EduGaming:

Bridging the chasm between education and gaming

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Abstract

In the digital era, with the growing influence of social media, YouTube and video gaming, research into how educational facilities can be linked up with worldwide engagement has become critical. Online learning facilities like Khan Academy, Skillshare and Codecademy are on the rise and paving the way for a new paradigm of education. Although many attempts have been made to combine video gaming with education, few have taken the effort to analyse the aspects of games which could be utilised to facilitate effective education. As a result, the label of 'educational games' has become synonymous with repetition, boredom and lack of engagement.

To investigate the potential for games to influence education, four different video game tutorials sharing a common set of mechanics were engineered. Participants were assessed on their knowledge of specific curriculum and then either given ten minutes of reading printed information on the curriculum or ten minutes of playing the tutorial which most closely matched their preferred learning style. Participants were then reassessed on the same curriculum to analyse the effectiveness of the tutorials as an educational tool. The outcome of the analysis is used to conclude how the mechanisms of video game tutorials affect player learning, information retention and problem solving strategies as well as the effectiveness of educational techniques used in video games. These conclusions then form the basis for a discussion of how these mechanisms can be refined and better utilised as a supporting medium to serve the purposes of a structured educational curriculum, enabling users to engage in their environments with a greater sense of agency and self-awareness. Although it does not offer a definitive conclusion for creating a perfect educational game, this paper lays the foundation for changes and new approaches which could help improve the quality of educational games to come.

Greg Williamson

Introduction

Ever since the release of *Pong* [1] in 1972 sparked the continuing rise in video game popularity, developers have devoted time and money towards refining the methods and mechanisms of teaching their users the required skills to enjoy, complete and master their games as stated in [2]. Around the same time, a new branch of psychology began to grow into the field of pedagogy, laying the foundation for the principle of individualised learning styles as mentioned in [3]. Despite the parallel growth of both paradigms, surprisingly little academic overlap occurred to support or develop either field.

The field of pedagogical psychology was in part pioneered by David Kolb, who proposed a model based on his *Experiential Learning Theory* (ELT) in [4], segmenting learning into the different aspects of physical experience and abstract conceptualisation. In 1982 Peter Honey and Alan Mumford took the basis of the ELT model and made a series of adaptations, transforming it into an analysis of the four common learning styles, *Activists*, *Reflectors*, *Theorists* and *Pragmatists* in [5]. At the same time, in [6] they developed their *Learning Styles Questionnaire* (LSQ), a comprehensive self-development tool used to categorise and support individual learning styles.

The majority of academic research which followed, including the popular *Visual, Auditory, Reading/Writing and Kinesthetic* (VARK) model proposed by Neil Fleming in [7], grew from the foundations of Honey and Mumford's modified version of Kolb's original model [4, 5]. Although a comprehensive literature review [8] criticised many of the established theories and testing procedures, the principles of individualised learning styles have been adopted and utilised all over the world [9], from global business enterprise to childhood education.

In stark contrast, academic analysis of learning in video games wasn't popularised until the early 21st Century, with the concept of *gamification*, abstract interactivity and Augmented Reality Games (ARGs) shown in [10]. However, evidence of significant advancements within internal game education can be traced back to the mid-90s with the advancements in 3D computer graphics [11]. As major development studios produced games with increasingly complex mechanics, interactions and challenges, so too did they invest in creating tutorials which both held the player's attention and imbued a strong sense of agency. *Portal* [12] is frequently referenced in this regard as a game which spends the majority of its play time teaching an incredibly complex and abstract set of mechanics to solve physics-based puzzles discussed in [13].

The methodology for creating a clear analysis and discussion of these topics involved the design, implementation and undertaking of a controlled experiment. The experiment consisted of four distinct parts, a pre-test to determine the baseline knowledge of participants, a psychological learning style test to determine their preferred learning styles, exposure to a form of educational material and then a post-test to compare the changes in knowledge and understanding from each participant's baseline.

Analysis of the results was then used as the basis for discussion of a wider view of video games as a medium for education and to establish reason and evidence for two key points of enquiry; how the mechanisms of video game tutorials affect player learning, information retention and problem solving strategies and how these mechanisms can be refined and utilised to serve the purposes of a structured education curriculum.

Method

To address the aims of this experiment and create results for analysis which can be used to draw conclusions about the posited theories, seventeen volunteers were invited to be participants in the experimental process. Participants were predominantly males aged between eighteen and thirty years of age who had completed at least four years of a formal secondary-level education and had no prior knowledge of the experiment. To create results relevant to the aims of the experiment, two groups were used, a control group measuring the effectiveness of traditional educational media and an experimental group measuring the effectiveness of video games as an educational medium.

To better understand the relationship between game mechanics and education, an experimental design was created to identify the effectiveness of indirect information exposition through a basic game. The process began by developing a simple, physics-based game which relied on principles commonly taught as part of the *New Zealand Qualifications Authority's* (NZQA) Level 1 *National Certificate of Educational Achievement* (NCEA) [14]. Utilising simple 2D sprite-based rendering, players are put in the position of Earth's Defense Commander, attempting to repel an imminent alien threat. The player begins with a limited amount of funds to purchase and fire missiles at the three alien invaders, which vary in cost depending on how much fuel, launch boost and weight each missile starts with. This forces the player to weigh the balance between the effectiveness and cost of each missile within the 90 second game time to find a strategy to defeat all three enemies.

To assess the effectiveness of the educational medium for each group, all participants were asked to complete a pre-test before exposure to the educational material and a post-test following this exposure to examine how their knowledge of the topic had changed. These changes were determined by analysing the differences between quantity and quality of answers between the pre-test and post-test for each participant within three categories, core concepts, misconceptions and relationships. Core concepts included key ideas and fundamental knowledge directly related to the topic. Misconceptions included common misunderstandings, mistakes and miscommunications related to the core concepts and other relevant knowledge. Relationships included the correlation between quantitative elements of the core concepts and proportionalities of the relevant physical relationships.

