacher front and center as guide and mentor, the “Dungeon Master” of education, so to speak. I believe in this model. I believe that educational video games will put teachers in the position of teaching the hard stuff—higher order cognition and inspiration. (Although AP students loved solving the problems by themselves, they still frequently turned to the teachers in the room for hints or help.) But not all of the groups currently developing for this field have such a high estimation of the teacher. When they bring their materials to a school group, they see students eagerly

and quickly embracing the games, and the teachers slowly lagging behind. In the nineties, I worked at a public charter school that used one of the first self-paced computer curriculums. By spring, the principal of the school (who had never been a teacher) repeatedly said, “I don’t know why I am paying all these teachers when I could just be using college interns with the self-paced program.” Given the current attacks on American schools, I fear that more and more administrators could embrace that attitude.

To pull teachers into an active role in the use and development of video games, and thus put them in a position of power during this technological transformation, I will be giving a presentation at the Colorado Technology in Education conference this summer as well as at the regional meeting of the American Association of Physics Teachers this spring. One presentation will teach the basics of making a video game. The other will present much of the material contained here. I may also be presenting at other conferences or writing articles that include portions of my research.

And that is the bold and risky direction in which my Action Research project has sent me.

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APPENDICES

APPENDIX A

HEAT SURVEY

Heat Game Review

How much did you play the game?

Not at all 1 2 3 4 5 More than an hour

How enjoyable was the game to play?

Boring 1 2 3 4 5 Super fun!

What aspect of the game could be improved?

What aspect of the game did you really like?

Why would the green ball 'heat up' the gas every time it collides with a red ball?

APPENDIX B

ADVANCED PLACEMENT SURVEY

AP Review Game Review

The game helped me learn physics

Strongly Disagree 1 2 3 4 5 Strongly Agree

Working problems in the game was more enjoyable than working problems in a textbook

Strongly Disagree 1 2 3 4 5 Strongly Agree

Entertainment aspects of the game did not distract from learning physics

Strongly Disagree 1 2 3 4 5 Strongly Agree

I would recommend the game to other AP physics students

Strongly Disagree 1 2 3 4 5 Strongly Agree

How did the game add to the problem solving process?

Besides fixing the bugs, how could your experience with the game be improved?

Other comments:

APPENDIX C

NINTH GRADE CIRCUITS SURVEY AND QUIZ

Video Game Analysis

Circle your answer.

	disagree				
agree					
Most of the gaming activities are related to the learning task	1	2	3	4	
5					
Generally speaking, I can remain concentrated in the game	1	2	3	4	
5					
I am not distracted from tasks that the player should concentrate on	1	2	3	4	
5					
I am not burdened with tasks that seem unrelated	1	2	3	4	
5					
Workload in the game is adequate	1	2	3	4	
5					
Goals were presented in the beginning of each scene	1	2	3	4	
5					
Goals were presented clearly	1	2	3	4	
5					
I receive feedback on my progress in the game	1	2	3	4	
5					
I receive immediate feedback on my actions	1	2	3	4	
5					
I receive information on my success (or failure) of intermediate goals immediately	1	2	3	4	
5					
The difficulty of challenges increase as my skills improved.	1	2	3	4	
5					
The game provides new challenges with an appropriate pacing	1	2	3	4	
5					
I feel a sense of control and impact over the game	1	2	3	4	
5					
I forget about time passing while playing the game	1	2	3	4	
5					
I become unaware of my surroundings while playing the game	1	2	3	4	
5					
I temporarily forget worries about everyday life while playing the game	1	2	3	4	5
I experience an altered sense of time	1	2	3	4	
5					
I feel emotionally involved in the game	1	2	3	4	
5					

I feel cooperative toward other classmates 5	1	2	3	4
I strongly collaborate with other classmates 5	1	2	3	4
The cooperation in the game is helpful to the learning 5	1	2	3	4
The game supports social interaction between players (chat, etc) 5	1	2	3	4
The game increases my knowledge 5	1	2	3	4
I catch the basic ideas of the knowledge taught 5	1	2	3	4
I try to apply the knowledge in the game 5	1	2	3	4
The game motivates the player to integrate the knowledge taught 5	1	2	3	4
I want to know more about the knowledge taught 5	1	2	3	4

Thank you!

Post-game Quiz

1. Describe current.
2. Describe a series circuit.
3. Do several resistors in series have more or less resistance than a single resistor?
4. Describe a parallel circuit.
5. Do several resistors in parallel have more or less resistance than a single resistor?

APPENDIX D

FIFTH GRADE CRYSTALS AND SOLUTIONS SURVEY AND QUIZ

Name _____ (can be a fake name)

Participation is voluntary and participation or non-participation will not affect your grade or class standing.

Video Game Analysis

Circle your answer.

	disagree				agree
Most of the gaming activities are related to the learning	1	2	3	4	5
Generally speaking, I can remain concentrated in the game	1	2	3	4	5
Goals were presented in the beginning of each scene	1	2	3	4	5
Goals were presented clearly	1	2	3	4	5
I receive feedback on my progress in the game	1	2	3	4	5
I receive immediate feedback on my actions	1	2	3	4	5
The difficulty of challenges increase as my skills improved.	1	2	3	4	5
The game provides new challenges with an appropriate pacing	1	2	3	4	5
I feel a sense of control over the game	1	2	3	4	5
I know the next step in the game	1	2	3	4	5
I become unaware of my surroundings while playing the game	1	2	3	4	5
I feel emotionally involved in the game	1	2	3	4	5
I feel cooperative toward other classmates	1	2	3	4	5
The game supports social interaction between players (chat, etc)	1	2	3	4	5
The game increases my knowledge	1	2	3	4	5
I catch the basic ideas of the knowledge taught	1	2	3	4	5
I try to apply the knowledge in the game	1	2	3	4	5
I want to know more about the knowledge taught	1	2	3	4	5

1. What happens to salt molecules when they dissolve in water?
2. How do salt crystals form?
3. What happens when baking soda is mixed with water

Thank you! (Use the back of the page if you need more room.)

APPENDIX E

IRB APPROVAL



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
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MEMORANDUM

TO: Erik Nickerson
FROM: Mark Quinn, Ph.D. Chair *Mark Quinn CJ*
 Institutional Review Board for the Protection of Human Subjects
DATE: January 12, 2011
SUBJECT: "Video Games in the Classroom" - [EN011211-EX]

The above research, described in your submission of December 7, 2010, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal Regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- ☒ (b)(1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- ☒ (b)(2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- ☐ (b)(3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- ☐ (b)(4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- ☐ (b)(5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- ☐ (b)(6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.