The Periodic Table of Elements via an XNA-Powered Serious Game

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Abstract. This publication concentrates on the production of a serious game on Microsoft's XNA Studio, which illustrates both the potential of a cost-efficient, off-the-shelf development platform itself for programmers of a medium skillset (such as for example educators) but also the possibilities of designing to completion a fully functional game that can be used as part of secondary education chemistry curriculums in order to teach the important topic of the periodic table of elements. Additionally, a 15-subject pilot evaluation study of the game (titled Elemental) is included, which displays initial evidence that there can be educational benefits for the experiment participants exposed to the work.

Keywords: serious games, physics, XNA, education, games development, software engineering.

1 Introduction

It is widely accepted that the term "serious game" was originally used in the late 1970s, referring to learning from predominantly board and card-based games. This theme carried on with advancing technology, forming today's concept that categorises serious games as interactive media for some sort of purposeful use other than amusement. This article will focus on serious game development and use for (secondary) school education. Currently, through a variety of educational systems across different countries, pupils/students learn skills in ranging subjects across a number of years. It is therefore evident that there can occasionally be limited avenues in terms of offering information in new ways as a teacher/educator. Serious games could be the key to diversifying teaching mediums.

The problem facing developers interested in delivering content for this area is two-fold, firstly how easy are serious games to design and develop; and secondly, do they educate enough to supplement or replace certain materials? Video games are today, with the advent of free community tools, much simpler to develop and if teachers, lecturers and other educating bodies are willing to explore other new mediums, video games could indeed be an excellent candidate. This publication will be looking at how to form a serious game design for secondary educational chemistry training, its

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subsequent detailed development and, finally, pilot evaluation of its usefulness as a learning tool using empirical data.

While the development of a full commercial game using a traditional production pipeline can be difficult, with the right tools, such as the Microsoft XNA Studio, as described in this article, even with minimal basic programming experience someone could rapidly develop a game in a few weeks. The educational game outlined here, called Elemental and deployed on the XBox 360 platform, is a chemistry game based around the periodic table of elements and atomic composition, a key part of the GCSE curriculum (an important UK secondary education academic qualification). The prototype of the Elemental game is evaluated using 15 participants during a 2-stage trial study. Using questions based around recent GCSE chemistry exam papers, a set of quizzes were developed to test participants, both before and post playing the game. The results suggest differences in evidence of the players widening their knowledge on the subject after the use of Elemental.

It should finally be noted that this publication is an extended version of the work presented by the authors at the IEEE VS Games 2011 (Third International Conference in Games and Virtual Worlds for Serious Applications) [1].

2 Background

The last few years have seen the emergence of the serious games movement; with games used in a number of new areas not associated purely with entertainment. Under the guise of terms such as edutainment, games have been used for purposes other than entertainment for a long time. It appears that only recently has this produced significant results; the modern serious games movement is now worth an estimated $200-$400 million in the US alone. Additionally, it is beginning to become characterised by the level of complexity and sophistication behind it, as well as the number of different directions explored. This fact, combined with advancing technology in both software and hardware and prior inhibitions about games in general lifted (for example, associations with violent and anti-social behaviour), has turned into interest from the educational sector in conducting further research in this field, including case studies. It remains true that the area of education, one of the first explored by serious games, even before this term was introduced, is the one that still holds the greatest potential.

There are a number of surveys in the area such as the ones by Vogel et al [2] and Dempsey et al [3] highlighting the many benefits in numerous application and subject areas that educational gaming can cultivate in an audience. Secondary education is an area of particular interest for the introduction of serious games. Current examples of pursuit of this avenue in the literature include the use of the medium in a variety of subject areas.

In science, Lopez-Morteo and Lopez [4] explored an approach for motivating students towards mathematics. This involved educational interactive software components presented through recreational mathematics. This work also included evaluation of the approach with three math courses for high-school students. Results were positive, indicating the methodology’s usefulness, particularly towards motivating students. Ke and Grabowski [5] also conducted research in the same area, that of mathematics, this time using 125 pupils. This involved the pre-test and post-test approach and also examination in a number of covariates and their correlation with the results. The results are once again very positive for game-playing but also for collaborative play which was also examined and was found to further enhance learning.

Another notable effort in teaching mathematics via game-based learning is Zombie Division [6],[7] (by Baker et al and Habgood respectively), a game which bears similarities to a typical adventure game and aims to teach elementary school pupils the subject of division. Employing basic combat mechanics and placing the player in the role of an ancient Greece hero, the pupil can progress by selecting the correct divisor number when confronted with a zombie enemy.

There is more research strongly indicating the help of computer games in the learning of maths curriculum such as the work by Sedighian and Sedighian [8], Rosas et al [9] and finally, more recently, Kebritchi et al [10]. It is interesting to see this subject area explored more than others by serious games development and manipulation. This can be partly attributed to the quantifiable manner mathematics learning can be observed and tested for.

Other subject areas have also been explored. In history, Egenfeldt-Nielsen [11] conducted a study as part of his PhD using 72 high-school students and also teachers in Denmark. This was achieved using a strategy game to draw conclusions about the potential benefits of video game playing in obtaining knowledge. Also in history, Squire used the very popular strategy game Civilization 3 to investigate learning via the medium [12]. In geography, and with particular attention to urban planning using SimCity 2000, Adams [13] also showcased positive results for the potential of game-based learning in this area.

Other research in geography-aimed game-based learning includes the work of Tüzün et al [14], who have employed a 3D MUVE called Quest Atlantis [15]. Quest Atlantis supports educational activities via different tasks in the guise of quests. This is set in the mythical land of Atlantis and offers a rich 3D virtual world experience but also the possibility of extensive collaborative teaching and learning. Because of the open nature of Quest Atlantis, work in distinct other curriculum areas, such as the teaching of writing has emerged, again supported by the use of this platform, such as the efforts of Barab et al [16] and Warren et al [17]. General science game-based learning has also been attempted on Quest Atlantis, and also in this case evaluated, as described by Lim et al [18].

Evidence of MUVE game-based learning has also been observed in biology teaching. Using the platform of the River City [19], a MUVE designed for participation-oriented immersive experiences, Dede et al [20] conducted an experiment which assessed the motivational effects of such an approach in teaching biology to pupils. Results were very encouraging, with biology knowledge and inquiry content showing signs of increase. Similarly, Nelson [21] performed a study using the same platform to establish the degree of guidance needed in teaching with MUVE as a tool, with insignificant results this time, despite demonstrating knowledge gain in the population sample.

In the area of chemistry and physics there are not many examples to draw knowledge from as it has not been as explored as much as other subject areas. The most important example is the work of Squire et al [22]. This focused on using a simulation game, called “Supercharged!”, tackling the subject of electromagnetism, an important physics concept.

While educational gaming has a lot to offer there are concerns too. Randel et al [23] bring up the issue of bias from the educator. Also, there is the sometimes dubious social aspect of game-based learning as discussed by Stoll [24] (although it has to be mentioned that many games since the publication of this research have included increasingly complex collaborative routes to further strengthen their delivery in this area) and finally, the distraction and the long-term retaining of knowledge acquired by game-based learning, as argued by Clark [25].

There is also the tendency in research to rely on commercial products or titles for the development of the serious game that is to be tested or trialled in an educational setting. While that can offer many advantages, it can also considerably hinder the exploration of enabling the teacher or educator to single-handedly produce a flexible tool that could aid him/her in this area.

The rest of this article pursues this avenue, demonstrating the process of an implementation such as that via the discussion of a number of key design/technical decisions, problems, issues and eventual trial of a custom-made educational game called Elemental. There is a strong focus on the technical development of the prototype so that an interested party could be presented with a comprehensive build guide on the creation of an educational game.

Elemental focuses on the periodic table of elements, the well-known tabular display of the 117 chemical elements used to classify different forms of chemical behaviour. The periodic table of elements is a particularly important part of the chemistry curriculum for the UK General Certificate of Secondary Education (or GCSE in short) academic qualification awarded in this corresponding subject. Undertaking GCSEs it should be noted is a huge and key part of secondary education for students of ages ranging from 14 to 16, i.e. in secondary education, across the span of the United Kingdom (i.e. in England, Wales and also Northern Ireland).

