EARLY STAGES OF GAME DEVELOPMENT

COMPANY FOR PHYSICS EDUCATION

by

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Dedicated to my mother.
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Early Stages of Game Development Company for Physics Education

Abstract

by

JOSEPH C. MEYER

With the knowledge that the design principles of a good virtual course and a good computer-based game are nearly identical, we are developing a computer-based game for physics. The goal of the game is to be a fun and compelling way for a physics student to practice solving physics problems. We imagine a teacher offering students the challenge of getting to a certain level in the video game as a way to prepare for class or study for an upcoming test. Computer games that already exist teach players how to play them in a fun and compelling way. Creating a game that teaches players physics is certainly technically feasible. We take this a step further and explore the feasibility of a game development company specializing in academic physics games.
1 The Current Problem

In 2013 and 2014, the Civil Rights Data Collection (CRDC) conducted by the United States Department of Education collected data from every public school and school district in the United States. This included 23,913 high schools marked in the data as a school with at least grades 11 and 12 and not juvenile justice facilities. The total combined student enrollment at these high schools was 15,581,196 students. The CRDC data shows that 35.2% (8,413) of those high schools did not offer a physics course that year. The total enrollment at the high schools not offering a physics course was 1,969,856 students (12.6%).
1.1 Contributing Factors

There are two main contributing factors to the inaccessibility of physics courses at the high school level. First, physics has a severe teacher shortage. Not only is there a shortage of teachers willing to teach physics, but there is a shortage of qualified physics teachers. Second, there is a standard practice of sequencing physics after biology, chemistry, and certain math courses. This sequencing of physics also leads students and educators to consider physics a more advanced course, which leads to lower demand for physics. The result of a lack of access, lack of qualified teachers, course sequencing, and perception of physics as the most difficult science course is that only one-third of high school students in the United States take a physics course before graduating.

1.2 Smaller Enrollment Schools

These factors exacerbate at smaller schools. The average enrollment for all high schools in the CRDC data was 651.6 students per school. The average enrollment at high schools that did not offer a physics course was 234.1 students per school. With an overall shortage of qualified teachers, it is often the case at smaller schools that creating a physics course is not cost-effective. With chemistry and biology being viable science alternatives, physics courses are mostly available in larger and/or well-resourced districts.

1.3 Increasing Physics Course Accessibility

The accessibility of physics courses are increasing with virtual options. State-run, private non-profit, and for-profit companies are offering accredited, online physics courses. Public schools and state-run virtual schools looking to bolster their course offerings use
virtual schools for help, but few of these virtual schools offer the most in-demand physics courses known as Advanced Placement (AP). To understand why virtual schools seldom offer AP physics, we must first understand virtual course implementation.

2 Virtual Course Implementation in Public Schools

Guidance counselors at public schools register students for virtual courses. Enrolled students dedicate part of their school day to the virtual course just as they would a traditional course. The student typically goes to the school library or computer lab to access the course materials online. The virtual courses have accredited and qualified teachers running them from a remote location who are available to answer student questions. Most virtual courses do not require live meeting times for all students and the teacher to gather as a class. In an online environment, students read lessons, work on assignments, and contribute to online discussions as long as they meet due dates and keep up with the flow of class. In addition, brick-and-mortar schools are required by virtual schools to provide a local facilitator, or mentor, for students taking a virtual course. The facilitator’s main responsibility is to monitor the student’s progress and assist with any technical issues in accessing the online course.

2.1 Popularity and Growth

In 2006, Michigan became the first state to require online learning for high school graduation. In the 2013-2014 school year, 25 states had state-run virtual schools. There were an estimated 1,344,136 enrollments in high school distance education in 2009-2010. As of 2017, Alabama, Arkansas, Florida, and Virginia have added the same graduation requirement as Michigan. Georgia, New Mexico, and West Virginia
recommend students experience online learning before graduation, but it is not a requirement. Figure 5 shows the number of course enrollments for each state in the 2012-2013 school year as well as whether virtual schools in the state are able to grant diplomas.

![Figure 3: States with multi-district Fully Online Schools and their course enrollments](image)

### 2.2 Florida’s Virtual School

The Florida Virtual School (FLVS) was founded in 1997 as a non-profit statewide internet-based public high school with 77 students enrolled. It was the first such school in the United States. In 2000, FLVS became recognized as its own school district. By 2003, it had 24,000 half-credit enrollments. Students are able to enroll on a course-by-course basis or as a full-time student. Tuition is free for all Florida residents and students outside of Florida may take the courses on an $800/credit fee basis. The Florida Education Finance Program funds the school based on course completion by FLVS students.
students. In 2012, Florida became the first state to offer full and part-time online options for all students from kindergarten to twelfth grade. That same year, FLVS has 410,962 successful half-credit, semester course completions. FLVS does not offer any AP physics courses. The school has built themselves on the following student-centric beliefs:

- “Every student is unique, so learning should be dynamic, flexible and engaging.”
- “Studies should be integrated rather than isolated.”
- “Students, parents, community members, and schools share responsibility for learning.”
- “Students should have choices in how they learn and how they present what they know.”
- “Students should be provided guidance with school and career planning.”
- “Assessments should provide insights not only of student progress but also of instruction and curriculum.”

2.3 West Virginia’s Virtual School

The state of West Virginia has a non-profit state-run virtual school created by the West Virginia Legislature in 2000. Third parties such as FLVS and for-profits like Apex Learning provide all the course content and teachers. Unlike FLVS, students are not able to attend WVVS full time and it does not grant diplomas. The state of West Virginia, local school system instructional budgets, and grants fund WVVS. Full tuition for the first ten students in a course per year is covered, pending funding availability. Above the first ten students, a $200 fee per student will need to be committed from the local district, which does not cover the entire tuition. The remaining tuition (ranging from $400 to $750) is covered by state funds. WVVS currently has approximately 10,000 students enrolled.
in their virtual school. Along with FLVS, the WVVS does not offer any AP physics courses.  

2.4 For-Profit Virtual Schools

The biggest for-profit virtual course provider is K12 Inc., which is a publicly traded company. Apex Learning is another for-profit company offering virtual courses for kindergarten through twelfth grade. Both sell directly to districts to supplement the brick-and-mortar school’s curriculum and fill curricular gaps. For example, Apex Learning partners with the West Virginia Virtual School and offers several of their courses through the state-run virtual school. In Apex’s first full year in 1997, they had 200 students. During the 2012-2013 school year, Apex served 435,000 students with over 1.5 million course enrollments. In the 2015-2016 school year, Apex had over 3 million enrollments. Similar to FLVS and the WVVS, neither Apex nor K12 offer any AP physics courses, the reasons of which are discussed below.

3 AP Physics Courses

The College Board has standardized high school curriculum with Advanced Placement (AP) courses, which culminate in a standardized exam. AP courses and exam grades are one of the most valuable credentials high school graduates use when applying to college. AP courses on a transcript are widely considered more important than the student’s GPA. The College Board requires all high schools offering an AP course to submit the course curriculum for approval that it meets AP’s standards. AP has created curriculum guidelines for four sections of physics:

13
1. AP Physics 1 – “Year long, algebra-based course covering Newtonian mechanics (including rotational motion); work, energy, and power; mechanical waves and sound; and introductory, simple circuits.”

2. AP Physics 2 – “Year long, algebra-based course covering fluid statics and dynamics; thermodynamics with kinetic theory; PV diagrams and probability; electrostatics; electrical circuits with capacitors; magnetic fields; magnetism; physical and geometric optics; and quantum, atomic, and nuclear physics.”

3. AP Physics C: Mechanics – “Semester long, calculus-based course covering fluid statics and dynamics; thermodynamics with kinetic theory; PV diagrams and probability; electrostatics; electrical circuits with capacitors; magnetic fields; magnetism; physical and geometric optics; and quantum, atomic, and nuclear physics.”

4. AP Physics C: Electricity & Magnetism – “Semester long, calculus-based covering electrostatics, electric circuits, conductors, capacitors, dielectrics, magnetic fields, and electromagnetism.”