Pre-Test

Each participant began by completing a ten minute pre-test (see Appendix A), aimed at evaluating their knowledge and understanding of the subject matter by answering open-ended questions which provided the opportunity for each participant to demonstrate their understanding, reasoning and problem-solving related to skills commonly sought in a structured curriculum.

The pre-test consisted of the following five questions:

1. Explain what you understand about momentum
2. Explain what you understand about kinetic energy
3. Explain what you understand about force
4. Explain what you understand about how objects are affected by their mass
5. Explain what you understand about how objects change velocity.

Learning Styles Test

Each participant was then given ten minutes to complete an eighty question learning style test derived from [6], aimed at determining their psychological tendencies and preferences towards the four learning paradigms; activist, reflector, theorist or pragmatist. Using a small piece of software, participants were then randomly divided into two groups of equal size, a control group and experimental group.

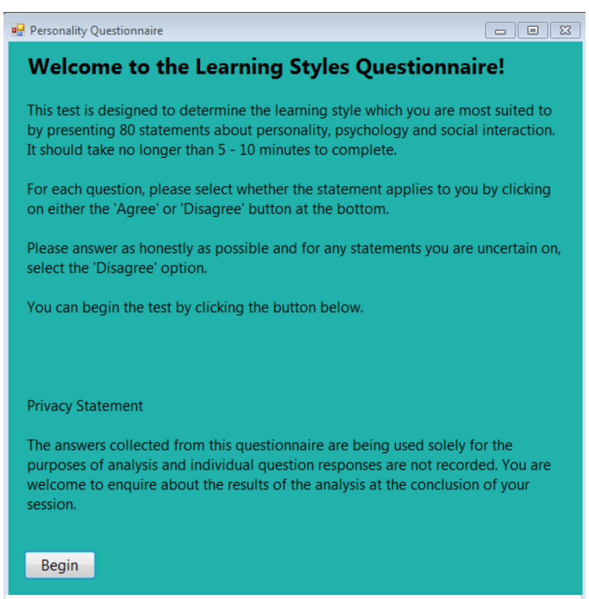


Fig. 1 - Learning Styles Test Start Screen

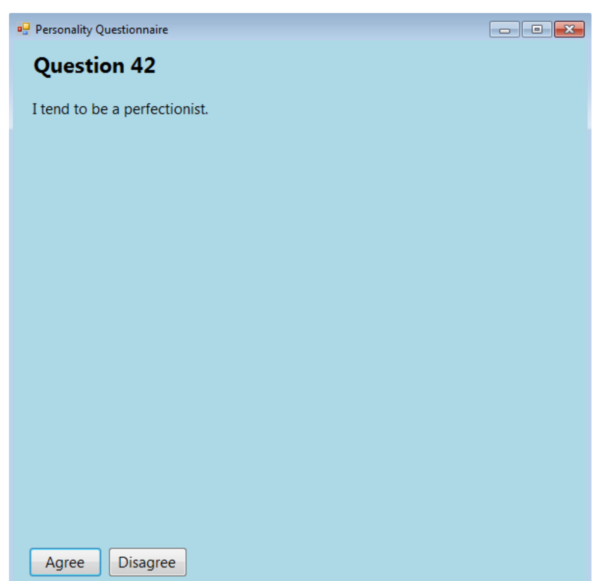


Fig. 2 - Learning Styles Test Question 42

Exposition

Participants in the control group were given ten minutes to read a piece of educational material related to the topic from [15]. Each piece of written material exposed a similar level of information to that provided by the mechanics of the game (see Appendix C).

Participants in the experimental group were given ten minutes to read game tutorial text specific tailored to their identified learning style and then play as many rounds of the game as possible within the remaining time. The game rounds lasted for a maximum of two minutes so it was expected that each participant in this group would be able to play a minimum of at least three rounds.

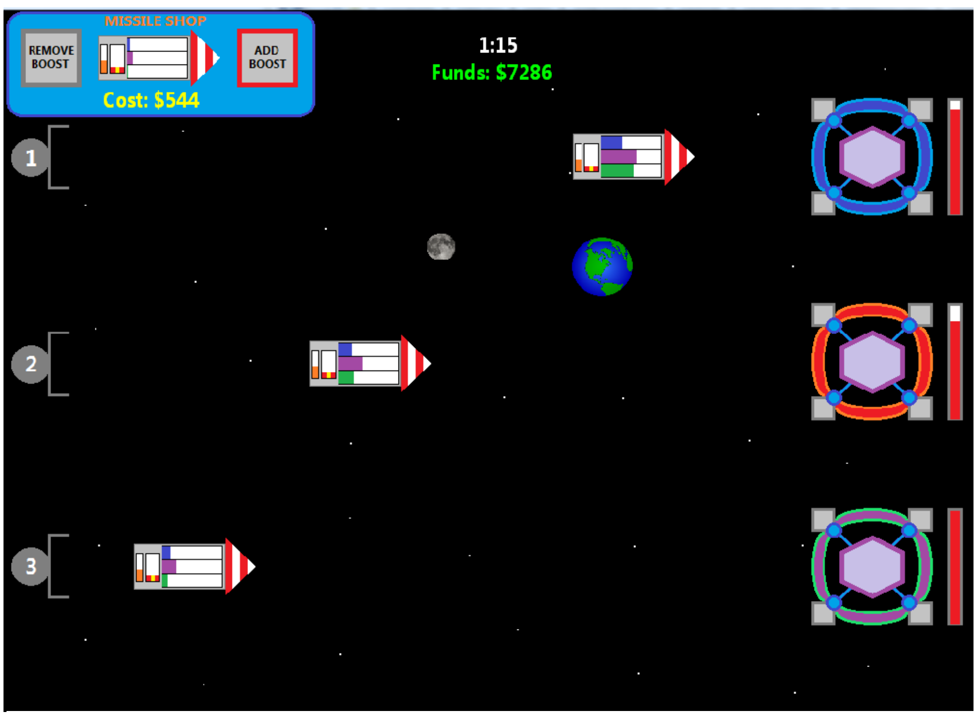


Fig. 3 - In-game screenshot

A small reward was also offered as a prize to the participant in the experimental group who could successfully complete the game in the fastest time from when the exposition period began. This incentive added a competitive aspect similar to that of a multiplayer game and also created motivation for participants to learn and master the mechanics of the game.