3 Requirements and Analysis

This section of the article focuses on the design requirements of the Elemental game. Using the waterfall method of software development, the requirements are the first parts of the game to be defined. This will then provide the project a direction, allowing design to cater to these requirements. There are multiple methodologies developers can use for this, spanning from rapid design and implementation using extreme programming (XP), to the more categorical Waterfall method methodology. For the Elemental implementation, a custom version of the Waterfall method will be used. The reason for this is that it features all of the most important stages of software development and can be customised easily. It can also be made to suit developing a small game by a single developer (i.e. a teacher/educator, as is intended in this case) who wants to deploy it quickly in a classroom as a project that will be used as complimentary to the usual teaching delivery. Originally, the method developed by Royce was for large-scale software development [26]. It follows 7 standard steps, which progress from requirements to implementation.

The requirements mainly come from the learning objectives and the game design process. Learning objectives consist of the knowledge the students should take away after playing the game. Testing will use these requirements to deduce when to finish with the implementation. The first set of requirements is based around defining the artefact as a game:

- The artefact will be made using game development tools
- The artefact will mentally challenge the player
- The artefact will have a defined game play
- Game play will contain a set of common sequences used throughout the game in a repetitive manner; however the content must change throughout

Firstly, to make a game there are many specialised tools already in place for developers. Large-scale projects will use many middleware tools to develop games, most of which are too costly or difficult to use for a single person with no or little budget. For a teacher and/or educator the decision on the platform needs to be heading in the opposite direction. The Elemental project has selected the Microsoft XNA Studio, along with Visual Studio 2008. The toolkit, essentially a wrap-around of the more extensive Microsoft DirectX API, is a very popular choice for many hobbyists exploring the graphics/game programming and already has a middleware set of libraries making game development easier. XNA (which according to Microsoft stands for XNA's Not Acronymed) was first announced in 2004 and, after its 2006 release, it quickly managed to become an established brand of collective assets for game developers, for a number of platforms. The major appeal of it is the fact that it is now a free download, enabling hobbyists, students and of course educators to experiment with it in order to create content of their own choice and for a variety of platforms. Prior to XNA, for the creation of similar content, more complex APIs such as OpenGL and DirectX had to be used. Due to the complexity of these API libraries and the basic access to hardware they provided, including key areas such as managing memory, creating game content was almost prohibitive for a novice. XNA, in an effort to deviate from generic game engine frameworks that the aforementioned APIs favoured, included a custom-made, existing content pipeline for the inclusion of 3D models, textures and audio (amongst others). Also, timing and render loops were created in a Game class with Update and Draw Methods for further simplification. Finally, a framework similar to a game engine, called Application Model provided hardware abstraction to a GPU.

For educators with some limited programming experience, the XNA platform is a great choice, as it provides an entirely clean canvas for game content creation, with the added benefit of being simple enough to master in a short period of time. Even today, there are few platforms that can offer the creative freedom, undemanding technical requirements and cost-effective attributes of XNA. It could be argued that more comprehensive, somewhat more recent, GUI-based and user-friendly middleware tools/engines such as Unity, OGRE or Torque X have emerged that could potentially provide equal levels of support, particularly for a novice developer. However, at the time of the development of Elemental Unity required a license fee, Torque X still does to this day (and is essentially a graphical-based "wrap-around" of XNA to begin with), while OGRE demands a far steeper learning curve in terms of programming skills because of the vast range of features it can offer (particularly for 3D games development, which was not needed on this occasion).

The second requirement is more related to a game challenge. The game has to challenge the user mentally, very much like sports games challenge the players physically. The challenge could take many forms, such as getting the user to remember something, identify something or react to something. Using challenges like this the player should learn something to aid them in better understanding the game and becoming “better” at it. As the game will be educational/geared towards learning, it is expected that it will be something ‘educational’ that is added into those challenges. The next two requirements refer to giving the game a structure. By developing a game with a specific set of rules to which the basic gameplay is defined, one can then be put in the changing content within that. If the players were to put the game down and come back in a week, it would still play in the same way and hopefully they would remember that style.

The next set of requirements will define the content:

- Content should be understandable without any prior experience in chemistry or the periodic table of elements
- Content will include an introduction to explain the game, the basic of atomic composition and controls
- Content should be displayed in a visual format
- Content will include every element (all 117) from the periodic table of elements
- Content will include the name, chemical symbol and composition of each element in the periodic table
- Content will include radiation, showing how radiation can be called
- The game will be based around a high score system
- The game will include a timer
- Content will display atomic composition of elements

The final set of requirements is defining the game system requirements:

- The game will run on a PC with a basic graphics card and for the Microsoft XBox 360
- It will be controllable by either a Microsoft XBox controller or a keyboard/mouse combination

The game should be as accessible as possible. This is why the game is being developed for both PC and the XBox 360. These can also be developed in line with each other as XNA Studio allows for this. The final requirement is that both versions will work with an XBox 360 controller. The controller can be used on any Windows XP/Vista/Windows 7 PC and will allow for streamlining of controls too. Coming up with a specification for software such as a game does differ to developing a piece of software for other functions or purposes. The reason for this is that games are increasingly seen more as an art form and do not always need to be developed to provide a solution to something. In this case, the solution is to provide knowledge of the periodic table of elements and atomic composition to a dedicated audience using specific content.

4 Design

This section of the article focuses on the design of the game covering areas such as class and code design. The project will be focusing on developing an element generating system over a compound creation system. The reason for this is that creating elements as the main game will meet the requirements of teaching the player about particle composition better. The game is based around building each element of the periodic table. The main mechanic will be the "catch and release" system. This system will use the same buttons to catch and release the different particles. They will be released in a 360 degree radius outside the screen and follow a path through the very centre. To catch them, the user has to use the same button, however when catching it is key to note which particle it is as to where it can be caught. For it to be as realistic as possible, the neutrons and protons are caught inside the nucleus which is depicted by the small red circle in the centre of the screen. The electrons can be caught on the shells on the outside.

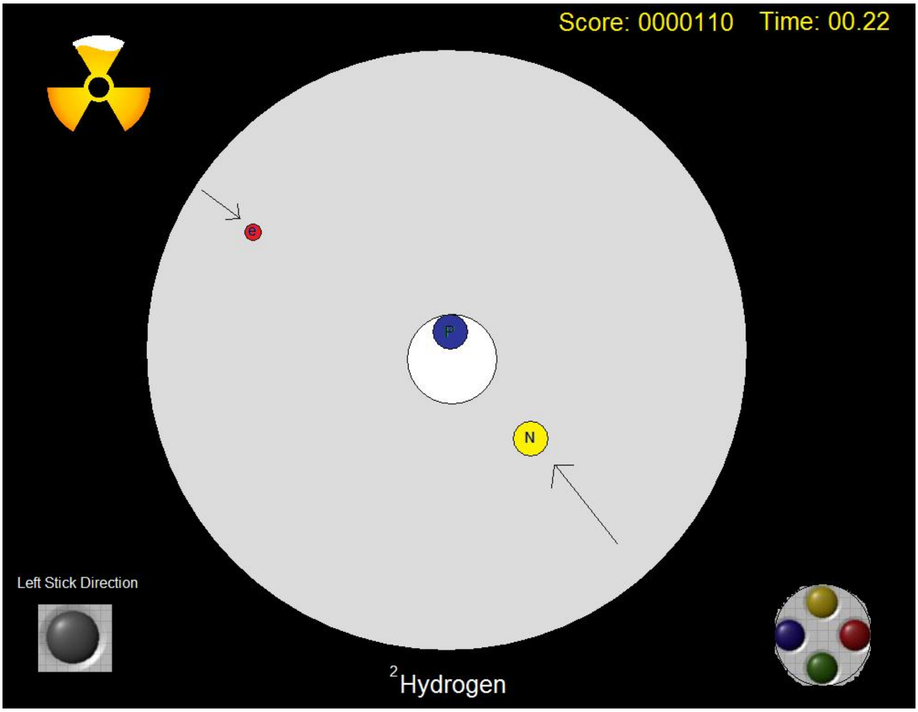

Fig. 1. Initial concept screenshot of the Elemental game

The next mechanic is the "particle gun" mechanism. The "gun" can move 360 degrees around the screen. Being able to move in both ways was also key; this was also initially added as the "charge of particles" mechanic would not work without it. The reason for this is because of how the particles work. Simulating realistic working particles of the same charge will repel, neutrons and particles of different types will cancel each other out, meaning they will disappear and will need to be re-released and caught. If the player is trying to catch a particle but misses its "catching area", it will move out of the screen in the same direction and increase radiation. Should radiation reach its limit of 100%, then the game will be 'over'. As radiation gets to a higher limit, the screen will also start to invert the colours, showing that the viewing piece is getting damaged. A scoring mechanic will increase points depending on which particle was caught. As electrons are harder, they will be worth more points. Another idea here was to also include a bonus score, should the player get a certain combination of particles.