3.1 Virtual AP Physics Courses

In the Advanced Placement course ledger, which lists every school offering a designated AP course, there are very few virtual AP physics options. See Figure 6 below. This is mainly due to the lab requirement associated with physics courses, which makes it impossible to offer the course in a fully virtual environment. Virtual schools that do offer an AP physics course require students to gather common household items for lab experiments thus making the entire course not virtual. These items may include a ruler, stopwatch, marble, protractor, meter stick, pieces of wood, safety glasses, digital scale, batteries, jumper wires, light bulbs, and more. Other virtual physics courses require students to purchase a lab kit from a third party, which has all the necessary lab materials inside. Basic lab kits can cost anywhere from $30 to over $1,000 for high school physics. This results in very few virtual schools creating Advanced Placement physics courses and diminishes potential gains of increased access to physics curriculum.
### Table 1: List of all virtual schools with their own AP-designated physics course for the 2015-2016 school year.

<table>
<thead>
<tr>
<th>School</th>
<th>Physics 1</th>
<th>Physics 2</th>
<th>Mechanics</th>
<th>E&amp;M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Department of Defense Education Activity</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Virtual High School</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Georgia Virtual School</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Illinois Virtual School</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Michigan Virtual School</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Virtual High School</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Virtual Virginia</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>AP4ALL</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stanford Online High School</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Northwestern University - Center for Talent</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Development Gifted LearningLinks Online</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VirtualSC</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Scholars Online</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Northwestern University Center for Statewide</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e-Learning</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center for Talented Youth at Johns Hopkins University</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

Checkmark indicates the school created that course in 2015-2016.21

#### 3.2 The Role of Labs

The scientific education community universally accepts the importance of these hands-on science labs. The AAPT released a position paper in 1992 stating the role of labs in high school physics. Their position states,

"The role of the laboratory is central in high school physics courses since students must construct their own understanding of physics ideas. This knowledge cannot simply be transmitted by the teacher, but must be developed by students in interactions with nature and the teacher. Meaningful learning will occur where laboratory activities are a well-integrated part of a learning sequence. The separation of laboratory activities from lecture is artificial, and not desirable in high school physics."22

The College Board cited and shared this position when creating their standards for Advanced Placement physics courses.23
3.3 Virtual Versus Hands-On

Today, however, virtual labs are widely used in the classroom. Physics Education Technology Interactive Simulations (PhET) is the largest creator and provider of interactive simulations and claims over 360 million of their simulations have been viewed.24 Yet, the position of the AAPT and the College Board based on the position of the AAPT from 1992, still specifically states that virtual labs do not replace hands-on labs in physics.25 The position that the AAPT and College Board share that virtual labs cannot replace hands-on labs is expected to change.26 In 2013, a research paper titled “Physical and Virtual Laboratories in Science and Engineering Education” was published by de Jong and Linn. They found virtual labs to be equally or more effective at teaching concepts in physics.27 Dr. Marcia C. Linn, an author of the paper, stated in an interview that AP would likely acknowledge the value of virtual labs in the future. This answer was in response the author’s question of, “When will AP designate virtual labs that fulfill curriculum requirements?” Dr. Linn also stated that well-designed virtual labs are just as effective and successful as hands-on labs, reinforcing her findings from 2013.28 This will bring more market opportunities to virtual course providers and their partners, particularly in creating computer-based resources for science and is a key assumption in the market feasibility for the commercialization of computer-based games for learning physics.

4 Market Opportunities

Inexpensive virtual courses and digital technology are creating ways for students to learn curriculum where there was no access. Overall, there is a democratization of
valuable educational resources, which brings former non-consumers to the market. Clayton Christensen defines this as “disruptive innovation”. In education, like never before, there are new market opportunities. Market opportunities are defined by the job a customer is struggling to get done. The Strategyn Institute uses “job statements” to define market opportunities. Jobs are the functional and emotional goals people want to accomplish, and problems they are trying to resolve. At the job statement level, there are several questions to ask that may uncover opportunities.

- Do some customers struggle more with executing this step than others do?
- What causes variability in executing this step?
- What does this step’s ideal output look like?
- Is this step more difficult to execute successfully in some contexts than others?

4.1 Student Job Map

The job-to-be-done from the student’s perspective is to acquire educational credentials from school, e.g., GPA, coursework, test scores, letters of recommendation, etc. Certainly, some students struggle more at acquiring these educational credentials than others do. Schools may not teach in the learning style, or at the pace, that best suits every student. Struggles may also result from the student not having access to educational resources such as teachers, parents, schools, funding, and so on. Providing a widely accessible platform for students to learn in a style and pace that suits them, which helps in the acquisition of educational credentials is the high-level market opportunity, or need. To understand the context and steps of this market opportunity in more detail, it is helpful to deconstruct the job into a job map. This not only defines the steps necessary to complete the job, but also highlights ways to innovate. Outcome Driven Innovation (ODI), a strategy and innovation process developed by Anthony W.
Ulwick, divides the job map into nine steps, as illustrated in Figure 5.31

<table>
<thead>
<tr>
<th>Define</th>
<th>• Make physics a goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locate</td>
<td>• Find a class</td>
</tr>
<tr>
<td>Prepare</td>
<td>• Take necessary pre-requisites</td>
</tr>
<tr>
<td>Confirm</td>
<td>• Enroll</td>
</tr>
<tr>
<td>Execute</td>
<td>• Learn physics including working out problems and taking exams</td>
</tr>
<tr>
<td>Monitor</td>
<td>• Receive grades and feedback</td>
</tr>
<tr>
<td>Modify</td>
<td>• Review concepts and change learning plan if necessary</td>
</tr>
<tr>
<td>Conclude</td>
<td>• Receive a final grade</td>
</tr>
</tbody>
</table>

*Figure 4: Universal job map of a student in the context of physics*

### 4.2 Outcome Expectations for the Student

The job map has provided a platform from which students’ expected outcomes (defined by ODI as “Outcome Expectations”) can be articulated. In the table below, examples are given for some job steps of the students. According to ODI, capturing outcome expectations can quantify the value of an idea. Appendix A contains the full ODI analysis for the student job. Our proposed approach that uses computer-based technology and gaming will use these same metrics when trying to help students earn physics coursework credentials.
<table>
<thead>
<tr>
<th>Job Step</th>
<th>Outcome expectations from students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locate</td>
<td>Increase the number of options</td>
</tr>
<tr>
<td>Prepare</td>
<td>Minimize the amount of requirements</td>
</tr>
<tr>
<td></td>
<td>Increase the likelihood of succeeding</td>
</tr>
<tr>
<td>Execute</td>
<td>Increase amount of physics knowledge</td>
</tr>
<tr>
<td></td>
<td>Minimize time it takes to learn physics</td>
</tr>
<tr>
<td></td>
<td>Minimize amount of stress due to frustration</td>
</tr>
<tr>
<td>Monitor</td>
<td>Increase frequency with which feedback is provided</td>
</tr>
<tr>
<td></td>
<td>Minimize the time it takes to answer questions</td>
</tr>
<tr>
<td>Modify</td>
<td>Minimize the cost of alternatives</td>
</tr>
<tr>
<td></td>
<td>Minimize time it takes to succeed</td>
</tr>
<tr>
<td>Conclude</td>
<td>Increase the amount of educational credentials</td>
</tr>
<tr>
<td></td>
<td>Increase the likelihood of being admitted to college</td>
</tr>
</tbody>
</table>

Table 2: Outcome expectations for students at various steps in the job map.

4.3 Teacher/Administrator Job Map

It is necessary to consider the job-to-done of teachers and administrators for full comprehension of opportunities, because in many cases they are the purchasers of educational resources. Virtual educational resources like computer-based games will supplement the efforts of the teachers and administrators in getting their job done. Their job-to-be-done is to facilitate courses for students in school, e.g., physics, English, math, chemistry, etc. Certainly, some struggle with facilitating courses with the quality or breadth that they would like. This may be because of a lack of available teachers for the course, too small a budget, or not having enough other resources required for the course. Providing resources to educators trying to facilitate or improve learning opportunities at their school is the high-level market opportunity. To understand the context and steps of this market opportunity in more detail, it is helpful to deconstruct
the job into a job map, as was done from the student’s perspective. Again, this not only defines the steps necessary to complete the job from the educator’s perspective, as illustrated in Figure 6.