Post-Test

At the completion of the exposition period, participants in both groups were given ten minutes to complete a post-test (see Appendix B) which was aimed at evaluating knowledge and understanding gained from the written document or game interaction, depending on their allocated group. The post-test had a short summary of the information which was exposed in either the written material or gameplay mechanics but contained open-ended questions identical to those in the pre-test.

The post-test for both groups consisted of the exact same five questions as the pre-test, however the post-test for the experimental group also contained a brief explanation of how the mechanics of the game applied to the topic (see Appendix D).

Results

The answers provided by each participant were compared to the model answers (see Appendix E) and scored based on the three different categories, core concepts, misconceptions and relationships. For the core concepts category, participants were awarded one point for each unique core concept listed in the model answers which was included in their answer. For the misconceptions category, participants were deducted one point for each unique misconception in the model answers which was included in their answer and deducted one point for incorrect or irrelevant information. For the relationships category, participants were awarded one point for each unique relationship in the model answers which was included in their answer irrespective of whether their answer included the positive or negative relationship where applicable. The data from both groups was then combined and averaged so that it could be compared and Table 1 provides a summary of these results.

Table 1 – Raw experimental data for both the control and experimental groups

Question	Category	Control				Experimental			
		Pre-Test	Post-Test	Change	Average	Pre-Test	Post-Test	Change	Average
1	Core Concepts	1	3	2	0.22	2	1	-1	-0.125
	Misconceptions	-4	-9	-5	-0.56	-7	-1	6	0.75
	Relationships	3	10	7	0.78	3	8	5	0.625
	Total	0	4	4	**0.44**	-2	8	10	**1.25**
2	Core Concepts	5	6	1	0.11	5	2	-3	-0.375
	Misconceptions	-1	-4	-3	-0.33	-3	-2	1	0.125
	Relationships	2	5	3	0.33	3	6	3	0.375
	Total	6	7	1	**0.11**	5	6	1	**0.125**
3	Core Concepts	7	8	1	0.11	3	2	-1	-0.125
	Misconceptions	-2	-9	-7	-0.78	-5	0	5	0.625
	Relationships	0	3	3	0.33	4	7	3	0.375
	Total	5	2	-3	**-0.33**	2	9	7	**0.875**
4	Core Concepts	3	2	-1	-0.11	0	0	0	0
	Misconceptions	-2	-7	-5	-0.56	-4	-1	3	0.375
	Relationships	4	8	4	0.44	7	10	3	0.375
	Total	5	3	-2	**-0.22**	3	9	6	**0.75**
5	Core Concepts	4	7	3	0.33	7	7	0	0
	Misconceptions	-1	-5	-4	-0.44	-1	0	1	0.125
	Relationships	3	6	3	0.33	1	3	2	0.25
	Total	6	8	2	**0.22**	7	10	3	**0.375**
All	Core Concepts	20	26	6	0.67	17	12	-5	-0.625
	Misconceptions	-10	-34	-24	-2.67	-20	-4	16	2.0
	Relationships	12	32	20	2.22	18	34	16	2.0
	Total	22	24	2	**0.22**	15	42	27	**3.375**

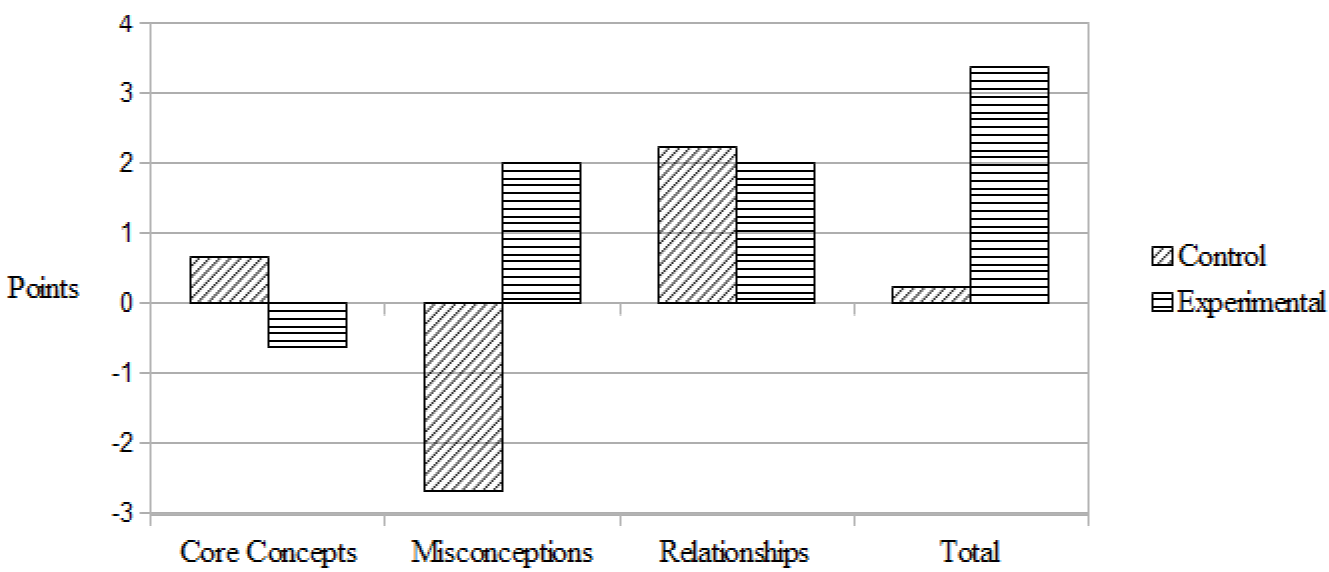
The length of each participant's answers were also counted to measure the differences between pre-tests and post-tests and to calculate an average length change for both the control and experimental groups. A number of responses were edited to remove content which was deemed inappropriate, irrelevant or unnecessary and therefore unlikely to appear in an academic assessment. The length of the edited responses was then calculated by using the word count functionality of word processing software for both groups and the results of this data is summarised in Table 2.