The game will play in levels. Each level will be a different element from the periodic table. There are a few ways this could work. The first and simplest is making each element in order of atomic mass (which was the one followed in Elemental). Starting with the basic element Hydrogen and working up the periodic table was how it was finally implemented in the prototype game. Using a timer on each level will add a sense of urgency and another point of failure for the player should the time run out. Each level will add a set amount of time giving the play extra time as there will be more particles.

The ideas above need to be converted into code. As C# (the programming language XNA uses) is an object-oriented language the game will be developed with this in mind. The easiest place to start is by deciding on some classes on which to begin formulating the game. Microsoft XNA Studio was developed to be a toolset for game developers (unlike for example DirectX, which is a more encompassing graphics library). For this reason, when one sets up the first project it will setup the first class and a set of functions. The first class in this case will be the "Game" class. This class will contain the working parts of the game including the engine that runs it. The next class is the "Particle" class. This class will be used to hold particle data for manipulation by the game engine. The "Level" class will contain the settings for each level. The last class is another developed by the toolkit and is called "Program". This class calls the "Game" class and contains the "main" entry method of the game.

The games constructor class will contain code to set up outside variables. This is to make sure they contain a value and are not null. The reason for this is when using global values they are not always defined, until certain requirements are met but will be needed by many functions. By default the XNA toolkit includes a variable to setup the Graphics Device Manager. This automatically detects the setting of the machine and implements the default resolution and display buffers. Other variables defined here will be ones such as the Window name and the root directory of the project contents.

The Load Content method will be used to define the content in the game. This includes loading in the element definitions, the sprite manager, textures such as buttons and also generating the lists holding the co-ordinates for the Nucleus, the electron shells and the particle gun circle. The Update function is where the logic of the program is run. The logic will define which level the player is on, check which particles have been caught, decide whether the level is complete and the process of collision detection and radiation. The Draw function will perform the drawing of content to the graphics device, which will be the screen. This includes drawing the buttons, particles, radiation, score and timer. As the function will be too large incorporating all this, it has been split and calls other functions to draw specific parts.

These are the main functions of the Game class. However, other methods are called where necessary to do specific tasks, these include:

- Draw Buttons, this function decides which buttons need to be drawn to the screen. The buttons will change to show a depressed button like that on the controller
- Get Mouse State, which checks the mouse wheel state. For the PC version, the mouse wheel will be used to rotate the "particle gun" by incrementing or decrementing the co-ordinates
- Get Key State, this will determine which state the keys are in on the keyboard or controller. Depending on whether it is ready to catch or release then it will also call the Create Particle function
- Create Particle, this function determines which type of particle should be created and adds it into the game
- Draw Particle, called by the Draw function it goes through each particle current in the game and draws them
- Draw Score, this uses the setup font and draws the current score to the player's view
- Draw Radiation, similar to Draw Score but with the radiation limit
- Draw Timer, similar to Draw Score but with a countdown timer
- Draw Limits, this function will draw the circle depicting the nucleus boundary and the outer shells
- Check Collisions, this function will check collisions between particles at every update

The main Particle class functions include:

- Particle constructor, called when a new particle is created, all data is input at this point
- Change State, this function changes the state of the particle to depict whether it is active or not
- Update End Position, this function will change the end position for when a collision happens and both particles are the same, it reverses the position so that it looks like it has been repelled

The only function Level has is the constructor. This is used to setup the level initially when called in the Load Content method of the Game class. No change ever occurs to the levels so no other functions are needed.

Some of the functions are specialised to the game. The first piece of code that will be challenging to design is the code for getting the circle points generated. The nucleus, particle gun, all outer shells and also the particles will be using these. The particle gun co-ordinates have to be setup slightly different than the other co-ordinates, because not only will each particle need the starting point, but it will also need to get the opposite point to move towards. To get around this, one could generate a half circle instead of a full circle and put it in an array. One can then generate another set of points to mimic the opposite side and store them in another array. When lining up the array, each co-ordinate will be mapped to its opposite co-ordinate in the other array.

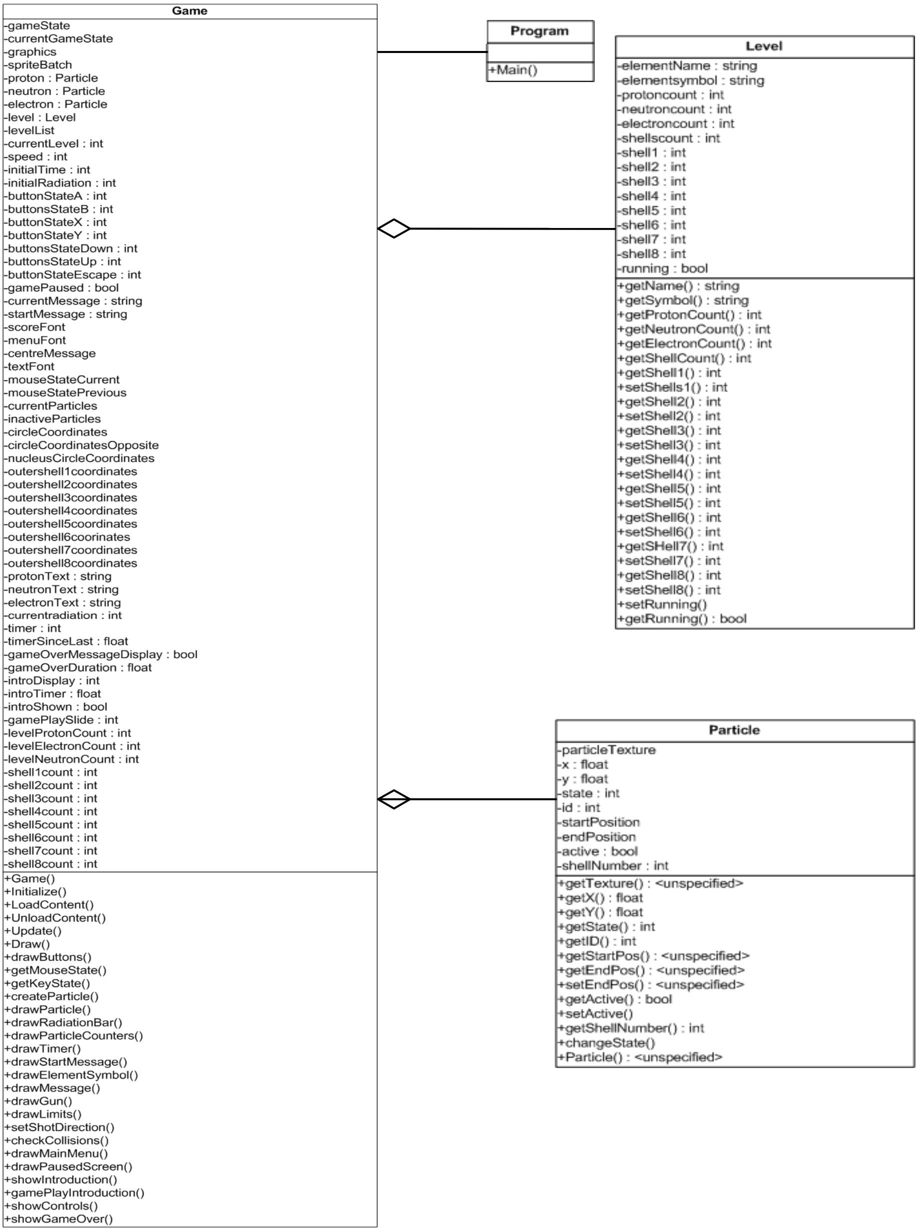

Fig. 2. Class diagram for the final version of the Elemental game

The code for generating the circle point will work as showcased in Figure 3. To develop the 2 half circles you can stop the loop after getting to PI and starting the next loop with the angle equalling PI. Processing the particles currently active in the game could cause problems as there will be multiple lists holding different types of particles.