![Job Map for Teacher/Administrator](image)

**Figure 5: Universal job map for a teacher/administrator.**

### 4.4 Outcome Expectations for Teacher/Administrator

The job map has provided a platform from which teachers' and administrators’ expected outcomes (defined by ODI as “Outcome Expectations”) can be articulated. In the table below, examples are given for some of their job steps. Appendix B contains the full ODI analysis for the teacher/administrator job. Our proposed approach that uses computer-based technology and gaming will use these same metrics when trying to help facilitate physics courses.
Table 3: Outcome expectations for educators at various steps in the job map.

<table>
<thead>
<tr>
<th>Job Step</th>
<th>Outcome expectations from educators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Locate</td>
<td>Increase the number of qualified teachers</td>
</tr>
<tr>
<td></td>
<td>Increase the number of qualified students</td>
</tr>
<tr>
<td>Prepare</td>
<td>Minimize the amount of teacher training</td>
</tr>
<tr>
<td></td>
<td>Minimize the cost of course materials</td>
</tr>
<tr>
<td>Execute</td>
<td>Increase the likelihood of understanding</td>
</tr>
<tr>
<td></td>
<td>Minimize the downtime due to students</td>
</tr>
<tr>
<td>Monitor</td>
<td>Increase the amount of interaction with each student</td>
</tr>
<tr>
<td></td>
<td>Minimize the time it takes to assess student</td>
</tr>
<tr>
<td>Modify</td>
<td>Minimize the cost of alternatives</td>
</tr>
<tr>
<td></td>
<td>Minimize the number of students failing</td>
</tr>
<tr>
<td>Conclude</td>
<td>Increase the budget</td>
</tr>
</tbody>
</table>

5 Computer-Based Games in Physics

The job maps of the student and educator have identified many areas for companies to innovate such as reducing the perceived difficulty of physics, reducing the costs of tutoring, and others listed in the Table 4 below. Computer-based games take full advantage of the digital medium being widely used in education with layers of enhanced video, audio, and interactive elements. Computer-based games are part of an industry with a long history of teaching people through digital means, although video games have successfully implemented player-centric learning for decades with non-academic content. Physics is the most fitting subject to begin a bond between academics and video games. The perceived difficulty of physics would be decreased by making learning take place in the context of a game. Also, all students would not be forced to learn and progress through the game as every other student. The game would be compelling to varied styles of learning and aptitudes by providing constant feedback for many levels of
achievement. The game would incorporate live online tutors similar to networked multiplayer games that exist today. Therefore, if a student is stuck at some point in the game, they can access a live person who tutors them in physics in the context of the game. Finally, the cost of even the most expensive-to-produce video games seldom goes above $60, which is still much less than half-credit virtual courses that cost a few hundred dollars.\textsuperscript{33}

<table>
<thead>
<tr>
<th>Areas of Innovation Identified from Job Maps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce costs of teaching physics</td>
</tr>
<tr>
<td>Reduce perceived difficulty of physics</td>
</tr>
<tr>
<td>Create more meaningful virtual curriculum in physics</td>
</tr>
<tr>
<td>Create physics content and curriculum aimed at early high school students</td>
</tr>
<tr>
<td>Create method of determining students chance of success in physics</td>
</tr>
<tr>
<td>Create physics educational content for varied styles of learning</td>
</tr>
<tr>
<td>Create methods of constant, meaningful feedback for students</td>
</tr>
<tr>
<td>Reduce costs of tutoring</td>
</tr>
<tr>
<td>Create new ways to communicate physics knowledge besides a grade.</td>
</tr>
<tr>
<td>Be able to alter the pace and teaching style of curriculum for individual students.</td>
</tr>
<tr>
<td>Create environment where students and schools are not penalized for students trying but not passing.</td>
</tr>
</tbody>
</table>

Table 4: Areas of innovation as identified by the universal job maps.

5.1 Principles to Good Video Games

Dr. James Paul Gee, an American researcher in psycholinguistics, sociolinguistics, and literacy, has defined 36 principles of what good video games do to facilitate learning that align with the areas of innovation highlighted above. As Gee puts it, “Good video games situate meaning in a multimodal space through embodied experiences to solve problems and reflect on the intricacies of the design of imagined worlds and the design of both real and imagined social relationships and identities in the modern world.”\textsuperscript{34}

The video games and the classroom share common principles, but children and young
adults want to play video games much more than they want to go to school. The World of Warcraft game had over 10 million subscribers in 2014.\textsuperscript{35} That same year, 2,342,528 students took an AP test (161,339 AP physics).\textsuperscript{36} Similarly, there were 2,195,929 college graduates in 2014 (7,526 physics bachelor’s degrees).\textsuperscript{37}

### 5.2 Successful Games Facilitate Learning

The most commercially successful video games are difficult and take a long time for the player to complete. Despite the challenges and time commitment, millions of people buy them, learn to play them, and complete them - all for fun! Video games have been getting longer and more difficult as the industry progresses. The video game industry works in a very Darwinian fashion where games are successful only if they are compelling to play and they facilitate learning how to play in a compelling way. If the game accomplishes this, players spend a lot of time playing it and it sells many copies. If the learning principles of the game are not very compelling then players will not learn how to play it, will not spend any time playing it, and it will not sell very well.\textsuperscript{38} The time it takes to complete various commercially successful video games are listed below in Table 5. This table illustrates the time commitment video games require the player to make and how that commitment has increased over time.
<table>
<thead>
<tr>
<th>Name</th>
<th>Date of Release</th>
<th>Time to Complete</th>
<th>Success</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pong</td>
<td>1972</td>
<td>&lt;30 minutes</td>
<td>Sold 150,000 units through Sears in late 1975</td>
</tr>
<tr>
<td>The Oregon Trail</td>
<td>1978</td>
<td>1.5 hours</td>
<td>65 million copies sold</td>
</tr>
<tr>
<td>Tetris</td>
<td>1986</td>
<td>7 hours</td>
<td>Over 170 million copies sold</td>
</tr>
<tr>
<td>Myst</td>
<td>1993</td>
<td>6.5 hours</td>
<td>12 million copies sold by 2003</td>
</tr>
<tr>
<td>Half-Life</td>
<td>1998</td>
<td>12 hours</td>
<td>9.3 million copies sold by 2008</td>
</tr>
<tr>
<td>Deus Ex</td>
<td>2000</td>
<td>23.5 hours</td>
<td>Over 4.5 million units sold</td>
</tr>
<tr>
<td>Dragon Age: Origins</td>
<td>2009</td>
<td>41 hours</td>
<td>Over 3.2 million copies sold by 2010</td>
</tr>
<tr>
<td>Kerbal Space Program</td>
<td>2015</td>
<td>145 hours</td>
<td>1.7 million copies sold</td>
</tr>
</tbody>
</table>

Table 5: Time to complete is for the main part of the games listed. There are extra levels and accomplishments in many games that take more time to complete.

### 5.3 Academic and Entertaining

Imagine a physics teacher offering students two options for an upcoming test. The first option is a set of practice problems. The teacher will recommend students be able to understand and complete the practice problems for test preparation. Our solution is a computer-based game. The teacher will recommend students be able to get to a certain level in the game in preparation for the test. This second option will be a reality if game developers and educators follow the principles that Gee has laid out. When applied to physics, the games can make learning physics compelling in new ways and accessible through multiple learning styles.
5.4 Student-Centric

Christensen and Gee see a student-centric future for public education. With virtual courses, teachers are already becoming individualized guides and tutors instead of lecture-hall speakers allowing students to make progress at an individual rate as opposed to with the entire class. According to Gee, this is a defining principle of well-designed computer games called “Multiple-Routes”. That is, the player is able to make progress based on their specific playing style. Good computer games are also able to be adjusted to different levels of play and reward each sort of player with some appropriate degree of success, if the player is putting in effort.

