Constructionist Learning in Anatomy Education:

What Anatomy Students Can Learn through Serious Games Development

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ABSTRACT. In this paper we describe the use of 3D games technology in human anatomy education based on our MSc in Medical Visualisation and Human Anatomy teaching practice, i.e. students design and develop serious games for anatomy education using the Unity 3D game engine. Students are engaged in this process not only as consumers of serious games, but as authors and creators. The benefits of this constructionist learning approach are discussed. Five domains of learning are identified, in terms of what anatomy students, tutors, and final users (players) can learn through serious games and their development process. We also justify the 3D engine selected for serious game development and discuss main obstacles and challenges to the use of this constructionist approach to teach non-computing students. Finally, we recommend that the serious game construction approach can be adopted in other academic disciplines in higher education.

Keywords: Serious games, game engines, game development, medical education, human anatomy, anatomy education, constructionist learning.

1 INTRODUCTION

Over the past ten years we have seen games technology become a commodity making it widely available and within reach of both professionals and enthusiastic individuals. Careful design makes games inherently fun and thereby entertaining for people of all ages, in particular, today's *games generation*. Given the high level of engagement that people exhibit whilst playing games it seems logical that combining the unique characteristics that make these games so engaging with conventional methodologies in education could provide a powerful means of encouraging students more effectively in learning activities. This concept forms the underlying principle of the idea of serious games coined by Sawyer and Rejeski [25]. In recent years serious games and game-based learning have received increased attention from researchers, educators, and psychologists [12], [15]. However, the majority of previous endeavour is about playing games for learning rather than making games for learning [13].

This paper discusses how 3D games technology can be used for human anatomy education and presents our experience of teaching students to develop interactive anatomy applications using a 3D game engine. The goal is to offer this as a case study for those wishing to create 3D educational content within an academic context and to incorporate computer technologies into their anatomy curriculum. It also shows what anatomy students can learn through serious game construction based on our practice on our MSc Medical Visualisation and Human Anatomy programme, which teaches students a combination of computer science, structure and function of the human body, anatomical and medical terminology, and cadaveric dissection techniques. Consequently, graduates from this course will be able to communicate 3D medical visualisation processes to a specialist audience and develop health-related products in a multidisciplinary team. The students that participated in this study are all from biomedical sciences background. They are engaged in this game-making process not only as consumers of serious games, but also as authors and creators.

This paper is organised into six sections. Firstly, traditional human anatomy education is reviewed and main challenges are discussed. The role of computer technology in education and training of future doctors, dentists, biomedical scientists, Allied Health Professionals, computer scientists and related professions is discussed. We then review previous serious games for anatomy education and higher education in general in section 3. Section 4 briefly describes the course design and the context of this study. The reason to select Unity 3D as the development tool for non-computing students is justified in section 5, and results are presented in section 6. Finally, we conclude the study and recommend that this constructionist approach can be adopted in other academic disciplines in higher education.

2 HUMAN ANATOMY EDUCATION

The use of computer technology, in particular computer graphics, has a long history within Medicine. However, its use within the teaching of medicine has somewhat curiously been overlooked. In a report entitled “Tomorrow’s Doctors” [11] the General Medical Council highlighted the advancement of technology and its role in the education and training of future doctors, biomedical scientists, allied health professionals and related professions as a strategically important area for development. With technology developing at such a fast pace and forming key areas for strategic development in these areas it is clear that a unique opportunity for enhancing medical education is emerging.

Understanding the function and spatial context of human anatomy forms a fundamental building block in a medical student’s education. At present anatomy is largely taught using a combination of three methods; book based learning, learning from physical models and cadaveric dissection. It is generally accepted that to gain a thorough and accurate understanding of anatomy a student should gain as much exposure to “real” anatomy as possible. However, due to the practical and cost issues in utilising cadavers for medical training, cadaveric dissection is often used sparingly and reserved for medical students rather than those training for related occupations. Consequently, the majority of anatomical education is based around learning from diagrams, images and physical models. This poses a number of problems. Firstly, it can often be difficult to appreciate the spatial relationships and physical sizes of the various components of the body from a photograph or image. Secondarily, the physical models of anatomical structures often lack the level of detail required to fully understand the various components. Finally, diagrams often form an abstract representation of the anatomical components, which if used on their own, can mislead students.