Table 2 – Pre-Test and Post-Test response lengths for both the control and experimental groups

Question	Control				Experimental			
	Pre-Test	Post-Test	Change	Average	Pre-Test	Post-Test	Change	Average
1	216	288	72	8.00	196	145	-51	-6.375
2	199	264	65	7.22	179	143	-36	-4.5
3	231	216	-15	-1.67	218	128	-90	-11.25
4	268	301	33	3.67	277	124	-153	-19.125
5	257	284	27	3.00	231	148	-83	-10.375
All	1171	1353	182	**20.22**	1101	688	-413	**-51.625**

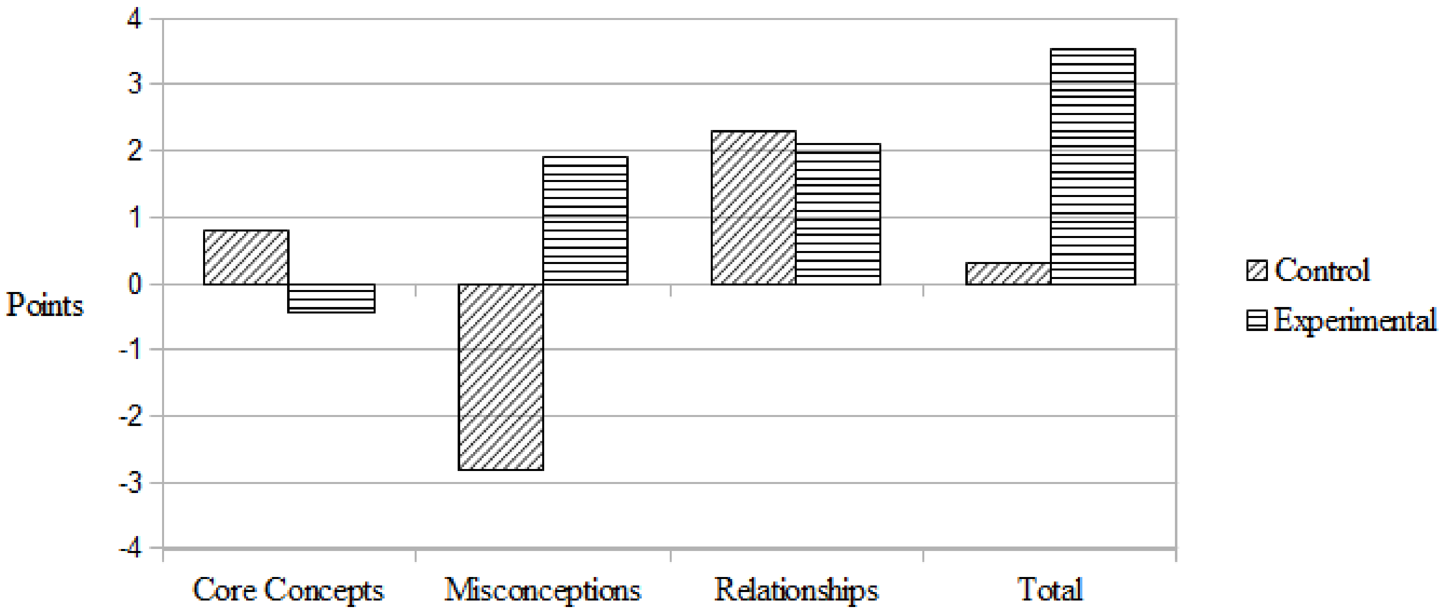
Using the data obtained in Table 1, a comparison between the average results of the core concepts, misconceptions and relationships categories as well as the total of both groups was performed. This comparison was used as the basis for an analysis of the effectiveness of the educational media presented to both the control and experimental groups and the results of this comparison is presented in Chart 1.

Chart 1 – Comparison of the average category score change between control and experimental groups