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple-routes</td>
<td>“Learners are given a range of paths to pursue forward, in which the learner can choose based on his/her strengths, weaknesses, and specific learning styles.”</td>
</tr>
<tr>
<td>Achievement</td>
<td>“The learner needs intrinsic rewards that are tailored to that learner’s level, effort, and mastery of the content.”</td>
</tr>
</tbody>
</table>

Table 6: Multiple-routes and Achievement principle definitions as defined by Gee.
5.5 Good Video Games Overview

In good video games, success for effort at different levels is built in, letting players, or students, know all the while that there will be greater successes for greater effort. The game operates within, but at the outer edge, of a player’s competence so at many points the game feels challenging but not impossible.55 Players can choose strategies that fit with their style of learning, thinking, and acting. Good video games allow for multiple solutions judged by a variety of standards, some of which are internal to the game and some of which the player sets by his or her own standards. This sometimes results in the player redoing scenes over to solve problems in different ways. Finally, good video games allow players not just to be passive consumers but also active producers who can customize their own learning experience.56

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Regime of Competence”</td>
<td>“The learner can function at the outer edge of his/her understanding to make concepts feel challenging, but not impossible.”</td>
</tr>
<tr>
<td>Cultural Models</td>
<td>“Learners can reflect on cultural models in a manner “outside” their real-world identities regarding learning, themselves as learners, and particular domains they are learning about.”</td>
</tr>
</tbody>
</table>

Table 7: “Regime of Competence” and Cultural Models principle definitions as defined by Gee.57

5.5.1 Identity Principle

Students bring to class their identities, which include their gender, race, age, culture, and so on. Identities also include pre-conceived notions about one's self such as "I am not good at learning" or "I am going to be a doctor". Students also bring cultural models or norms with them to class. These may include "A college education is valuable" or "School is not fun". The classroom and teacher are responsible for challenging students' taken-for-granted views about themselves and the world.
5.5.2 Getting Students to Pretend

The only way to challenge some of the identities and cultural norms a student brings to class is to get them to pretend. Good teachers get students to identify, even if just for a moment, as a scientist, writer, or mathematician by getting them thinking, talking, and acting like one. If students cannot or will not make bridges between one or more of their real-world identities and a virtual identity in the classroom, then learning is jeopardized.\textsuperscript{58} The student must be enticed to participate, despite their identities and cultural models. The student must be enticed to put in lots of effort even if he or she begins with little motivation to do so. The student must achieve some meaningful success when he or she has expended this effort. This is the basis of good learning and this is the basis of good computer-based games.\textsuperscript{59}

5.5.3 The Student’s Approach

A common cultural norm is that physics is hard. In addition, according to college physics professor Dr. Edwin Meyer, students come to class commonly thinking that to learn something is to memorize a definition or series of systematic instructions. As a result, he says, students rely heavily on equations to plug numbers into or rules to follow.\textsuperscript{60} In other words, students are looking for routines they can automate. When teachers present problems that do not work with automated routines, students struggle. Overall, students tend to look for the most efficient way to get a passing grade and have little interest or time in exploring the subject. When playing a video game, players have an opposite approach.
5.5.4 The Player’s Approach

Compelling video games encourage players to explore rather than complete the game as quickly as possible. While actions in the game do become automated for the player, good video games make players operate at the edge of their competence and encourage new ways of thinking by breaking up the routines every so often.61

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identity</td>
<td>“The learner is able to choose multiple identities in such a way that they can reflect upon ‘new’ and ‘old’ identities.”</td>
</tr>
<tr>
<td>Self-Knowledge</td>
<td>“The learner learns about themselves and their potential range of skills, in a self-reflective process.”</td>
</tr>
<tr>
<td>“Psychosocial Moratorium”</td>
<td>“The real-world consequences do not exist, allowing learners to take greater risks. This creates a safe space for the learner to fully engage with the environment.”</td>
</tr>
</tbody>
</table>

Table 8: Identity, Self-Knowledge, and “Psychosocial Moratorium” principle definitions as defined by Gee.62

5.5.5 Subdomains

Good video games allow players to learn to play the game by starting in a subdomain of the actual game. This gives information to the player couched in ways that make sense in the context of their practice.63 These are typically in the form of training modules and early episodes built as simplified versions of the main part of the game. As a result, players are not overtly aware of the fact that they are learning, how much they are learning or how difficult it is. These early episodes offer the player a concentrated sample, or an ample number of the most fundamental, basic artifacts and tools the player needs to learn to use, along with the actions the player needs to learn them. This sets a good foundation for later learning.
5.5.6 Active Learning

Giving information in the context of action is active learning.\textsuperscript{64} In the physics classroom, students are trying to learn a completely new semiotic domain known as physics. There are new words, symbols, histories, allegory, and meanings that make up the content of physics and are foreign to the student. The best way for a student to learn the content of new domains is in an active manner as opposed to a passive manner. Imagine a textbook that contained all the facts and rules about a subject read by students who used the facts and rules in any context. No one treats rulebooks for games as content apart from the game, but this is how physics is largely taught in the classroom. Following are some examples how active learning with computer-based games could be influential in physics education.

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text</td>
<td>“Texts are not just understood by understanding the words in the text, but by understanding the texts through experience.”</td>
</tr>
<tr>
<td>Intertextual</td>
<td>“Learners understand connections between texts by understanding, through experience, the meaning of some texts and relating that meaning to other related texts.”</td>
</tr>
<tr>
<td>Subset</td>
<td>“Learning first occurs in a simplified subset of the real domain.”</td>
</tr>
<tr>
<td>Multimodal</td>
<td>“Meaning is learned through multiple modalities besides words (e.g., sounds, images).”</td>
</tr>
<tr>
<td>Bottom-Up Basic Skills</td>
<td>“Basic skills are learned in context.”</td>
</tr>
<tr>
<td>Active, Critical Learning</td>
<td>“Every aspect of the learning environment should be set up to encourage active and critical learning, instead of more traditionally passive learning environments.”</td>
</tr>
</tbody>
</table>

*Table 9: Text, Intertextual, Subset, Multimodal, Bottom-Up Basic Skills, and Active, Critical Learning principle definitions as defined by Gee.\textsuperscript{65}*
5.6 Prototype Game Development

A prototype game using Gee’s principles defined above is in development by the author. The goal of the game is to be a compelling way for a physics student to practice solving problems using physics concepts and math appropriate for their level. The game’s primary genre is a role-playing game (RPG), where the player controls the actions of a character immersed in some virtual world. The goal of an RPG is to have the main character “win” by completing a series of quests or by reaching the conclusion to a central storyline. In RPGs, players explore the game world while solving puzzles. A key feature of RPGs is that the character grows in power and abilities. The qualities of RPGs align perfectly with how a student is intended to make progress in a classroom.

5.6.1 Prototype Gameplay

The game will allow the player to customize the virtual character aesthetically and in ability. Each level in the game puts the character in a maze or series of mazes. To move through a maze, the player must solve a physics problem that relates to the movement or action of the character. As the player solves the problems and moves the character, points are earned, which the player can trade in for various tools and abilities that will make future movements more efficient and exciting and more complex mazes possible. Finally, the mazes will encourage full exploration by giving the player extra points or other incentives for going down “dead-ends” and not just completing each maze as quickly as possible. The rest of this section looks at examples of how this gameplay can be used with certain topics in physics.
5.6.2 Unit Analysis as a Central Storyline

Unit analysis is a critical skill in all of physics and is something the prototype game will emphasize heavily. A potential storyline of the game is for it to begin with the player being told a unit is a name for something, that there are many types of units, and units of the same type can be converted. The game then gives the example that the player and a physicist are the same type of thing - a human. However, one-thousand players are equal to one physicist. As the player progresses through the game, their conversion factor to being a physicist will get smaller. Upon successful completion of the game, the player will be “equal to” one physicist.