Over recent years, anatomy within medical education has seen a significant reduction in content delivered and time allocated to this subject [22], [33]. Also, with the loss of staff in anatomy that are skilled in teaching the subject, there has been an increasing need for new approaches to be developed in aiding anatomical teaching and training both for the educator and the student [3], [33].

The recent advances in gaming technologies puts forward interesting opportunities to expand upon these approaches to learning by bringing the lessons learnt from playing and developing games into the classroom. By combining computer models of anatomical structures with custom software we can present students with new ways of interacting with anatomy that could not be achieved during cadaveric dissections or in static images and diagrams.

3 GAMES FOR ANATOMY EDUCATION

Serious games have been used for education in various formats (non-digital games, digital games, gamification, live action role play games based on pervasive technologies, etc.) and ways (commercial off-the-shelf games and bespoke custom-made games), and based on different philosophies of education (instructionist and constructionist philosophies) [13].

The majority of educational games on the market are instructionist games, which integrate game scenarios with the content to be learned. Constructionist educators take a differing viewpoint. Rather than asking students to play instructional games and learn from it, they provide students with opportunities to construct their own games. Learning can happen more effectively when people are active in making things.

The constructionist approach has been tested in non-digital game format by Carter [6], who worked with school children to design *Dungeons and Dragons* board games as a student-initiated, teacher-guided independent study. The games integrated different skills and subject areas across the curricula, including mathematics, social studies, written communication, artistic and creative development, social and emotional development. This approach has also been tested in digital game format [28] with computer science undergraduate students.

With the right authoring tools (more discussion on this in section 5), the game making process does not require expensive technologies and programming skills to create rich and interesting game worlds and characters. Our attempt to expand this approach to non-computing disciplines provides evidence of this.

3.1 Serious Games for Higher Education

There is a large amount of evidence available to suggest that the use of serious games for learning can make positive impacts on learning outcomes at all levels of education, ranging from primary [6], secondary [19], higher education [7], [14], and for children with special educational needs [35]. Educationalists often argue that the sophisticated computer skills and development costs required for producing these games prohibit their use in higher education. These obstacles can be overcome by adopting Commercial-off-the-Shelf (COTS) video games in education or the constructionist approach, both of which limit the need to create bespoke instructional games by professional game developers.

Instructionist Games for Higher Education. In higher education, the use of games is not only focused on learning a particular subject, such as using a bespoke serious game for learning a foreign language [27] and modding an existing game NeverWinter Nights to teach Structured Query Language (SQL) [29] etc., but also on the ability of the instrument to develop learning in general, e.g. to develop strategies for reading three-dimensional images, to develop learning through observation and hypothesis testing, to broaden the understanding of scientific simulations, and develop divided visual attention [12].

Using COTS Games for Higher Education. COTS games are designed for entertainment, not for learning. However, they can be incorporated into the curriculum, enable educators from multiple disciplines to engage students in learning and to reduce the costs of developing bespoke, custom-made instructional games.

Novak and Nackerud [20] proposed an adoption model for evaluating COTS games, particularly massively multiplayer role-playing games, for learning and teaching, and investigated the approach on a range of courses including history, English or literature, business, and physical science. The majority of research on using COTS games for education is aimed at students below the higher education level [9]. In higher education, educators tend to use virtual environments such as Second Life [5], [16] or modify COTS games (a.k.a. *modding*) [9], [29] in an educational setting.

Constructionist Games for Higher Education. Based on the constructionist learning philosophy, Smith [28] discussed three *domains of learning* for computer science students and lecturers in the process of the students developing their own serious games. As illustrated in Figure 1, students learned not only discipline-specific content of the serious games they created (Domain 1), but also more importantly, computing skills (Domain 2) when they go through the software (game) development process. As a by-product, since they create the game from the educator's perspective, they also learned assessment, rewards, feedback, and various approaches in game-based learning. In addition, the teacher/lecturer is learning of teaching computing undergraduates (Domain 3) by reflecting on his/her own practice.