One list will hold particles currently in motion and ready to be caught by the player. Another will be used as storage, while the particles are processed after moving to it.

1. START
2. Define X as resolution width / 2
3. Define Y as resolution height / 2
4. Define radius of co-ordinates
5. Define angle
6. WHILE angle is less than 2 * PI(Pie)
7. Define temporary x as Cosine of the angle * radius * X
8. Define temporary y as Sine of the angle * radius * Y
9. Define temporary vector with the co-ordinates X, Y
10. Add the temporary vector to the correct list
11. Increment the angle by a certain amount

Fig. 3. Pseudo-code for the generation of the circle point

The final is for particles which are now out of use after being correctly caught. Neutrons and protons are caught in the same way and share the code for being caught. Electrons however can be caught in different shells. This means having to check the position of the electron being processed against all known shell points. For each particle in the currently active list the program will need to determine how far they have travelled each update. To do this, both x and y co-ordinates of the particle are checked against the position it is moving to. The statements then adjust the co-ordinates factoring in speed. The final Elemental prototype game (and its help screen) are shown in Figures 4, 5 and 6.

Fig. 4. Control help screen for the Elemental game

Fig. 5. Final game played during the experiment

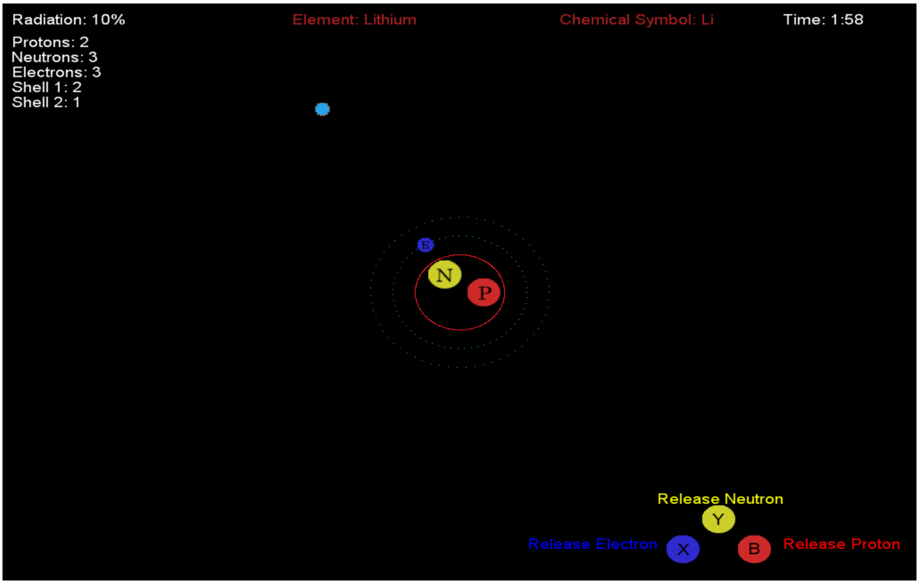

Fig. 6. Final game screenshot

5 Evaluation Study

The pilot evaluation took place in 3 stages and focused on whether the game could fit into a teaching environment and be classed as a serious game. More importantly, the facilitation of learning within the context area (periodic table of elements) needed to be examined. The first stage was to develop a suitable questionnaire. The second was the process of getting individuals to evaluate the game. The third involved the analysis of the results. Wilson describes the first part of designing a questionnaire is to have clear objectives [27].

These objectives are going to be based in 3 areas and will cover these 4 hypotheses:

- Does the game show indication of teaching the players in the field of chemistry?
- Does the game challenge players in a coherent style?
- Can the game be played by players who lack experience in the field of video games?
- Can the game be played by players who lack experience in the field of chemistry?

The first hypothesis looks into whether the game can teach a player. This is part of the criteria to make the game serious and forms the most important hypothesis of the project, essentially asking the question “can the game teach?” The second hypothesis is used to define the software as a video game. Going back to the introduction, it was stated that video games need to challenge players mentally, while offering a stylised way of playing. Without having a questionnaire, we can already interpret the game possesses this last attribute. It clearly plays in one style but at the same time does have a range of deferent content to keep players engaged.

The last two hypotheses are looking at whether the game can be played by someone with little or no knowledge of video games or chemistry. This was originally a single question but splitting this up meant that we can see which factor may make more of an impact in learning from a serious game. The next concept from Wilson is to get people to answer questions carefully and completely [27]. To do this, the questions will mainly use a 5-point Likert scale. This will give enough scope for the user to put a reasonable answer, while restricting the ambiguous nature of open answers. However, one of the flaws of using this approach is that it does restrict the participants from expressing themselves. For this reason, a comments box will be added to the end of the questionnaire for anything else the participants wanted to express but could not in their Likert-type answer. The questionnaire data collection took place in 4 stages and followed this format:

Initially participants were given a short set of demographics questions. This included age, sex and occupation. The next 4 questions focused on understanding the experience level of the participant. This was expressed as experience in video games, educational games, chemistry and the periodic table of elements. These 4 questions (and their corresponding answers) could be used to group participants into skill levels when analysing the results.

The quiz part was taken immediately after the demographic questions. There were two quizzes given to the participants which both followed a similar format. The questions themselves mainly came from past GCSE exam papers and were multiple choice (three possible answers). Sample questions included the following; “What is the chemical symbol for Lithium?”, “How many electrons does Nitrogen have?”, “Which element has the chemical symbol: B?”, “How many protons does Neon have?" etc. The first quiz was taken and they were then shown the Elemental game, which was to be played for 15 minutes in total. Once the 15 minutes had elapsed, participants would then take the second quiz. For both quizzes, questions were to be answerable from playing the game during a 15-minute time period.

After the post-gameplay quiz participants then had the last section of the questionnaire to fill in. This section related to the game, the content, knowledge gained and how the participants now perceived serious games. A comments box at the end was for anything extra which was qualitatively-natured information that may have been of use during the analysis of the evaluation study results.

The pilot evaluations took place during a 2-week period using an XBox 360. 15 participants took part with each session lasting about 30 minutes (10 male and 5 female). The pilot study was conducted mainly in Bournemouth University, UK, therefore the majority of participants were students and also staff from the University itself. Demographics data for the experiment are shown in Figure 7.