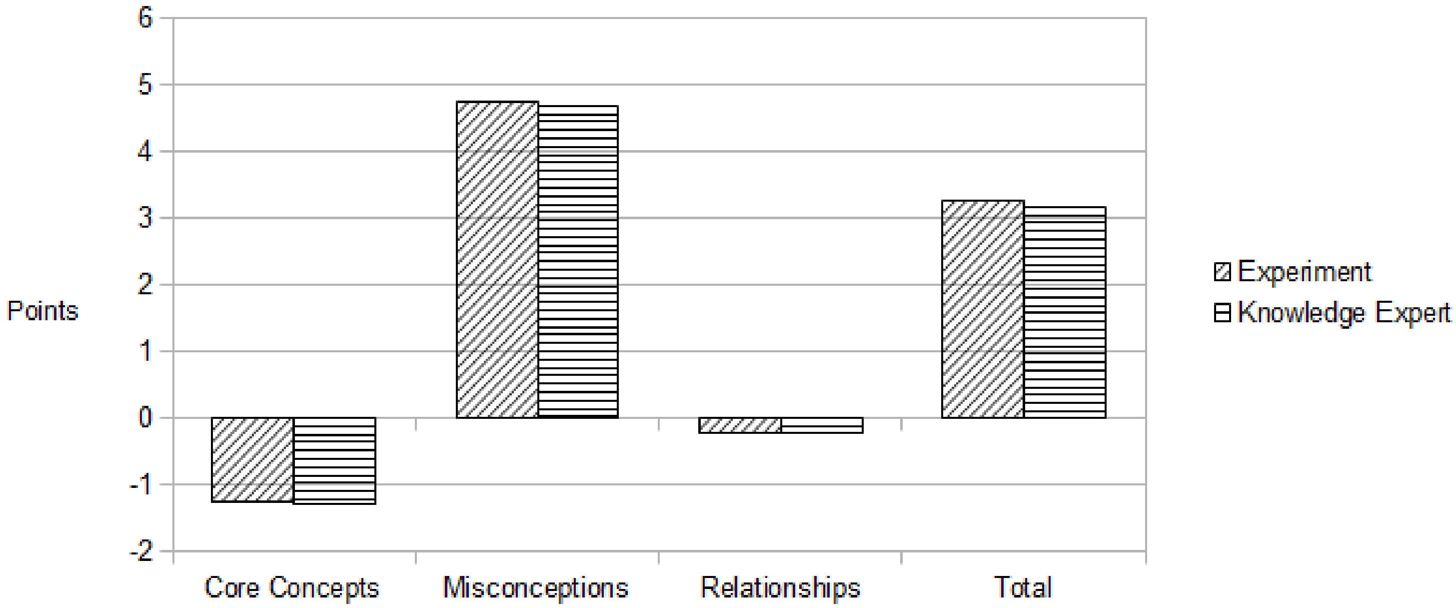
In order to mitigate the subjectivity related to production of the results, an impartial knowledge expert was consulted to provide an independent analysis of the participants' responses. The knowledge expert was provided with a copy of the model answers, a copy of each participant's pre-test and post-test (with the participant's name removed to maintain confidentiality) and an explanation of the assessment criteria. The feedback provided was then used to confirm the validity of the results produced from this experiment but was not used as the basis for the subsequent analysis of the raw data. A summary of the analysis performed by the knowledge expert is presented in Chart 2.

Chart 2 – Knowledge Expert comparison of the average category score change between both groups



Confirmation of the validity of the results was calculated by comparing the difference between the results obtained from the experiment (presented in Chart 1) with the results obtained from the independent knowledge expert (presented in Chart 2). By calculating the absolute difference between the results for each category, an overall absolute difference was created as the sum of the absolute differences and the results of this calculation is presented in Chart 3.

Chart 3 – Comparison of absolute difference between calculated scores for Experimenter and Knowledge Expert



Analysis

Analysis of the results from this experiment was performed by means of comparison between each participant's pre-test and post-test answers and then comparison of the average results of the control group and experimental group. The validity of the experiment was established through independent consultation with a knowledge expert who performed a similar analysis of the results with no prior knowledge of the experiment or initial results obtained. The difference between the total of the analyses was 2.6% which supports the validity of the results produced from this experiment as well as confirming the accuracy of the model answers used.

In order to minimise subjectivity during analysis, the results of both the pre-tests and post-tests were compared by a relative measure rather than an absolute measure. The pre-test created a baseline analysis through which each participant's knowledge and understanding of the topic could be measured as well as their ability to communicate the related concepts. This was performed by counting the number of relevant concepts covered in each answer and analysing how succinct the written answer was.

From this baseline, the post-test results were then be used to analyse how each participant's understanding had changed following their exposition, either written or through game mechanics. Each participant's post-test answer was compared to their pre-test answer to determine how many new topics were understood, how many misconceptions had been resolved and how much more succinctly the ideas could be conveyed.

Although assessing overall understanding of a topic presents difficulties in relation to maintaining objectivity, the purpose of the analysis was not to measure how much had been learnt through interaction with the game mechanics but rather, to measure the difference in learning between a conventional form of learning and interactive medium presenting the same concepts. Analysis of these relative results, rather than absolute outcomes provides a more robust and objective foundation on which to draw conclusions.

Beginning with a broad analysis of the results, the most significant result was the comparison between the total average increase of the control group (0.22%) and experimental group (3.375%). The increase of over 1400% strongly suggests that the quality and/or quantity of knowledge gained by the experimental group who interacted with the game was far greater than that of the control group who only read information on the topic. To better understand the nature of this improvement requires a closer analysis of each individual category so as to determine what changes in quantity and quality of knowledge occurred for each of the groups.

The 'Core Concepts' category measured how many relevant ideas each participant was able to identify, with one point counted for each idea. The results for this category identified an unexpected trend, with the control group averaging 0.67 points of improvement but the experimental group averaging -0.625 points of improvement, indicating that the experimental group could identify fewer relevant ideas in their post-test. However, a possible explanation for this result could be that participants in the experimental group assumed that ideas identified during their pre-test answers did not need to be repeated during their post-test answers. Another possible explanation involves a decreased confidence in certainty of knowledge during the post-test, which will be discussed later.