Gamification in Higher Education. Instead of using, modding, or making games for education, teachers can also adapt and facilitate gaming experience to the learning process. Gamification is a newly coined term referring to the application of game mechanics, e.g. points, badges, levels, and league tables, to non-gaming processes. It focuses on sociological approach in which the main goal is the use of games effects on specific areas such as marketing promotion and education. Gamification does not require huge investment in technology.

The use of gamification in higher education is wide ranging from economics [8], psychology [14], to computer science [7]. For instance, in an economics course at Pennsylvania State University, the course content is integrated in 'Who wants to be a millionaire?' game play. The students are notified that grades are for sale and that the primary way to acquire capital is by answering multiple-choice questions correctly [8].

3.2 Serious Games for Anatomy Education

Instructionist Anatomy Games. There are a few instructionist anatomy education systems available online. Some of them are not really 'games' [19], [30], [36] since they are lack of certain game features like goals, rewards, and winning conditions, etc. In terms of presentation, most of them are two-dimensional [18], [19], [30], others are three-dimensional [1], [36] or pseudo-3D [4]. They fall into four categories:

- Games/quiz: BBC Human Body & Mind [4] and Artificial Anatomy [19]
- Simulations: there are a number of anatomy and surgery simulations for medical education. Some not only provide a photorealistic look but also feel real and allow the user to touch and manipulate using haptic interfaces [2].
- Browsers: Google's body browser [36] and eSkeletons [30],
- Education tools: Anatronica Interactive Anatomy 3D [1] and MEDtropolis' Virtual Body [18]. The Anatronica Interactive Anatomy 3D includes a quiz component as well.

BBC Human Body & Mind [4] is a series of drag-and-drop jigsaw games for learning human anatomy. The games include internal organs game, skeleton game, muscle game, nervous system game, and senses challenge quiz. The games are designed and involve drag-and-dropping a body part onto a transparent human figure. When the player is rotating a body part, the games use a series of images to fake a three-dimensional view. Artificial Anatomy Body Parts [19] is a short 10-question quiz on body parts. The player needs to identify a thumbnail image of a body part and match it with its location on a skeletal structure named *Jerome*, which is a paper mache anatomical model. The player can turn Jerome around for front view and back views. Anatronica Interactive Anatomy 3D [1] and Google body browser [36] are among the best instructionist anatomy education applications so far in terms of the level of details and anatomical and functional completeness. There are a number of anatomy applications available on smart phones, ranging from two-dimensional illustration, e.g. SusaSoftX Human Anatomy for both iPhone and Android, to three-dimensional models, e.g. Anatomy 3D-Anatronica for Android phones.

Constructionist Anatomy Games. Constructionists suggest that learning is more effective when a student is actively engaged in the learning process rather than attempting to receive knowledge passively.

Murray and Stewart [37] use the constructionist approach in a non-digital form. Their students used coloured electrical wires to model the somatic peripheral nervous system. The modelling of nerves is overlain onto a life sized plastic articulated skeleton (Fig. 1). This method helps students understand the origins of the nerves, the pathways that they take to reach the structures that they innervate; and it provides an indication of the spinal nerves which contribute to each peripheral nerve and the way they come together to supply particular structures or body compartments.

We adopt the constructionist approach in a digital form to encourages learners creating their own anatomy games like [1], [4] and [19]. The teacher facilitates the process of learning in which students are encouraged to be responsible and autonomous. Figure 2 illustrates the five domains of learning in constructionist anatomy games from both learners and educators perspectives. Instructionist anatomy games only cover the first domain of learning (D1) and are for those at the receiving end of serious games, i.e. the players. From the perspective of students who are engaged in the game development process, i.e. the game designers (and developers), the constructionist games also cover D2 and D3 learning domains (software development and human anatomy). The learner is involved in all the design decisions and develops technological skills, which are essential to implement his/her game design. These consist of 3D modelling, texturing, rigging, animation, game engine scripting, game mechanics, and agile project management etc. From the tutor's perspective they include two additional domains of learning, which are teaching non-computing students software development and teaching human anatomy using constructionist serious games.