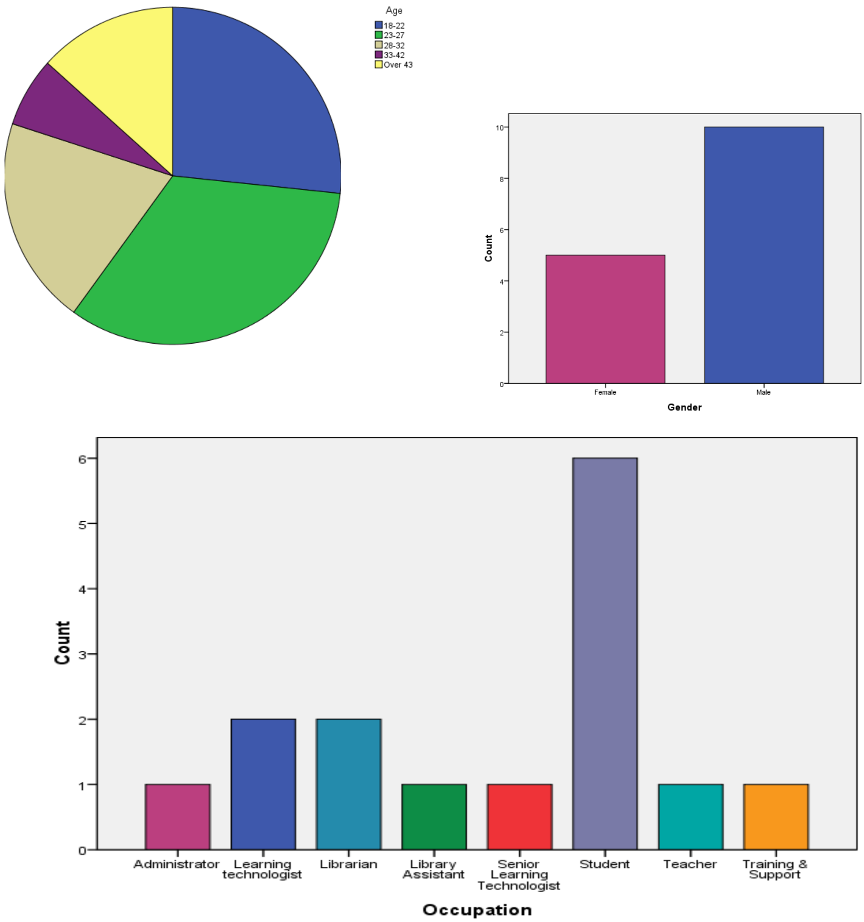

Fig. 7. Demographics data for the Elemental experiment

Experience is something that the study cannot change. Each individual will have different experience levels in different areas, so to cater for this it was decided to ask them to record it in a self-reported capacity. All collected experience results from the study are shown in Figure 8. Starting with experience in playing computer or video games, the overall data showed experience in this area to be moderate to high. It is clear that those who rate themselves as higher are in the younger categories of age. As serious games are (to this date) fairly specialised, the result from experience in educational games is expected, with the majority scoring themselves as low in experience. A similar response was given with the experience in chemistry. This was possibly due to the fact that no one who participated was involved in any work related to chemistry. The last question before the pre-game quiz was regarding the experience of the periodic table. Figure 8 shows that the majority of participants rated themselves between no experience and average experience. Surprisingly, although most participants expressed that they had low prior chemistry experience, the highest count for knowledge of the periodic table was higher than the chemistry knowledge. One reason for this may be that due to there being a high number of student participants, they may not have remembered much about chemistry in general but remember the periodic table. Another reason may be that because the periodic table of elements is only a small part of chemistry (and its curriculum), the participants generally felt they knew more in this specific area.

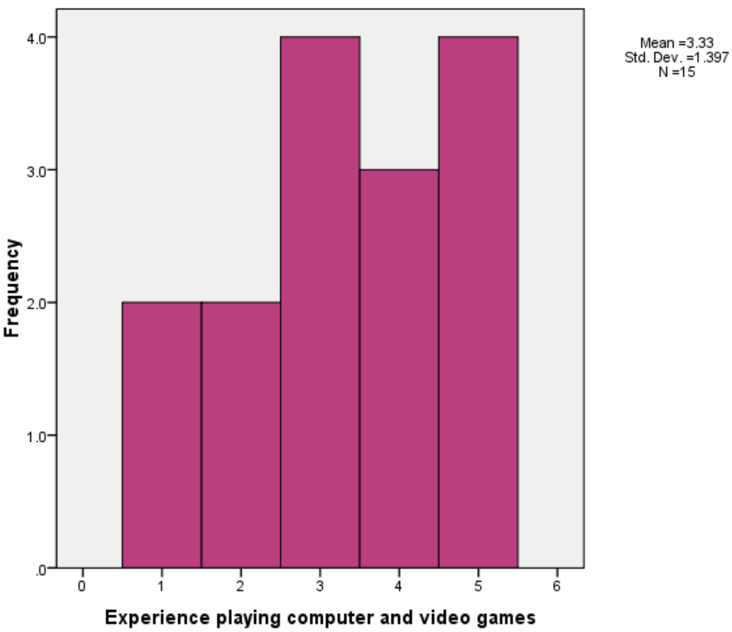

Fig. 8. Prior experience data collected

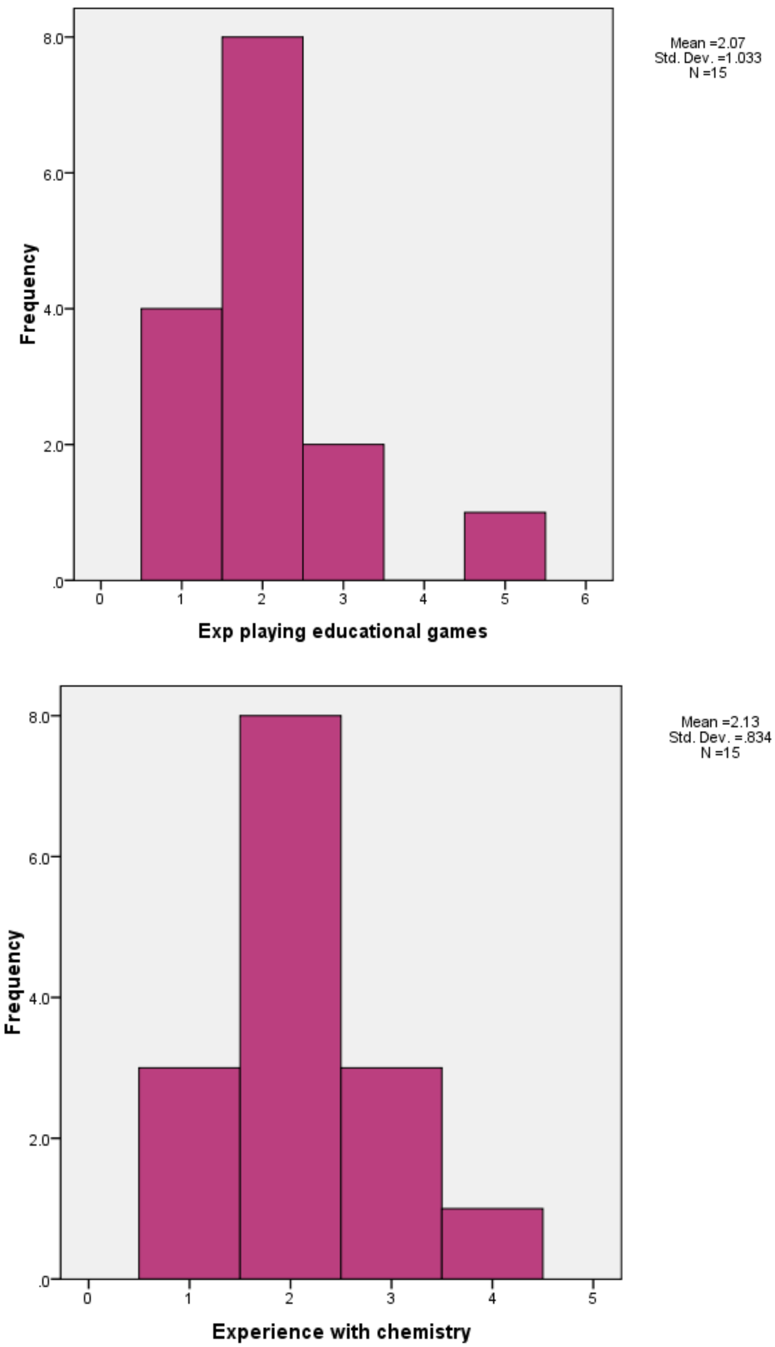

Fig 8. (*Continued*)

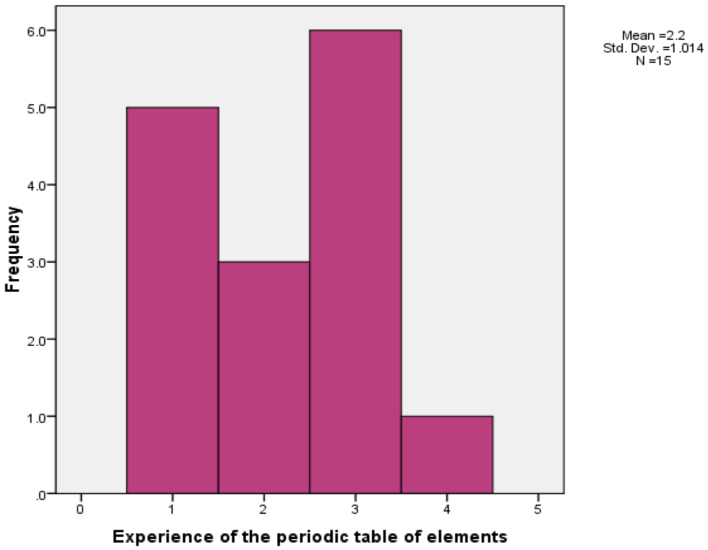

Fig 8. (*Continued*)