5.6.2.1 Kinematics

AP physics 1 courses begin with one-dimensional motion. One-dimensional motion is the first application for unit analysis and the first type of movement through a maze. The player will select a destination for the turn and will be given the distance to that
destination. The player will also be given either the speed at which they will move to that destination or the amount of time they will have to get to the destination. The player must input the value not given (speed or time). Once the player enters the input, the player must hit “Go” and will watch the movement of their character. The results will be that the player went too far, not far enough, or exactly as far as they intended when selecting their destination. The magnitude and units of distance, time, speed will be changed randomly every turn so the player must pay close attention. At first, the player will be limited to destinations that are perpendicular to their current position. After completing four levels of this movement, the player must demonstrate full understanding of one-dimensional motion. To do this, the character will be put in scenarios outside of the maze environment, which offer opportunities for more advanced problem solving and critical thinking. As an example, the character will be moving at a faster speed than an object with a high point value, which is a given distance in front of the character. To capture the object and earn the points, the player must enter the exact time the character will catch up to the object.

![Prototype screenshot where user has chosen then 3 highlighted tiles and is prompted to enter a time for the move given the distance of 3 meters and speed for 1.5 meters/second.](image)

*Figure 8: Prototype screenshot where user has chosen then 3 highlighted tiles and is prompted to enter a time for the move given the distance of 3 meters and speed for 1.5 meters/second.*
5.6.2.1.1 Subdomain of the Game and Classroom

The attention the player must pay to units while applying it to kinematics in the context of the gameplay will serve as a subdomain for learning physics and playing the game. More complex concepts such as acceleration, two-dimensional motion, Newton’s laws, conservation of momentum, conservation of energy, simple harmonic motion, and thermodynamics build upon these fundamentals in the classroom and in the game. These concepts will offer more advanced and exciting actions for moving throughout future mazes by being launched over walls of the maze as a projectile, using force to break through the walls, or to move as a mass on a spring. The maze provides a platform for the player to see the concepts in physics play out in a compelling way for them and their character.

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ongoing Learning</td>
<td>“The learner will go through cycles of learning new material, automating the material, undoing some automatization, and reorganizing the automatization.”</td>
</tr>
<tr>
<td>Intuitive Knowledge</td>
<td>“Knowledge that cannot necessarily be verbalized, such as the knowledge gained through practicing a task, is valuable.”</td>
</tr>
<tr>
<td>Situated Meaning</td>
<td>“All of the meanings of signs are situated in embodied experiences of the learner.”</td>
</tr>
</tbody>
</table>

Table 10: Ongoing Learning, Intuitive Knowledge, and Situated Meaning principle definitions as defined by Gee.66

5.6.3 Electromagnetism

AP physics C: Electricity and Magnetism courses begin with electric fields, electric potential, and Coulomb’s law. Here again, unit analysis and rates of change versus time are the fundamental tools more complex concepts are built upon. Physics teachers might even try to draw analogies between the gravitational force and the electric force assuming that the student is already familiar with gravity. Along the way through the
curriculum in class, students must try to imagine this subatomic world without any experience or context in it. In the game’s maze, students can apply the same concepts by adjusting charge values on the character and other objects in the maze resulting in the character’s movement.

5.6.3.1 Comparison with Minecraft

Electromagnetism is particularly difficult for students because the world of electromagnetism is so hard to imagine. It is a completely new semiotic domain, just like a new video game. Electrons, capacitors, resistors, magnetic fields, and light waves are new concepts that involve words, symbols, and grammar specific to physics. Minecraft is an immensely popular video game with over 121 million copies sold as of February 2017. Minecraft: Essential Handbook, written by the creators of Minecraft, is 80 pages long and covers everything a player would need to know to complete the first few days of playing. Minecraft’s three essential concepts of Redstone, construction, and combat are covered in separate handbooks each 80 pages in length for a total of 320 pages. For comparison, a top-selling book titled AP Physics 2 Essentials is 336 pages long and comprehensive high school physics textbooks are approximately one-thousand pages in length. The complexity of immensely popular video games, such as Minecraft, is not that different from the complexity of high school physics courses.

5.6.4 Theoretical Physics

More advanced concepts in physics exhibit the same learning principles that good videos games are based upon. Mary L. Boas opens her book, Mathematical Methods in the Physical Sciences, by writing directly to the student. She writes, “To use your
mathematics effectively in applications, you need not just knowledge, but *skill*. Skill can be obtained only through practice. You can obtain a certain superficial *knowledge* of mathematics by listening to lectures, but you cannot obtain *skill* this way...The only way to develop the skill necessary to use this material in your later courses is to practice by solving many problems. You will find both drill problems and harder more challenging ones at the end of chapters.”\(^70\) She also mentions in her preface that while the chapters in the book are not independent, many rearrangements are possible.\(^71\) Boas has, in her own words, defined the Multiple-Route, Text, Intertextual, Practice, and Committed Learning principles Gee has defined for good video games.

<table>
<thead>
<tr>
<th>Principle</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Practice</td>
<td>“Learners need a great deal of practice in a context where they are engaged with the material, not bored with it.”</td>
</tr>
<tr>
<td>Committed Learning</td>
<td>“Learners will participate in extended engagements as an extension of their real-world identities in relation to their virtual identities. The learner feels a commitment to continue their effort and practice.”</td>
</tr>
</tbody>
</table>

*Table 71: Practice and Committed Learning principle definitions as defined by Gee.\(^72\)*

5.6.5 Medical Imaging

In the textbook titled, Magnetic Resonance Imaging: Physical Principles and Sequence Design, chapter 1 is a preview of magnetic resonance imaging. In the first concepts, the student is encouraged to imagine the hydrogen proton as an electrically charged spinning gyroscope – something most humans have no experience with. Because of this motion, this spinning gyroscope has an effective loop of electric current around the same axis on which the proton is spinning. This current loop then creates a magnetic field, which has various properties that allow it to interact with an external magnetic field. There are equations detailing the spin, spin density, and spin properties.\(^73\)
Understanding these concepts relies solely on the student’s ability to create this imaginary world of spinning proton gyroscopes in their head. The textbook, like many others, is like a game manual. Yet, game manuals come with games for the players to experience what they have learned in the compelling world of the game. Textbooks do not come with any way for the student to experience what they are learning in a similarly compelling manner.

![Figure 9: Illustration of the circular motion of a proton about a magnetic field.](image) Copyright 2017 John Wiley & Sons.

### 5.7 The Process of Playing

Understanding how players approach video games is the final key component to creating good video games. Gee also defines how good video games require the player to engage in a four-step process:

1. **PROBE**: “The player must probe the virtual world.”
2. **HYPOTHESIZE**: “Based on reflection, while probing and afterward, the player must form a hypothesis about what something might mean in a usefully situated way.”
3. **REPROBE**: “The player re-probes the world with that hypothesis in mind, seeing what effect he or she gets.”
4. **RETHINK**: “The player treats this effect as feedback from the world and accepts or rethinks his or her original hypothesis.”
Allowing the student to engage regularly in this four-step process while playing the game relates to how compelling the game is. This process is comparable to the scientific process, which students in school labs learn. To be compelling, the game must offer quick cycles through this process. In video games, the four-step process sometimes takes just a second or two. However, to be academic, the process will need to involve careful thought, which will slow this process down, potentially making it less compelling. An essential factor in the prototype game will be a balance between the quick cycles through Gee’s four-step process with Garland’s academic scientific process (Figures 11 and 12). Finding the right balance will determine how compelling and academic the prototype game is for students.

The Scientific Method as an Ongoing Process

![Diagram of the scientific method as taught in school](https://example.com/figure10.png)

*Figure 10: Scientific process as taught in school.*
5.7.1 Academic Angry Birds

Angry Birds is video game franchise with more than 3 billion downloads as of July 2015. The game primarily consists of using a slingshot to launch birds at fortresses. The birds collide with the fortresses, toppling them. When playing the game, the player mainly controls the launch angle of the birds. Players quickly probe by launching the birds. Based on the resulting status of the fortress, they launch the next bird, and rethink from there. This is a very quick process taking only a few seconds to assess the fortress and “eyeball” the launch angle. If the game gave the launch velocities and masses of the birds and asked players to calculate the launch angle before using the slingshot, this would make the game more academic, slow down the process of playing, and thus make it less compelling to play. An academic and entertaining game will strike
a balance between Gee’s quick four-step process and the academic scientific process Garland has defined.