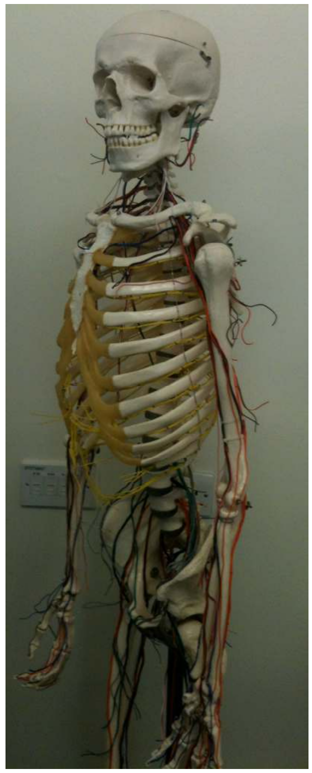

Fig. 1. Using coloured wires to model nervous system [37]

4 COURSE DESIGN

We tested the constructionist approach in the learning and teaching practice of the MSc Medical Visualisation and Human Anatomy at the Glasgow School of Art and University of Glasgow. The students on the Masters course come from life sciences or medical/ biomedical related subjects, e.g. immunology, anatomy, and biomedical engineering.

They spend their first semester at the Digital Design Studio, Glasgow School of Art learning 3D modelling and animation, computer graphics and applications in medicine, software development, and volumetric visualization of medical data. In semester two, students take three modules at the Laboratory of Human Anatomy, University of Glasgow: introduction to anatomy, structure and function of the human body, and cadaveric dissection techniques. There is a logical progression from an introduction to anatomy and imaging through to examining key regions of gross anatomy, followed by dissection of a focal region. Nowadays, anatomy degrees do not focus enough on gross anatomy and cadaveric dissection, which means that this component is uniquely placed in delivering actual cadaveric dissection and related training. In the third semester, students undertake a Masters research project. Dependent on the students' interests and background, the project can either be undertaken in a specialist field within human anatomy or the technological applications of medical visualisation.

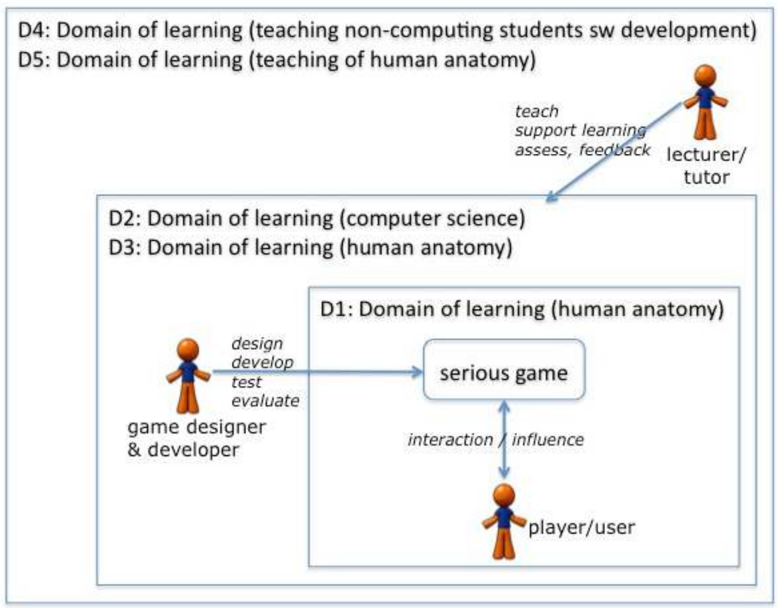

Fig. 2. Five domains of learning in constructionist games

The study was conducted in the first semester. Although the modules in this semester did not teach human anatomy in particular, students learned it from their mini-projects which required them to develop anatomy games using commercial software such as Maya and the Unity 3D engine. The assignments were designed to teach students not only about their chosen anatomical subject, e.g. dentistry (names of human teeth and dental treatment), upper body muscles, bones and orthopaedics (four-corner arthrodesis in wrist), but also about the basics of software development. Along with the anatomy games, students were required to submit a reflective development journal detailing each step of the process, discussion of the final game, and future aspects.