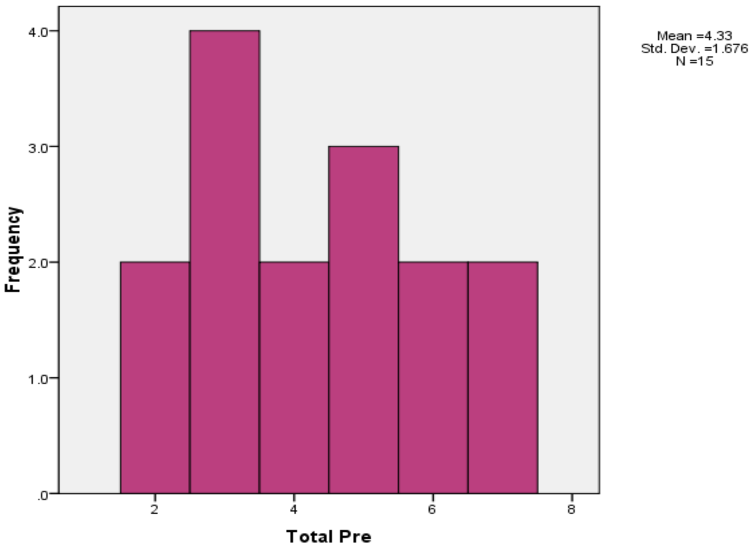

Fig. 9. Pre/post gameplay quiz results

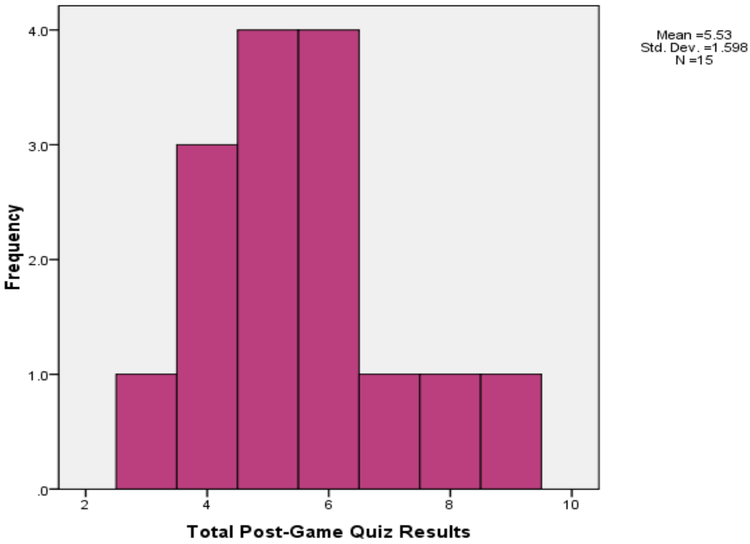

Fig. 9. (*Continued*)

Figure 9 shows the results of the pre-game quiz. The Figure shows that 8 out of 15 participants answered under half of the quiz correct. Figure 9 also shows the results of the quiz after playing the game. Initially, the results display that the highest result was higher than anything in the pre-game quiz. Also, 8 people (over half of the participants) scored between 5 and 6 (out of the total 9 questions) right. The pre-game quiz showed that over half of the participants scored a total under 5/9. Calculating the mean/average, the results show that each participant was roughly scoring 5.53 questions correct after playing the game.

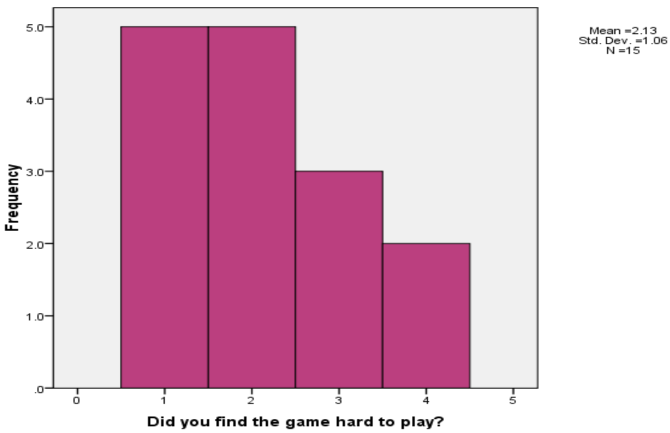

Fig. 10. Perceived difficulty-in-play results

The pre-game quiz had a mean/average result of 4.33 questions per participant. This “jump” in grading represents almost a whole extra question per participant. The results here appear to indicate that, on average at least, the participants did take in some knowledge from the game.

The questions presented after the game were used to show more about the game and how it played. Figure 10 shows the results from how difficult participants found the game. The scale was defined as following; 1 as easy to play and 5 as the hardest. The majority of players found the game to be in the first 2 categories. This means that overall participants felt the game was easy to play. Considering this is a serious game for secondary education, that is very positive, as games with hard to learn controls and mechanisms may cause the players to lose interest.

Similarly, Figure 11 shows that the majority of the participants found the controller easy to use. The controller was part of the game and would have also had a learning curve to those with less experience with it. General observations during the evaluations showed that participants differed greatly in the way they would use the controller. Some would hold it in a way able to access all buttons; others would use it on a hard surface without picking it up.

Figure 12 shows the count of people who found the introduction helpful in understanding how to play the game. It is interesting to see that the introduction was not regarded as understandable by all participants.

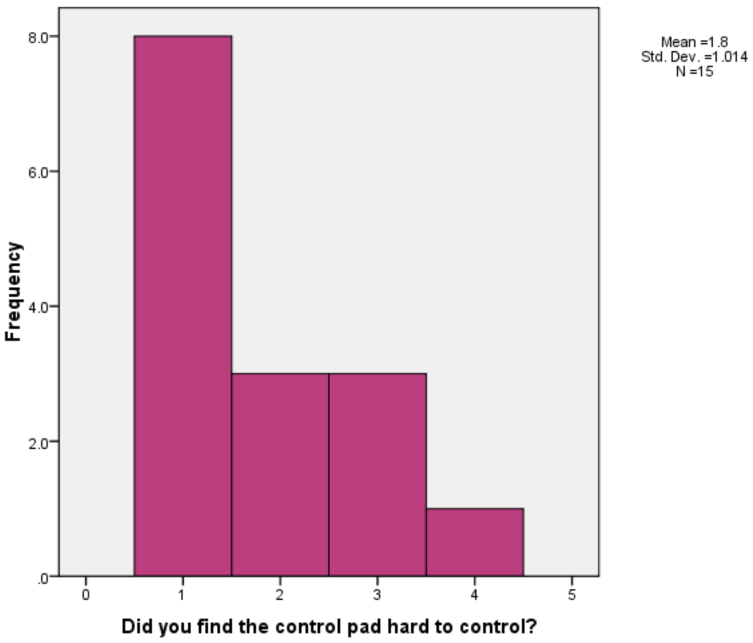

Fig. 11. Perceived difficulty in control

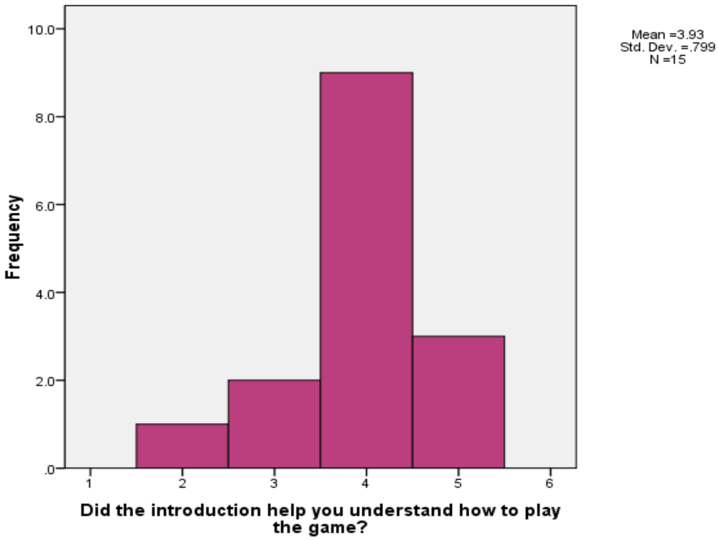

Fig. 12. Perceived difficulty in introduction-helpfulness results

The quizzes were designed using past GCSE papers. The game was also designed on a subject which had specific GCSE questions asked about it each year. The purpose of the quiz was to determine whether the game had any teaching potential. To relate the quizzes to the gameplay, the questions needed to be something the game could provide the answer for. The purpose of this question was to determine whether the participants did think and/or perceive they could get the answer from the game after playing. Figure 13 shows the relation to be perceived as high between all the participants. This means that a high majority of players felt they could answer both quizzes with enough time on the game.