5.8 Socialization Around Games

The prevalent sharing of games, playing styles, reviews, and observations, illustrate the socialization of players, which spans both virtual and real worlds. Players talk about games, comment on them, team up to play them together, talk while playing them together, and watch others play them. There is usually an affinity group around good games with rich content shared between members. These social groups based around video games have created some of the largest social networks in existence.

5.8.1 Twitch

Twitch, a subsidiary of Amazon, is a livestreaming platform specifically for watching people play video games. It is the fourth largest source of internet traffic behind Netflix, Google, and Apple with 1.5 million broadcasters and 100 million visitors each month.79

5.8.2 Pewdiepie

Felix Arvid Ulf Kjellberg, better known by his online pseudonym Pewdiepie, has had the largest subscriber base on YouTube since December 2013 with over 54 million subscribers in March of 2017. The nature of his video content is commentary and reactions while playing video games. His videos have been viewed nearly 15 billion times.80
6 Benefits

The video game industry offers well-established benefits to customers by selling games that are highly motivating, widely accessible, and have established business models. By implementing video games in education, the education industry can capitalize on these same benefits. However, with education, these benefits have the potential to more positively change society.

6.1 Intrinsic Motivation at School

Motivation can be extrinsic and intrinsic. Extrinsic motivation is that which comes from outside the task. For example, a person might learn to do something not because he or she found the task itself stimulating or interesting, but because learning it would give her access to something else she wanted. This is the most common form of motivation in school. However, video games rely solely on intrinsic motivation, which is when the work itself stimulates and compels an individual to stay with the task because the task by itself is inherently fun and enjoyable. The main benefit of computer-based games is that they will bring intrinsic motivation for students to learn.

6.2 Using the Technology

The number of computers with internet access has grown tremendously since the 1980s. In 1996, Bill Clinton made over $2 billion available from grants as part of the Technology Literacy Challenge Fund, which challenged schools to make computers available to every student. In 2003, there were an average of four computers with internet access to every student in U.S. public schools. In 2010, school districts were beginning to implement programs that provided every student a personal laptop. The
infrastructure to support student-centric learning is already in place. Video games can
deliver even more academic value and benefits from the technical infrastructure that
exists today.

7 Business Model Canvas

A business model defines the rationale of how computer-based games create, deliver,
and capture these values and benefits. The business model canvas, as designed by Alex
Osterwalder, illustrates the business model with nine segments. The type of business
model most fitting for student-centric learning through video games is one where
students represent a large customer segment and are able to continuously benefit from
the game free-of-charge or for very low cost. Other parts of the business model and
other customer segments finance the non-paying or low-paying students, such as in-
game purchases of tutoring time. This type of model attracts the maximum number of
users. The segments of the business model are described in more detail in the rest of
this section.
7.1 Customer Segments

Customer segments are the different groups of people or organizations the value proposition aims to reach and serve. Physics students will be the largest customer segment for student-centric learning in physics with video games. Physics students represent a mass market because they broadly have the same needs and problems and the entire business model focuses on them. Parents, teachers, and schools are other potential customer segments, which reflect a multi-sided market where two or more interdependent customer segments are required for the business model to work.


7.2 Value Propositions

The value proposition is the bundle of products and services that create value for a specific customer segment.\textsuperscript{88} The product and service that this business model delivers is a computer-based game that teaches physics. Other aspects of the value proposition are a fun way to study physics, entertainment, a way to display intelligence, and access to physics students. These fall under common types of value propositions by helping customer segments get the job done, making things more convenient and easier to do, and by increasing accessibility to value.

7.3 Key Activities

The key activities are the most important things a company must do to make its business model work.\textsuperscript{89} Two common activities for businesses are production and problem solving. Production is the designing, making, and delivering of a product in substantial quantities and of superior quality. Problem solving is the creation of new solutions to customer problems. In this business model, the key activities are creating and promoting academic and entertaining computer-based games. In addition, students need to play the games and learn physics while playing them.

7.4 Key Partnerships

Key partnerships make up a network of suppliers and partners that make the business model work. Partnerships typically optimize allocation of resources and reduce certain risks and uncertainties.\textsuperscript{90} In this business model, key partnerships will start with physics teachers. After speaking with superintendents, assistant principals, and physics teachers at the high school and college levels, it is clear that teachers are the primary
gatekeepers to the students. If a teacher finds an educational resource valuable and cost-effective for students, that teacher will most likely recommend that resource to their students. For example, only teachers provided the vetting process for Khan Academy before it began appearing in classrooms. After initial success with teachers, the partnerships will grow to schools, districts and the AAPT, which has been a similar path Khan Academy has taken. On the development side, contracted software developers reduce uncertainty in meeting game development milestones.

### 7.5 Key Resources

Key resources are the most important assets required to make the business model work. These assets fall under common categories of physical assets, intellectual assets, human assets, and financial assets. In this business model, the story and distinctive characters of the game will be key along with the development environment for creating the games. Unity is a cross-platform game engine widely used to develop video games for PC, consoles, mobile devices, and websites. Other key assets are physics educators providing insight for the game content, gameplay style, and how concepts are delivered, practiced, and built upon in the game.

### 7.6 Channels

Channels are how a company communicates with and reaches its customer segments to deliver the value proposition. Common channel types are wholesalers, partner stores, web sales, and a sales force. For delivering video games teaching physics, video game stores, web stores, schools, parents, and teachers will all be channels. Steam, the largest digital distribution platform for PC, is a commonly used partner store for new
developers. A direct web store is another option where students pay for access and play games directly in a web browser.

### 7.7 Customer Relationships

This defines the types of relationships a company establishes with specific customer segments. The nature of these relationships depends on what customers expect, how costly the relationships are, and how integrated they are with the business model. For this business model, downloading or accessing the game requires a relationship, as well as an online support and information community where game experts interact with students. There is also the potential for live, in-game support from physics teachers or tutors. This would function as a tutoring session in the context of the game.

### 7.8 Revenue Streams

Revenue streams simply represent the cash a company generates from each customer segment with earnings being costs subtracted from this revenue. For the value proposition of video games that teach physics, revenue from high volume computer-based game sales will be the main source of revenue. Other revenue streams are subscription fees, in-game tutoring time, and advertising.

### 7.9 Cost Structure

The cost structure defines all the costs incurred to operate a business model such as inherent costs, expensive resources, and expensive activities. This business model will operate with fixed costs and will be cost-driven. The most expensive activity will be the development of the games. Promoting the games will incur further costs.
8 Financial Projections

A reverse income statement as illustrated in “Discovery-driven planning” written by McGrath and MacMillan is an effective tool for making financial projections. Video game development requires approximately $100,000 for simpler games. Hence, the revenue needs to be at least $100,000 per year if there is no other funding support. Assumptions made for this business model are based in business rationale. The reverse income statement for a model year is detailed as follows. All relevant key assumptions are stipulated.