The 'Misconceptions' category measured how many incorrect or misunderstood idea each participant identified, with one point subtracted for each idea. This category had the most significant difference of results, with the control group averaging -2.67 points of improvement and the experimental group averaging 2.0 points of improvement. These results are supported by other works which identified the influence of psychology towards learning and knowledge acquisition, specifically in regard to confirmation bias, which is “the seeking or interpreting of evidence in ways that are partial to existing beliefs, expectations, or a hypothesis in hand” as defined in [16]. One advantage this identifies in the use of video games is the inability for users to be influenced by confirmation bias in their interactions with mechanics and required knowledge. By design, the rules which video games abide by cannot be directly influenced by the player and therefore any misconceptions and misunderstandings the player has about the system are either punished or prevented by the logic used to create the game. In contrast, when reading information where no external influences are present, there is a far greater chance of misinterpretation by confirmation bias, due to a lack of punishment or prevention for incorrect understanding.

The results for the 'Misconceptions' category further support the analysis of trends within the 'Core Concepts' category by providing a basis for the decreased results of the experimental group. It has already been established that participants in the experimental group had on average two fewer misconceptions about concepts in their post-test and this is likely due to a decreased influence of confirmation bias. This likely introduced an uncertainty for the participants which caused them to doubt their certainty of knowledge related to core concepts and therefore cause them to provide fewer fundamental ideas in their post-test, leading to the observed result.

The 'Relationships' category measured how many of the related proportionalities each participant was able to identify or explain, with one point for each pair of related values. The results for this category showed no significant difference, with the control group averaging 2.22 points of improvement and the experimental group averaging 2.0 points of improvement. Results in this category were important for validating the use of video games as an educational medium because, although it is important to identify and correct misconceptions about knowledge, this is provides little benefit if correct knowledge is not also imparted. The average increase of the experimental group was around 90% that of the control group and this could likely be increased by improving the quality of the game as well as a longer interaction time with the mechanics of the game.

One final comparison to be analysed is the difference in the length of answers provided by participants. For both groups, the length of pre-test answers was approximately the same, with the control group averaging 130 words per answer and the experimental group averaging 138 words per answers. However, the post-test answers created a substantial difference between response lengths, with participants in the control group averaging 20 more words than pre-test answers while participants in the experimental averaged 52 fewer words than pre-test answers. Analysis against the 'Misconceptions' category suggests that participants in the experimental group were significantly less likely to include information they were unsure of in their answers. Results from the 'Relationships' and 'Core Concepts' categories also support this, as the reduction in average score from the experimental group compared to the control group was 31% while the reduction in answer length was 72%. By comparison, participants in the experimental group were able to more succinctly answer questions in the post-test, have fewer misconceptions and still include a comparable amount of key concepts and relationships.

Combined, the analysis of each group then forms the basis of a more substantial analysis of video games as an educational medium. Compared with traditional textbook-style learning, video game learning identified two key areas related to education, the removal of incorrect knowledge and the acquisition and retention of correct knowledge. Participants in the experimental group successfully identified and eliminated their own misconceptions based on interaction with the game, however participants in the control group were more likely to confirm and increase their confidence in their own established misconceptions despite exposure to material intended to provide accurate information. This is a crucial element in education because acquisition of correct knowledge is often hindered by misconceptions and misunderstandings and in many forms of structured curriculum there is little time or opportunity to identify and correct misconceptions. Participants in the experimental group were also able to acquire a similar amount of new knowledge compared to the control group although the game likely introduced some uncertainty and reduced confidence in established knowledge. This demonstrates that video games are able to provide a similar level of education compared to traditional methods and therefore viable as an educational medium. A number of other studies have identified that video games can be powerful tools for education, especially in the form of tangential learning and the results of this experiment support a viable model for constructing games to serve a more structured educational curriculum.

Discussion

One of the primary issues with creating digital learning resources is failure to identify the intended outcome of the expositional interaction. Many early attempts at creating educational games relied on activity repetition to teach the concepts of problem solving, evident in titles such as *Math Blaster!* [17] and *The Typing of the Dead* [18]. The reliance on repeatable mechanics as an educational mechanism fails to address two key aspects of game design; repeatability and agency. In order to more effectively analyse the outcomes of learning through video games, a greater focus was needed on assessing what players understood about their newly-acquired knowledge within a wider context of application.

From the outset, one of the aims of the experiment was investigating how the mechanisms of video game tutorials affect player learning, information retention and problem solving strategies. The analysis so far has shown that the immutable nature of the mechanisms causes players to more effectively break previous misconceptions of knowledge and retain information to the same degree as other common educational media. The interactive nature and responsive feedback of games also allows player to rapidly iterate through problem solving strategies and thus improve rationalisation of thought regarding knowledge and its application.

By presenting the educational opportunity as part of the game's mechanics rather than the goal, the aspect of repeatability was more effectively addressed and allowed game design to be focused more on the fluidity of the combat mechanics which created a more enjoyable experience. The key to successfully presenting repeatable mechanics is creating an internal psychological desire within the player to learn and master the mechanics. When the player is aware that knowledge is being forced upon them, they become more resistant to learning, but entire competitive gaming communities have been formed by players who have mastered mechanics as a means to achieve their goals. Harnessing this potential requires careful attention to player interactions and personal goals which are primary motivators for enjoyment and growth.

One game which has made effective use of this potential is *World of Warcraft* [19], specifically the endgame raid instances. Maximising survival chances in these instances requires players to invest hours of game time in learning boss mechanics, mastering combat rotations and obtaining the most powerful gear available as alluded to by [20]. Additionally, successful completion of these instances requires players to utilise effective team strategies, maintain clear communication and coordinate teams of 10-25 players as discussed in [21, 22]. However, the reward for successfully killing a boss at this difficulty is 3-6 pieces of gear meaning that only a small percentage of the team are rewarded. The individual goals of each player to obtain better gear and satisfaction derived from 'progression' (the killing of a boss for the first time) creates enough motivation for the players to persist with the repetition required for mastering of these skills as analysed by [23]. In this process, many players inadvertently learn leadership and management skills that large corporations spend millions of dollars teaching to their staff, shown in [24].