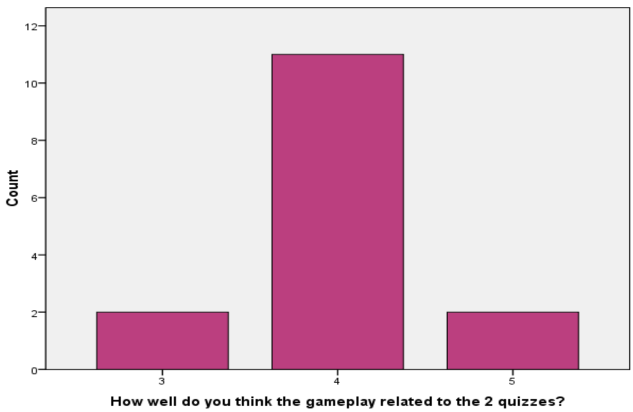

Fig. 13. Perceived game relation to periodic table of elements results

Figure 14 shows the results of whether participants thought they gained additional knowledge of the periodic table of elements. Over half of the participants rated this as 4 and 5. This means that participants generally thought they gained some knowledge about the periodic table of elements.

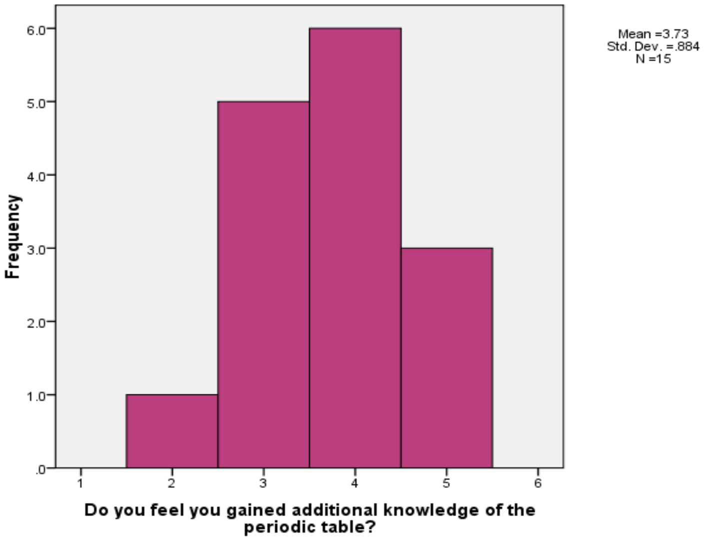

Fig. 14. Perceived knowledge generation results

Another important question asked was whether participants felt engaged while playing the game and found it to be fun. Figure 15 shows there was no rating in the bottom 2 categories showing that participants thought the game was an activity they found fun to play with and kept them engaged while playing. This question was used to see if the serious game fitted to the "video games" objectives.

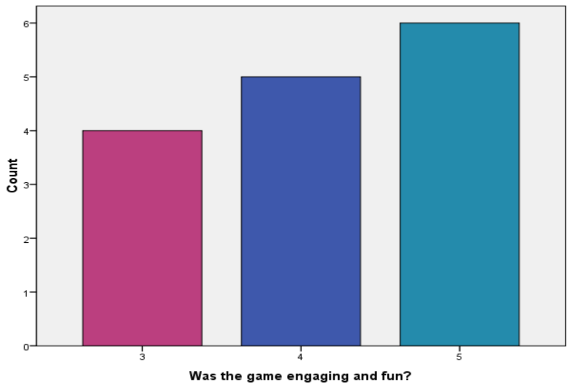

Fig. 15. Perceived fun and engagement results

The final question asked in the evaluation study was directed towards grasping the perception of the participants on serious games. The question specifically asked about how they would perceive a game in helping independent learning. The reason for this was to get a general consensus on how video games are perceived at present. Figure 16 shows the results, which are suggesting that almost every participant felt that games could be very successful in helping someone to independently learn.

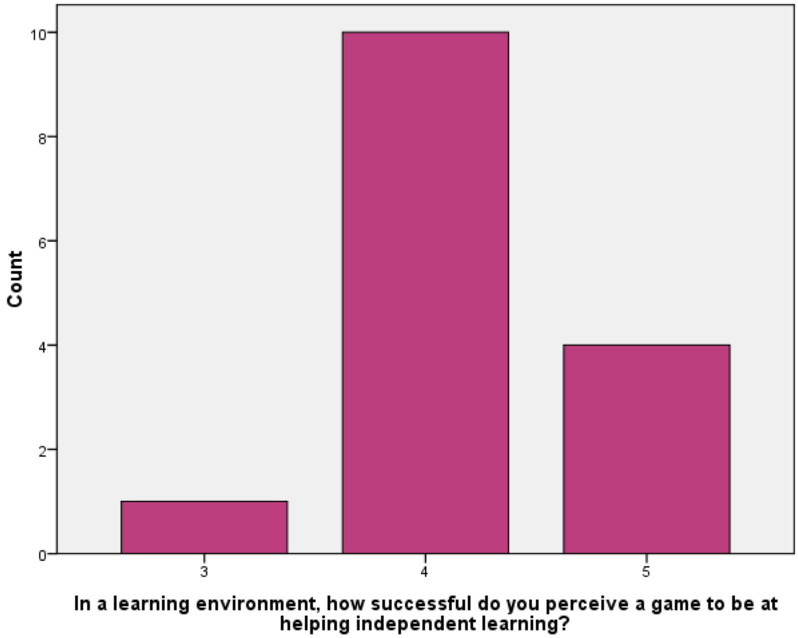

Fig. 16. Perceived learning results

We can also focus on a deeper analysis of the quiz results. This will be achieved by analysing the experience levels against the results in order to understand which ones had the biggest and smallest impacts. Figure 17 shows the pre-game quiz results with video game experience. The Figure shows a varying scale of results, comparing the participant's final result against their gaming experience.

It does demonstrate an indication that some of the less experienced gamers did worse in the tests and some of the more experienced gamers managed to do better in the post-game quiz. This could show that prior experience of gaming has made the game easier for participants, leading them to learn more about chemistry from the Elemental game.

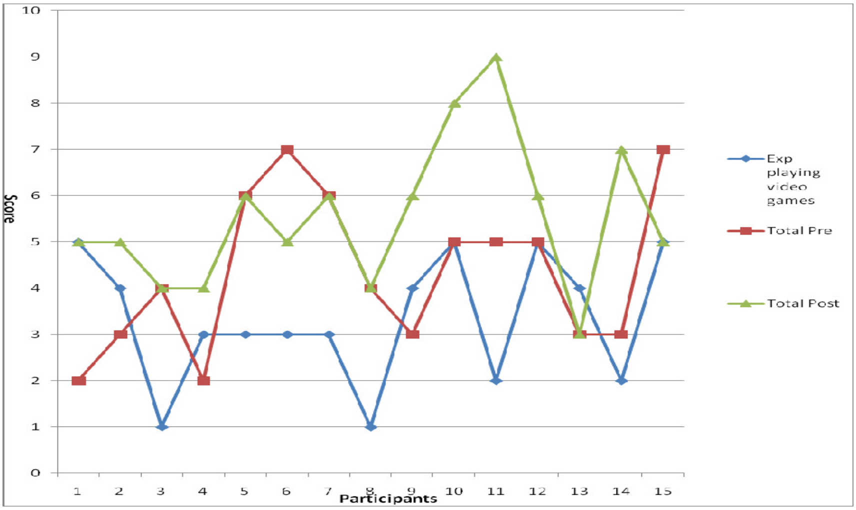

Fig. 17. Correlations between game experiences and pre/post gameplay results in the quiz

The education game experience correlation Figure 18 displays similar results, which suggest that the participants associated experience of educational games as a lesser version of experience with games. Looking at this a little bit more closely, the majority of participants had a difference of -1 to -2 between experience of games and experience of educational games.