<table>
<thead>
<tr>
<th>Table 93: Assumptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Required Profits</td>
</tr>
<tr>
<td>ROS (return on sales)</td>
</tr>
<tr>
<td>Price</td>
</tr>
<tr>
<td>Number of physics students (based on AP)</td>
</tr>
<tr>
<td>Market size including fringe</td>
</tr>
<tr>
<td>Salaries, Average per person</td>
</tr>
<tr>
<td>Base headcount</td>
</tr>
<tr>
<td>Overhead (20% per person)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 104: Operation Speculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales</td>
</tr>
<tr>
<td>Required Sales</td>
</tr>
<tr>
<td>Development</td>
</tr>
<tr>
<td>Equipment/Technology needed</td>
</tr>
<tr>
<td>Headcount needed</td>
</tr>
<tr>
<td>Salaries</td>
</tr>
</tbody>
</table>
Table 115: Milestones

<table>
<thead>
<tr>
<th>Milestone</th>
<th>Assumption to be checked</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Research</td>
<td>Development days</td>
</tr>
<tr>
<td></td>
<td>Headcount</td>
</tr>
<tr>
<td></td>
<td>Market Size</td>
</tr>
<tr>
<td>Prototyping</td>
<td>Development cost</td>
</tr>
<tr>
<td>Testing By Customers</td>
<td>Unit price</td>
</tr>
<tr>
<td>Production and Selling</td>
<td>Revenue</td>
</tr>
<tr>
<td></td>
<td>Delivery cost</td>
</tr>
<tr>
<td>Market Reaction</td>
<td>Unit price</td>
</tr>
<tr>
<td></td>
<td>Profit margin</td>
</tr>
<tr>
<td>Game redesign</td>
<td>Development cost</td>
</tr>
<tr>
<td>Re-pricing analysis</td>
<td>Profit margin</td>
</tr>
<tr>
<td></td>
<td>Revenue</td>
</tr>
<tr>
<td></td>
<td>Unit Price</td>
</tr>
<tr>
<td></td>
<td>Market size</td>
</tr>
</tbody>
</table>

8.1 SWOT analysis

There is an effective way of combining strengths, weaknesses, opportunities, and threats (SWOT) with the business model canvas to assess this business model's overall integrity. The analysis also provides a matrix for planning strategies, which are summarized in the matrix table. Following the rules of using strengths to take advantage of opportunities, overcoming weaknesses by taking advantage of opportunities, and using strengths to reduce threats and minimize weaknesses will ideally lead to strategies that facilitate a sustainable business.
Table 126: SWOT analysis matrix

9 Competition

Virtual courses and schools supplied by numerous companies with varying business models are already bringing value to students, teachers, schools, and parents by delivering student-centric learning in its earliest form, such as FLVS and the Michigan Virtual School. Computer-based games will be another delivery vehicle for student-centric learning. The following companies and services are potential competition to computer-based games that teach physics.
9.1 SuperChem VR

SuperChem VR is an immersive virtual reality chemistry lab created in 2016 by Schell Games. Schell Games, a Pittsburgh-based video game development company with over 100 employees, won support of the Institution of Education Sciences (part of the U.S. Department of Education), and the Small Business Innovation Research (SBIR) program to develop the software. The phase one award was $149,911.42 lasting six months. SuperChem VR allows students to interact safely in a virtual lab environment, thus removing the need to invest in tangible lab equipment. Students need to perform actual measurements correctly to complete tasks and learn real lab procedures while in a virtual world. There is no need to worry about breaking materials and running out of resources. SuperChem VR’s market release has not happened yet, but some schools are getting access to early releases. Schell Games used the Unity game engine in SuperChem VR’s development.
PhET, originally standing for “Physics Education Technology” is a project at the University of Colorado Boulder. The project, founded in 2002, is non-profit and an open educational resource. Nobel Laureate Carl Wieman, who began with a vision to improve teaching and learning in science, founded PhET. The stated mission is "To advance science and math literacy and education worldwide through free interactive simulations." The project designs and manages over 125 free interactive simulations in the fields of physics, chemistry, biology, earth science, and mathematics. The simulations have been translated into over 65 different languages and in 2011; the PhET website received over 25 million visitors. Sponsors contributing $100,000 or more to PhET include the National Science Foundation, New Schools Venture Fund, the William...
and Flora Hewlett Foundation, the O’Donnell Foundation, and the Gordon and Betty Moore Foundation.\textsuperscript{105}

9.3 Portal

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{portal_screenshot.png}
\caption{Screenshot from Portal. Copyright 2017 Valve Corporation.}
\end{figure}

Portal is an award-winning first-person puzzle-platform game developed and published by Valve Corporation, a private video game developer and distributor headquartered in Bellevue, Washington. Portal has become immensely popular and the gameplay relies on mechanics, which has led to its use in physics classrooms. Since its release in 2007, players have downloaded Portal over four million times.\textsuperscript{106} In 2011, Valve released Portal 2, which included a cooperative campaign requiring two players to rely on each other to complete the puzzles. In addition, user-generated content played a large role with Portal 2. A mapping editor system was released in 2012 and within a few days, 35,000 maps were created with 1.3 million downloads through Steam.\textsuperscript{107}
9.3.1 Teachwithportals.com

Figure 15: Portal Puzzle Maker screenshot. Copyright 2017 Valve Corporation.

This led to Portal’s use in education. The website, teachwithportals.com offers free lesson plans, forums, blogs, and other information on how to incorporate the video game Portal into the classroom by designing levels of Portal. Lesson plans cover physics, math, game design, and language arts. Valve Corporation, with $2.5 billion in capital equity and approximately 360 employees, funds the development and use of Portal in education.

10 Conclusion

Finally, the combination of hope and lack of trust in the public education system is a crucial issue facing the U.S. today. It is an issue with implications as large as national security. Computer-based games have taught us two things: learning is fun and games are effective ways to learn. It is time that school, the primary place where learning happens, is more fun while not losing its rigor. Academic computer-based games can solve these large issues not only for physics education but for the entire educational system.
Appendix A

Define: Make Physics a Goal

The first step is for the student to determine that their goal is to take a physics course. The ideal output of this step is that all students would define taking a physics course as a goal. Some students do not determine this and so there is variability here. It is unlikely that a student attending a high school that does not offer physics will make taking a physics course their goal. In addition to lack of access, lack of interest in physics and perceived difficulty decrease the number of students defining physics coursework as a goal. *This step offers areas to innovate by increasing access and by decreasing the perceived difficulty.*

Locate: Find a Class and Lab

The next step is for the student to determine where they will take the physics course. The ideal output of this step is that the student has access to an accredited physics course. This is mainly in the form a course offered by the student’s brick-and-mortar high school. Virtual courses are gaining popularity and acceptance as being a viable, accredited alternative. Still, virtual physics courses are not complete virtual experiences because of the lab requirement. The variability in this step offers areas for companies to innovate by increasing access to physics courses and by creating virtual labs that can replace hands-on labs.

Prepare: Physics First
The next step is for the student to prepare for the execution of the job. Depending on the level of the physics course the student intends to enroll in, there may or may not be pre-requisite requirements. Two-dimensional motion, an early concept in physics, requires algebra and geometry knowledge. Still, the AAPT has created the Physics First program, which recognizes that teaching physics to students early in high school is important to bringing physics to a larger number of students. The AAPT emphasizes the need for further development of materials and pedagogy appropriate to the mathematical preparation and cognitive development of students taking their first physics course early in high school.\textsuperscript{112} This offers areas for companies to innovate by creating physics course content and curriculum relevant to a “Physics First” class.

**Confirm: Enroll in Physics**

The last step before execution is for the student to commit and enroll in a physics course. The ideal output from this step is that all students are able to enroll in a physics course. At brick-and-mortar schools, guidance counselors are responsible for enrolling students in virtual and traditional courses. There are two reasons for variability in this step. First, some high schools do not offer physics and if they do, the school might not offer it every year. Second, guidance counselors and teachers may discourage certain students from taking physics courses. According to an interview, this may be because of a perceived risk that the student will not do well in the course as indicated by that student’s GPA.\textsuperscript{113} Companies can innovate by increasing the viability of offering physics every year and developing more accurate methods to determine how prepared a student is for a physics course.
Execution: Learn Physics

The next step is the execution step, which is the primary task in successfully completing the job-to-be-done of earning physics coursework credentials. The ideal output of this step is that the student has successfully learned the physics curriculum and passes the course. As with acquiring any new knowledge and skills, some students will struggle with this step more than others do. This step may also be easier for students with better teachers, better preparation from previous courses, personal tutors, and more resources. The areas for companies to innovate involve supporting students through this step with educational resources that are accessible and helpful. Ideally, the successful completion of this step relies solely on the student's motivation and willingness to learn the material. Not on their learning style, how quickly they learn, or ability to afford resources.

Monitor: Understanding Progress

Students, teachers, and facilitators monitor the progress of the execution step at the school. Parents or guardians might also monitor their student’s progress through a course. The ideal output of monitoring is being able to understand precisely how much a student has learned and how well they have learned it throughout the course. Frequent grades from homework assignments, tests, and quizzes provide some ability to monitor the progression. Feedback that students receive based on their assignments in the course is the area with most variability.