5 SOFTWARE SELECTION

Since the majority of the students enrolled on the course have little to no formal training in computer programming, the focus of the course was to provide an introduction to building interactive anatomical applications rather than about the complexities of game development. The rise in popularity of computer games over the past decade has caused a wide range of game engines to enter the market in order to support their development. The role of modern game engines is to streamline and simplify the process of game development by providing the developer with common functionality and visual development tools from which to build an application. However, the types of features and functionality that each engine offers and the ease of interaction can vary widely. Due to these differences it was decided to outline a set of requirements upon which to base the decision on. Firstly, the game engine should provide a graphical user interface which students can use to put together the bulk of the functionality. Secondarily, any code that is required to provide game logic should use a simple scripting language rather than complex strongly typed languages such as C++ or Java. Finally, the game engine should provide common functions such as model loading, window creation and graphical user interface elements. Given these broad requirements the following game engines were highlighted for further consideration.

5.1 Unreal Development Kit

The Unreal Development Kit (UDK) from Epic Games [32] is perhaps one of the most well-known games engines currently on the market. It has been widely used in commercial development and has been responsible for some of the best-selling games of recent years. In early 2011, Epic Games made the decision to make their toolset free to use for non-commercial projects, enabling schools and universities to use it for teaching without cost. The UDK is a fully fledged game engine providing all of the latest shader effects, network capabilities and gameplay functionality required to make commercial quality games. The UDKs user interface combines the use of graph based visual programming and their custom scripting language called 'UnrealScript' to provide game logic. Epic's toolset is clearly designed to seamlessly integrate into the complex workflows of a functioning game studio and therefore assumes some level of expertise from its users. Consequently, the sheer amount of options and functionality that are available to the user make initial interactions a daunting task. Whilst there is a strong community of support around the toolset it was felt that the UDK was perhaps over-specified for our application.

5.2 Quest 3D

Quest 3D [24] presents itself as a graphical programming environment for generating interactive three-dimensional environments. It offers a comprehensive set of model loaders, effects and graphical user interface components and is targeted to users without any programming skills. Applications are constructed using a visual programming language whereby users can drag and drop components onto a workspace and connect them together in order to produce the desired visual output. Additional components and more complex functionality can be added using an API or alternatively using a scripting language. Quest 3D's simple interface makes constructing an interactive 3D scene straight forward. The graphical programming approach is beneficial for students as it requires very little programming, thereby allowing them to focus on content creation rather than solving the numerous potential pitfalls involved in traditional programming. However, whilst it does exhibit many of the features of a game engine, it is targeted more as a general visualisation tool. This is not necessarily a bad thing since students will only be capable of using a very limited subset of a more fully featured game engine all of which are well within the scope of Quest3D's feature sets.

5.3 Unity

Unity [31] is a multi-platform game engine that allows users to create applications on desktop operating systems such as MacOS and Windows, as well as mobile platforms and games consoles. This flexibility in deployment and its easy to use interface has made Unity a very attractive development tool for independent games developers. As with the other engines, Unity offers a comprehensive graphical user interface to use in building an application but relies on JavaScript to provide the game logic. The use of scripting to bind graphical elements together means that students have the flexibility to be creative with their ideas and are not constrained by the limitations of the software. However, this does pose potential problems for students that have no experience of programming as basic programming concepts will have to be learnt before they are able to start creating their applications.

5.4 Evaluation

All the engines above were considered perfectly capable of providing students with the tools that they would need to create their application. However, given the limited time that is available in the first semester, the choice came down to ease of use and cost. Whilst the UDK is arguably the most fully featured of the three, it was felt that flooding the students with options would only serve to confuse them. Consequently UDK was ruled out due to the unnecessarily steep learning curve for this application. Quest 3D on the other hand takes a much simpler route, its graphical programming interface makes it far more approachable for students without any traditional programming experience. However, given that students on the course were expected to gain some knowledge of how to build an application it was felt that Unity, with its mixture of visual and traditional programming, was the best candidate for the course.

5.5 Other Game Development Tools

There are a few other game development tools, which are not suitable for this specific application, but may be considered when adopting the game constructionist approach to other disciplines.