Educational games could be greatly improved in terms of uptake and effectiveness by adopting this model of gameplay and changing the endgame goals from knowledge to game-related abstractions which will motivate the players into wanting to master the mechanics. Through this, education can then be achieved by a mastery of the mechanics and a presentation of how the mechanics have application to the real world, as demonstrated by the results of this experiment. However, given more time and feedback, the presentation of the real world applications of the mechanics could be greatly improved from the simple exposition used in the post-test of the experimental group (see Appendix D).

The other aim of the experiment was to form and justify theories for how the mechanisms of video game tutorials can be refined and utilised to serve the purposes of a structured educational curriculum. The core concepts, misconceptions and relationships used in this experiment were derived from a structured educational curriculum as the first form of evidence towards justifying the use of video games as a form of educational media.

The refinement of these mechanisms within games simply requires the application of time and careful consideration towards the desired outcome. Designing the initial experiment for the purposes of educating within the topic of Newtonian physics required several iterations of prototypes before deciding on a space-setting using combat-based mechanics. This had two key advantages, the first being the removal of friction (air resistance) which simplified to the concepts to the same as those presented in the educational curriculum. The second advantage was the need to indirectly understand the relationships involved in order to successfully complete the game. The abstraction of concepts as a means to accomplish goals which were presented as interactive, competitive and enjoyable ensured that the repetition required to master an understanding of the relationships was derived from the game mechanics and not from presentation of information.

It should be noted that the analysis of these results currently only have application specific to the field of physics, however similar results would be expected with other numeracy-based subjects such as statistics, calculus and chemistry. This is supported by the three categories used to produce the results of the experiment which are common to the majority of numeracy-based subjects and therefore likely to be equally effective.

One significant advantage video games have over traditional educational methods such as textbooks and lectures is the ease of internationalisation. Game mechanics are seldom language-specific or culture-specific and popular titles are commonly produced and distributed in a number of languages so as to reach the widest possible international audience shown by [25]. Translation is usually only necessary for dialog, text-based assets and subtitles and is more important for creating and maintaining story immersion than for teaching mechanics. Expanding on this idea to include games intended for education, creating a single game to teach a specific subject or topic which relies on minimal text or dialog becomes significantly cheaper and more effective than trying to create a compendium of knowledge and then translating and localising that knowledge.

Conclusion

From the results and subsequent analysis of this experiment, a number of conclusions can be drawn. Beginning with conclusions related to the initial aims of this experiment, it can be concluded that the mechanisms of video game tutorials influence player learning by identifying and eliminating misconceptions. The mechanisms also affect information retention by providing a similar quantity of knowledge as compared to textbook-style presentation and support problem-solving strategies by utilising environments which allow for rapid iteration and testing of strategies. It can also be concluded that refinement and utilisation of these mechanics to support a structured educational curriculum requires little more than the investment of time to design the intended educational material into game mechanics.

Taking a broader view, conclusions can be formed about how communication and support can be established and maintained to benefit both the video game industry and education as a whole. By using the immutable nature of a game's rules, coupled with the presentation of problem-solving repetition as an aspect of game mechanics, education can be presented more subtly than it has been in previous attempts to create educational video games. Educational providers would be able to take advantage of the huge number of fans and appeal of successful titles. Game studios would gain access to a new market capable of providing rigid and structured feedback which could be used to improve the quality of tutorials, mechanics and gameplay and therefore increase the potential for sales and subsequent profits. With both educators and game producers standing to benefit from this relationship, academic research and publications would take the role of forming the middle ground between the two industries, through which theories and methods could be tested and subject to peer review.

Future Work

To build on the foundations of this research and extend the conclusions further, focus will need to be expanded to include other topics from the core educational curriculum such as numeracy, general science, social science and literacy. A comparison study between the effectiveness of education through video games for numeracy-based subjects compared with literacy-based subjects would also be necessary to determine if the use of video games as an educational medium is viable across the educational curriculum as a whole.

Effective analysis of the application of conclusions drawn in this experiment would require input from knowledge experts in relevant fields to ensure an adequate quantity and accurate quality of information is included for both a control and experimental group. Consultation with professional game development studios would also provide the opportunity to expand the game used in the experimental process to other genres such as real-time strategy, role-playing and first-person shooter. This would also allow for a significant increase of the quality of the game and subsequent level of engagement for players which would likely magnify the results of the experiment.

Improvements could also be made to the method for exposition of the relationship between game mechanics and real world knowledge. Ideally an assessment system would be created which presented the knowledge and problem-solving strategies learned from the game as opportunities for solving problems which have real world application. An effective assessment system of this nature would also serve to reward players for mastery of game mechanics and strategies rather than create the unsatisfactory expectations of written examinations.

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Appendix A – Pre-Test

Pre-Test

Name:

1. Explain what you understand about momentum.

2. Explain what you understand about kinetic energy.

3. Explain what you understand about force.

4. Explain what you understand about how objects are affected by their mass.

5. Explain what you understand about how objects change velocity.

Appendix B – Post-Test

Post-Test

Name:

1. Explain what you understand about momentum.

2. Explain what you understand about kinetic energy.

3. Explain what you understand about force.

4. Explain what you understand about how objects are affected by their mass.

5. Explain what you understand about how objects change velocity.

Appendix C – Control Group Educational Material

Newton’s Laws of Motion

First Law

Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it.