Personal, Meaningful Feedback
Teachers are the primary source of individualized attention and feedback for a student, but are not always available for questions when a student has them. At virtual schools, the communication between students and teachers is typically only through electronic means and is asynchronous with teachers allowing themselves up to twenty-four hours to provide a response.\textsuperscript{114} In addition, some teachers are better at providing more meaningful feedback than others are. Those students with more access to meaningful, personalized feedback will have an easier time executing the job. Companies can innovate in this area by ensuring students are getting timely, individualized feedback that helps them master new concepts, keeps track of what they have already mastered, and areas where they still need practice.

**Modify: Adapt the Way Physics is Learned**

Based on the feedback from the monitoring step, students and educators can make decisions on modifying the execution of the job. If modifications are necessary, the ideal output of this step is for a struggling student to improve the learning process and an untroubled student to keep learning more.

**Tutors**

A personal tutor is a common modification made by students during a course. Some schools offer free tutoring to students. The tutors might be higher-performing students, students who have taken the class before, or a college student volunteering from a nearby university. A study done by the National Center for Education Statistics found that 21.7% of K-12 students in lowest performing public schools received free
tutoring. For students at schools without free tutoring resources, there are other free or fee-based options online and in-person. Fee-based tutoring increases variability because not all students are able to afford personal tutoring services.

**Special Education in Public Schools**

Some students qualify for federally funded programs assisting children with special needs. These students require individual approaches and receive an individualized education plan. In addition, students who are not proficient at the English language are placed into custom-designed educational programs. Customization is important for these groups of students but it comes at a high cost. Spending increases for special education students have outpaced spending for regular education for over forty years. Consequently, there is a constant struggle over who is eligible for "special" consideration. Companies can innovate in the modification step by reducing the costs of tutoring and by providing course content in multiple ways to suit different learning styles.

**Conclude**

Finally, the student concludes with receiving a final grade in the physics course, which will go on their official transcript. The ideal output of this step is for each student to receive a passing grade in the course. The student will then be able to use the transcript as an educational credential recognized by post-secondary schools and employers. Still, there is variability in this step because not all physics courses are the same. The College Board has standardized more advanced physics curriculum with Advanced Placement
physics courses. High schools commonly offer non-AP physics as well as AP physics courses, but the AP Physics credential has more value with post-secondary schools. Companies can innovate by providing other ways for students to communicate their level of physics understanding besides the final course grade or exam score in their transcript.
Appendix B

Define: Offer Physics

The first step is for the educator to determine that their goal is to offer a physics course at the high school. The ideal output of this step is for all educators to make offering a physics course their goal. Some educators do not determine this and so there is variability here. The sequencing of physics after biology and chemistry is common in high schools because the physics curriculum tends to require more math knowledge than chemistry or biology do. This is a misconception and the AAPT promotes a “Physics First” high school curriculum, which accounts for the math and knowledge level of early high school students. Companies can innovate by creating physics course content appropriate for early high school students.

Locate: Physics Teachers and Students

The next step is for the educator to determine who will teach the course and to recruit and register potential students. The ideal output of this step is to have a qualified teacher identified with enough recruited students to justify the cost of the course. Schools with smaller budgets and smaller enrollments will have a lower chance of finding qualified teachers within their school and enough student demand to justify offering a physics course. In addition, there is a dearth of qualified physics teachers available. Despite a high school not having a qualified teacher on staff, there are virtual schools such as the Michigan Virtual School that do offer physics courses, which students can take at brick-and-mortar schools. The variability in this step results from
the size of the school, the budget of the school, and the lack of available qualified physics teachers. Companies can innovate by enabling every high school to have a viable virtual physics course option, creating more qualified physics teachers, and to reduce costs associated with offering physics courses in schools.

**Prepare: Training and Materials**

In the preparation of a physics course, educators must define a syllabus, choose a textbook, and submit course material and details for addition of the course in the course catalog. For “Physics First” courses, the AAPT recommends workshops, in-service training, and in-service support to help teachers implement “Physics First” courses effectively. For Advanced Placement courses, teachers are highly recommended by the College Board to attend AP-specific teacher trainings or workshops before they teach an AP course for the first time. Some states mandate that all AP teachers attend training before teaching AP courses. The ideal output from this step is for all educators looking to offer a physics course at their school to get the course added to the course catalog. Variability arises from the preparation of the physics teacher.

**Less Preparation for Virtual Courses**

With virtual courses, there must be a local mentor or facilitator for the student. Therefore, while the student is learning the curriculum from a remote teacher, there is still a local presence to help the student. That local mentor may or may not be prepared to help with the course content. It is not required that a physics teacher be the facilitator to a student taking a virtual physics course, which makes offering the course
much more feasible. However, this also means that the student and school completely rely upon the virtual course to teach the material. This provides areas for companies to innovate by making well-prepared teachers more accessible through online tutoring. There are also opportunities to make teacher training more accessible by lowering the costs or by offering training virtually.

**Confirm: Physics Students are Enrolled**

The last step before execution is for the physics teacher to receive approval that the physics course is in the school’s course catalog with students enrolled. The ideal output of this step is that everything is in place for the course to run successfully with the students’ chances of learning the material and earning a passing grade maximized. Variability arises in the number of students enrolled, which can affect the outcome of this step. The cost-effectiveness of the course diminishes if too few students enroll, which can cause administrators to drop the course from the catalog. Still, students that are interested in the course may register for virtual course options. Companies can innovate by making smaller classes more cost-effective at the brick-and-mortar schools and by increasing the accessibility of virtual courses.

**Execute: Teach Physics**

In the execution step, educators facilitate the teaching of physics curriculum to the students enrolled in the course. The ideal output is to have the entire course curriculum taught in a way so that each student enrolled in the course has the best opportunity to learn the material. Many factors cause variability in the output of this step. The most
prominent cause of variability is in the teaching style. Styles that help some students learn may not work for others. In addition, teachers are limited in their time with students. Typically, classes only meet for approximately an hour per day five days per week. This limits the amount of interaction with the students versus lecturing to the students. Other factors play a role such as student attendance and teacher’s experience with the course material and structure. Companies can innovate by making the length of the course more flexible for slower or faster learners and by offering resources to teachers that enable them to teach with different styles depending on the preferences of their students.

**Monitor: Understanding Effective Teaching**

Educators and students monitor the progress of the execution step. The ideal output of monitoring is observing positive progression of the teacher towards teaching the physics curriculum. A teacher lecturing or presenting course content in a style that suits them does not necessarily mean that teacher is successfully teaching. Understanding how the students are progressing provides the necessary evidence to indicate successful teaching is happening. Companies can innovate by creating new ways to evaluate teaching that factors in the aptitude of the students. Teachers who have more motivated and prepared students will appear to be effective teachers, even though they might not be, if the only measurement is student outcome. While teachers who have less-prepared students will appear to be less effective by that same standard, even though they might not be. Evaluating teacher efficacy while accounting for student ability will give teachers meaningful feedback and offer ways to improve.
**Modify: Ability to Change Styles**

Teachers need to take the feedback from the monitoring step to determine if modifications are necessary. If modifications are necessary, the ideal output of this step is for the educator to improve the teaching of the physics curriculum. Teachers notice that certain students have a harder time than others do learning material. Teachers also notice that it comes faster or slower to other students. When educators identify struggling or excelling students, there is no common method for making modifications. This results in variability at the modification step. Companies can innovate by creating a method to identify the most effective teaching style for a particular student and a way for the student to learn the material in that style.

**Conclude: Final Grades**

The educator concludes with giving students final grades, which will appear on the students' transcripts. The ideal output of this step is for all students enrolled in the course to have earned a passing grade in the course. If the student takes a virtual course, a passing grade is more impactful to the educators because it can effect school funding. Some states, such as Utah, give half the funding to the school up front and the other half after the student passes the course. There is variability in that not all students enrolled the course will pass and receive course credit. Companies can innovate by changing the funding scheme so educators are not punished for students trying a course but not passing it.
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