GameMaker and Scratch. GameMaker [21] and Scratch [26] are 2D game development tools that are oriented towards beginners and amateurs that know little about how to program. They allow users to design and create their own games using easy-to-learn drag-and-drop actions and a scripting language. Provided that users are supplied with high quality graphics, the user can create professional-quality games in a short period of time. Both engines support fundamental game features, such as animated graphics, pathfinding, particle effects, and GUI elements. It is also possible to use GameMaker to create pseudo-3D games which actually are two-dimensional. Both games engines are supported by large communities of amateur and indie game developers from around the world.

However, due to the geometric and spatial complexities of human anatomy, it was felt that the use of three-dimensional graphics was essential for the process of memorisation, understanding and visualisation tasks in anatomy education. Given this requirement, GameMaker and Scratch were deemed to be unsuitable for use in our study. However, they have successfully been used in other subjects, which do not require three-dimensional presentation. For example, Penta [23] evaluated five game development tools, including GameMaker and Scratch, for the use of game construction for mathematical learning in secondary education.

Game Modding. Many commercial video games provide level and character editors to extend the life-cycle of the games, for example, Valve's Half Life, World of Warcraft, Everquest II, NeverWinter Nights, Cilvilisation, and Second Life, etc. UDK is actually one of them, originally for the *Unreal Tournament*. These development tools could be very useful to lower the bar for the constructionist learning approach for students or for tutors to make instructionist games. Successful case studies include using a NeverWinter Nights mod to teach SQL [29] and using Garry's Mod, which was originally a Half-Life 2 mod, to teach molecular chemistry [10]. The game provides a physics sandbox and allows the lecturer to create a virtual object to represent a molecule structure that he can duplicate, pick up, move, connect them to one another and play around with.

6 RESULTS

In this section the results of the taught module are described and discussed. The work of three students is used to illustrate the type of applications that were created as coursework over a two-month period. Each student chose a different subset of anatomical structures from which to create their game and was provided with three-dimensional models of their chosen areas which they were free to alter if they wished. These are highlighted in Figures 2 – 4.

Student A designed a game based around the muscles of the upper torso (Figure 3). The goal of the game was to identify a specified muscle on the body, by clicking on the associated muscle. Some of the muscles are located on the posterior aspect of the model. To gain access to these, the user can use a rotating button to turn the model and use arrow keys to control the view (virtual camera). A scoring system was implemented to keep track of the number of correct answers and the user was able to review their answers at the end of the game. Using Unity the student was able to load in a model of muscles in the upper torso with texture maps and provide visual and audio feedback during the game play. An animation sequence of the muscle man applause with clapping audio is played at the end of the game.

The student identified future improvements in her development journal. For instance, "to make the game more educational and less one dimensional, after correct identification the function of that muscle would be displayed"; the game could provide two modes− learning mode and assessment mode. In the learning mode, the correct muscle is highlighted/flashes, or name of the selected muscle and its function could be displayed on the screen, to assist learning.

Student B created a dental game (Figure 4) for assisting learning tooth notation and anatomy. The game shows a dental model consisting adult teeth, maxilla, and mandible. It allows the player to select (highlight) any tooth (or maxilla/mandible) and enter its number and name. The player can use a rotating button to turn the model and use arrow keys to control the virtual camera to gain access to individual tooth. A scoring system was implemented to keep track of the number of correct answers and the user was able to review the results at the end of the game. An animation sequence of teeth chattering with accompany audio is played on completion of the game.

Student C made a game to aid the learning of the anatomy of the forearm, wrist and hand bones. The game is based on a multiple choices quiz. For each question, a bone is highlighted on the screen and the player can choose one of the four answers. The scoring system and camera/model manoeuvring are similar to the above two games. For the 3D modelling and animation assignment, the student created an animation of four-corner arthrodesis in wrist, showing the range of movement before and after the operation.