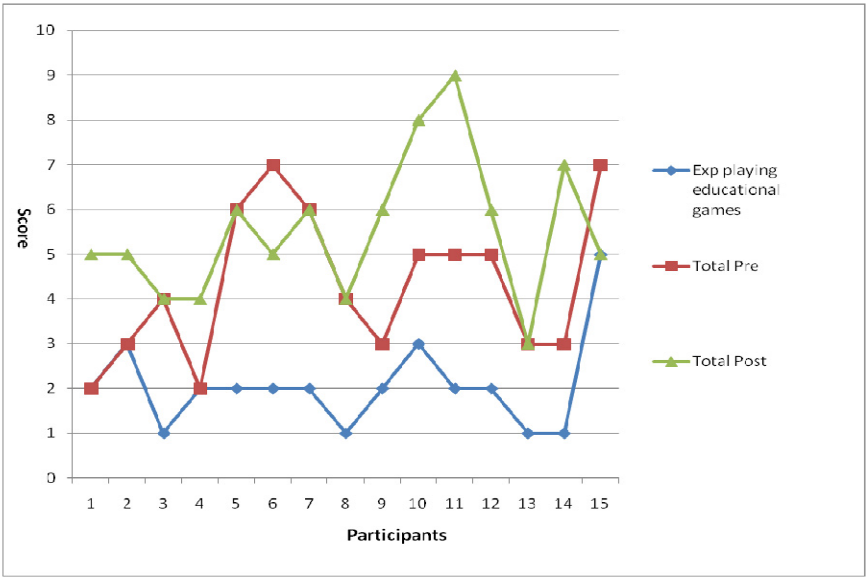

Fig. 18. Correlations between serious games experiences and pre/post gameplay results in the quiz

Figure 19 shows the correlation between experience in chemistry and the results of both quizzes. Although the effect appears marginal, those with more knowledge did generally better in both quizzes. The issue with this question is that chemistry is a broad subject and both the quizzes and the game only focus on a small portion/part of it. So while participants may have a good knowledge of chemistry, they may have had it in a different area of the subject.

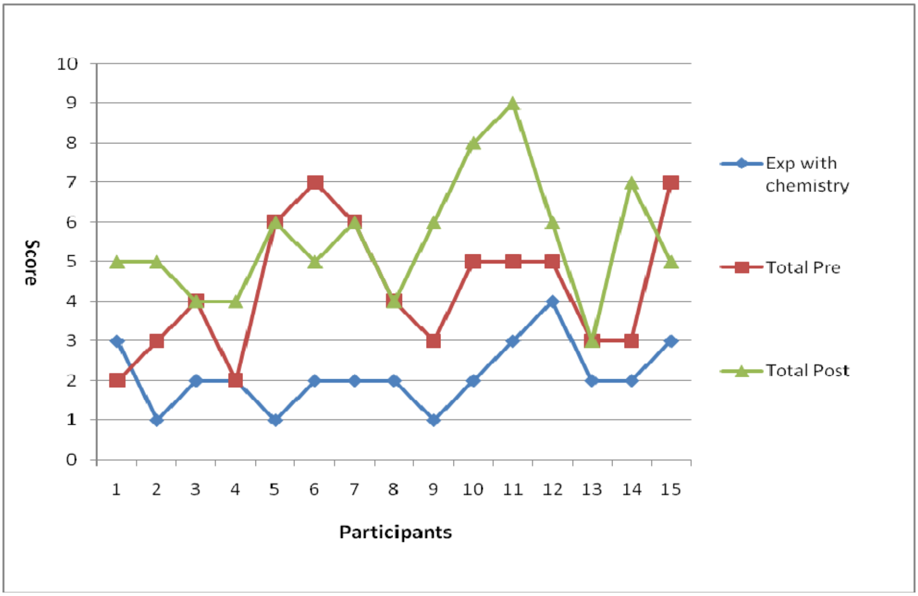

Fig. 19. Correlations between chemistry knowledge and pre/post gameplay results in the quiz

Finally, Figure 20 shows the correlation between results and experience of the periodic table. Looking at the results, it is clear that many of the peaks and troughs were mostly in the same locations. This indicates that those with less experience in the periodic table of elements generally did worse in the quizzes. However, looking at the post-game quiz results alongside it, it does suggest that they learned or stayed the same in the majority of cases. The higher experience participants seemed to do better by a wide margin in the post-game quiz.

While there are indications of the game facilitating learning of the desired content (the periodic table of elements), the population sample in the trial described is far too small to provide data that can be analysed with the appropriate statistical models (the McNemar's test would be more appropriate on this particular occasion, given the multiple-choice format of the periodic table of element questions).

It would be very difficult to gauge statistical significance of pre/post gameplay knowledge for example from this experiment. Correlations with age and gender, which could provide very useful data for further discussion, would also need a larger population sample for appropriate conduction.

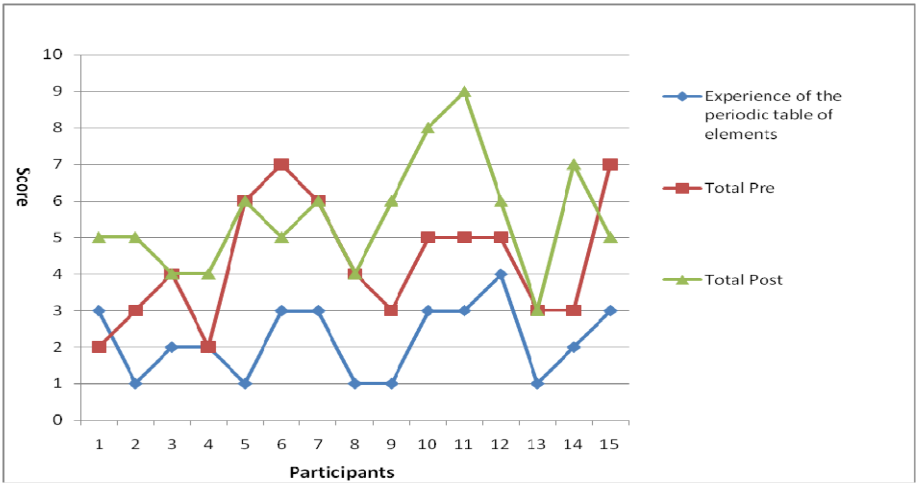

Fig. 20. Correlations between periodic table of elements knowledge and pre/post gameplay results in the quiz

6 Conclusion

This article explores the development and pilot evaluation of a chemistry educational game called Elemental, created using XNA and deployed on the PC/XBox 360 platforms. The results of the evaluation appear positive regarding the value of the game. There were 4 original hypotheses; the first was the game showing indication of teaching the players in the field of chemistry. The post-game quiz managed a better means result that the pre-game quiz. The mean/average of the first being 4.3 and the second being 5.53. On average, each participant scored better by 1 question. The second hypothesis was that the game challenged players in a coherent style. All participants addressed this with a value of 3 or more in the Likert scale used. This shows that the game had a common style, which allowed players to engage well with the game. They also had fun playing and generally this is not done with content which is too easy or too hard, therefore this hypothesis is true. The last two hypotheses were also both true with all levels of video game and chemistry experience participants being able to play the game. Some of the participants with a low experience in chemistry received a better mark in the post-game quiz, as did some of the participants with low experience in video games.

These hypotheses were all shown to be true through a pilot evaluation of the game with 15 participants. The game developed had the characteristics of other video games plus also managed to show educational usefulness, despite being developed using fairly modest techniques and inexpensive tools. The next step would be to explore the Elemental's game use with its intended audience; secondary school students.

Finally, overall recommendations from the experience of creating and also evaluating the Elemental game include the following;

- background research reveals that it is not uncommon to target, with a variety of gaming development platforms and, more importantly, gaming genres traditional areas of classroom curriculum, as many successful approaches to this are already in existence

- XNA can be an ideal tool for developing small scale game-based learning projects intended for classroom use for a variety of reasons; it is a free download, supports a number of Microsoft platforms, is supported itself by a large development community, is simpler to use than other game development programming APIs and can offer great control to a novice programmer, while at the same time providing many pre-made game development classes for use

- the requirements set out for a game created for classroom use need to "draw" as much as possible from prior experience the pupils inevitably will have of computer / video games. Building in game mechanics such as recognisable controls, an informative introduction and help system, as glossy as possible visuals, a timer feature, a high score feature etc. could potentially improve the implementation's desired learning impact

- iterative creation (there were over ten distinctly different versions of the game developed before it was exposed to a classroom) can allow for progressive improvement and feature additions to the game and also for a gradual development of the programming skills of the educator himself/herself whilst creating the implementation

- based on the empirical results, which suggest some pre/post test questionnaire differentiation (with post-test yielding a more informed mean to GSCE-level periodic table of elements questions), the approach of using a game similar to Elemental, developed using the methodology described in this paper, can be of benefit in classroom use to enhance and further support learning of traditional curriculum subjects such as chemistry.

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