Second Law

Force is equal to the change in momentum per change in time. For a constant mass, force equals mass times acceleration

Third Law

For every action, there is an equal and opposite reaction

Explanation

The motion of an aircraft through the air can be explained and described by physical principals discovered over 300 years ago by Sir Isaac Newton. Newton worked in many areas of mathematics and physics. He developed the theories of gravitation in 1666, when he was only 23 years old. Some twenty years later, in 1686, he presented his three laws of motion in the "Principia Mathematica Philosophiae Naturalis." The laws are shown above, and the application of these laws to aerodynamics are given on separate slides.

Newton's first law states that every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force. This is normally taken as the definition of inertia. The key point here is that if there is no net force acting on an object (if all the external forces cancel each other out) then the object will maintain a constant velocity. If that velocity is zero, then the object remains at rest. If an external force is applied, the velocity will change because of the force.

The second law explains how the velocity of an object changes when it is subjected to an external force. The law defines a force to be equal to change in momentum (mass times velocity) per change in time. Newton also developed the calculus of mathematics, and the "changes" expressed in the second law are most accurately defined in differential forms. (Calculus can also be used to determine the velocity and location variations experienced by an object subjected to an external force.) For an object with a constant mass m, the second law states that the force F is the product of an object's mass and its acceleration a:

For an external applied force, the change in velocity depends on the mass of the object. A force will cause a change in velocity; and likewise, a change in velocity will generate a force. The equation works both ways.

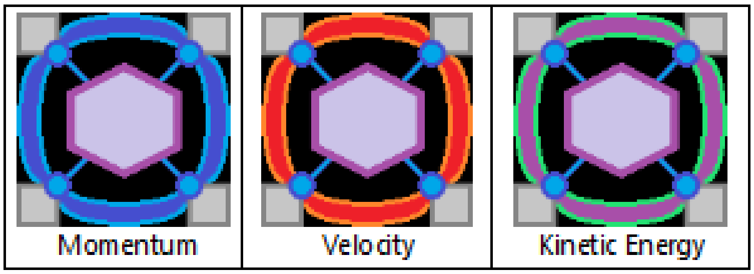
The third law states that for every action (force) in nature there is an equal and opposite reaction. In other words, if object A exerts a force on object B, then object B also exerts an equal force on object A. Notice that the forces are exerted on different objects. The third law can be used to explain the generation of lift by a wing and the production of thrust by a jet engine.

Appendix D – Experimental Group Post-Test

Post-Test

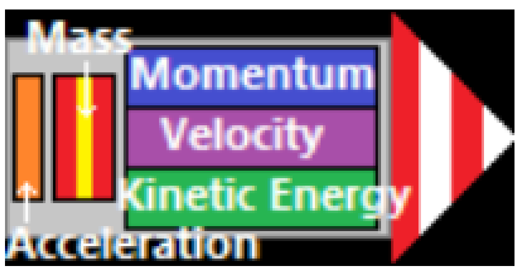
Enemies

Each enemy shield took damage depending on a physical property of the missile



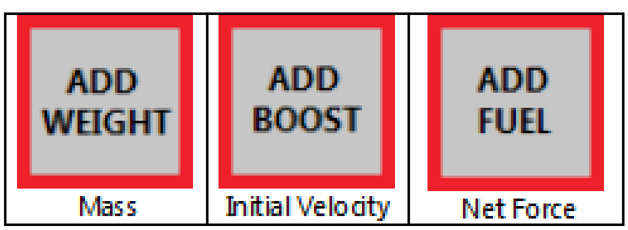
Missiles

Each stat bar on the missile measured a different physical property



Missile Shop

Each upgrade from the missile shop affected a different physical property



Appendix E – Model Answers

Pre-Test Answers

1. Explain what you understand about momentum.

   Concepts

   - Total momentum is always conserved
   - Momentum is a measure of an object's mass and velocity
   - Changing momentum requires the application of an external, unbalanced force

   Misconceptions

   - Momentum is not a form of energy
   - Momentum is not a measure of inertia
   - Momentum is not acceleration
   - Momentum is not a force
   - Two objects with different masses will gain the same momentum from an equal force
   - Objects with a constant unbalanced force have a changing momentum

   Relationships

   - Momentum increases proportional to mass
   - Momentum increases proportional to velocity

2. Explain what you understand about kinetic energy.

   Concepts

   - Total energy is always conserved
   - Kinetic energy is a measure of the energy of an object due to its motion
   - Changing kinetic energy requires a change in velocity or mass, velocity has the greater effect

   Misconceptions

   - Kinetic energy is not stored potential energy
   - Kinetic energy is not created when objects stop
   - Friction is not a form of kinetic energy
   - Kinetic energy does not determine the maximum velocity of an object

   Relationships

   - Kinetic energy increases proportional to mass
   - Kinetic energy increases proportional to the square of velocity

3. Explain what you understand about force.

Concepts

- Constant, unbalanced forces on an object will result in constant acceleration
- Force is any interaction with mass which causes it to change its motion
- Every action force has an accompanying reaction force

Misconceptions

- Force is not interchangeable with kinetic energy
- Objects with a net force of zero can have a non-zero velocity

Relationships

- Force increases proportional to mass
- Force increases proportional to acceleration

4. Explain what you understand about how objects are affected by their mass.

Concepts

- Objects with more mass require a greater unbalanced force to have the same acceleration as objects with less mass
- Travelling at the same speed, objects with more mass have more momentum and kinetic energy

Misconceptions

- Objects with more mass do not accelerate faster under gravity
- Accelerating a mass does not create force
- Mass does not cause objects to decelerate

Relationships

- Kinetic energy increases proportional to mass
- Momentum increases proportional to mass
- Force increases proportional to mass

5. Explain what you understand about how objects change velocity.

Concepts

- A change in velocity is the result of net acceleration on an object, which is created from an unbalanced force on the object.

Misconceptions

- Velocity does not require a constant force to be maintained

Relationships

- Change in velocity is proportional to acceleration