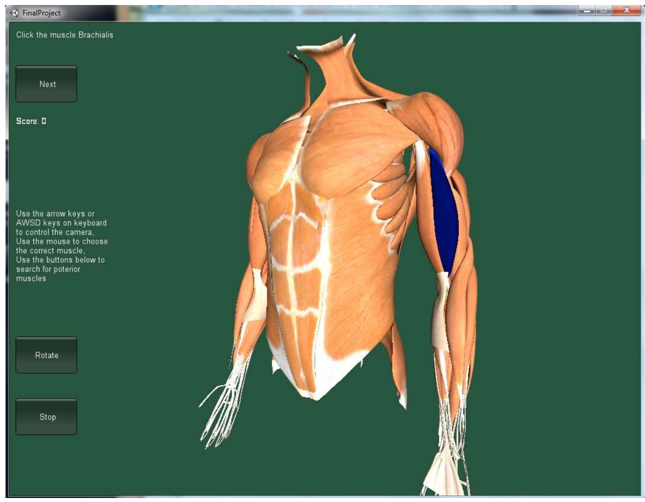

Fig. 3. Upper body muscles game

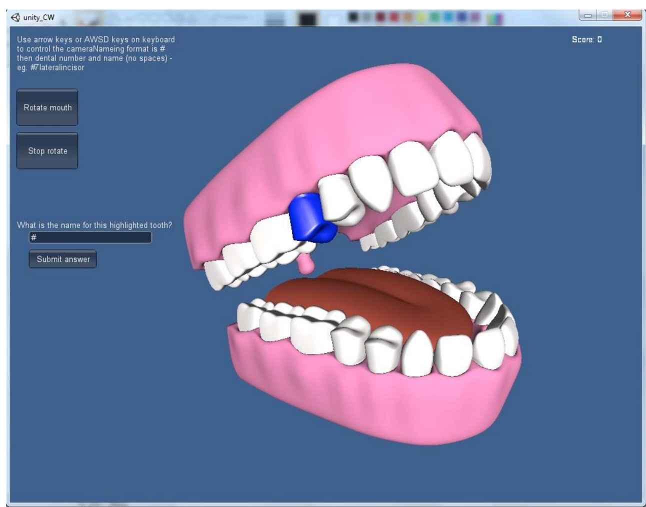

Fig. 4. A dental anatomy game

Below is student feedback on the game construct learning approach. It shows that students welcome this novel and active learning approach.

- "I think that using the computer programs to gain a better understanding of anatomy was a great way to cement the structure and names of the various parts being modeled and animated into your memory. Teaching and learning anatomy are both hard in themselves, but I believe that using the programs help a lot with remembering the multitude of detail required for understanding the bodies form and function."

- "I actually felt I learned some anatomy whilst working on the project. Probably due to the nature of the length of time it takes to model. I found when it came to the lower limb this term I actually had a good base knowledge of the bone structure and the spatial relationship between the bones of the foot after having sourced many reference pictures throughout that project."
- A student whose first degree was anatomy commented: "The first semester provided an opportunity for me to revise some of the anatomy I covered as an undergraduate anatomy student, for example the names and morphology of the carpal and metacarpal bones. However, I feel that I did not learn new anatomy during this period although I feel that this is because of my background knowledge of anatomy."

7 CONCLUSIONS

This novel approach of constructionist learning in anatomy education, whereby students are involved in the creation of the specimen, and the questions and answers, encourages greater engagement with both the computer software and also the anatomy of that region used. Design of this type of material could be used across many higher education disciplines to encourage participation in the learning process from a more active role, rather than from a didactic, passive role.

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Anatomy is one of the most difficult subjects you learn in vet school. Memorizing all the anatomical structures and their functions is tough enough as it is, but you have a number of other classes to study for as well! Talk about time management. To help you be successful in your classes, weâ€™ve come up with 13 tips for studying anatomy more effectively: 1. Schedule it in. This is key for making your life easier right before exams. We all know how stressful it is trying to cram in all the material youâ€™ve learned the entire semester just one week before exams. Itâ€™s very tiring, stressful, and fr â€¢ Constructionist Learning in Anatomy Education: What Anatomy Students Can Learn through Serious Games Development more. by K. Bale. and Minhua Eunice Ma.Â The benefits of this constructionist learning approach are discussed. Five domains of learning are identified, in terms of what anatomy students, tutors, and final users (players) can learn through serious games and their development process. We also justify the 3D engine selected for serious game development and discuss main obstacles and challenges to the use of this constructionist approach to teach non-computing students. Finally, we recommend that the serious game construction approach can be adopted in other academic disciplines in higher education. Save to Library.