

## The Development and Evaluation of a 3D Visualization Tool in Anatomy Education

*Pembangunan dan Penilaian Alat Visualisasi 3D untuk Pendidikan Anatomi*

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### Abstract

The current learning tools are two-dimensional visualization tools, which complicates the construction of mental models of three-dimensional (3D) anatomical structure consisting of the elements of breadth, width, and depth. To overcome this problem, a virtual three-dimensional anatomical visualization tool was developed and evaluated based on virtual reality technology running on the web. The waterfall development model was used to develop the 3D tool which consisted of manipulation and exploration features to facilitate visualization of complex 3D anatomical structure. Eighteen respondents (18) were involved in the experiment to evaluate the usability of the 3D visualization tool. Results showed that the usability of the 3D visualization anatomy tool was high, suggesting its usefulness for teaching and learning of human anatomy.

**Keywords** anatomy education, usability evaluation, virtual reality, visualisation tool, ict in education

### Abstrak

Alat-alat pembelajaran yang ada ketika ini adalah terdiri dari alat-alat visualisasi dua dimensi yang merumitkan pembinaan model mental tiga dimensi (3D) untuk struktur anatomi yang mempunyai kedalaman, kelebaran dan ketinggian. Sebagai satu penyelesaian, alat visualisasi maya secara tiga dimensi dibina dan diuji berasaskan teknologi realiti maya yang berfungsi dalam persekitaran web. Model pembinaan air terjun digunakan untuk membina alat 3D ini yang mempunyai ciri-ciri manipulasi dan explorasi untuk membantu proses visualisasi struktur anatomi yang kompleks dalam tiga dimensi. Lapan belas (18) orang responden terlibat dalam eksperimen untuk menilai kebolegunaan alat 3D ini. Dapatan menunjukkan bahawa kebolegunaan alat visualisasi 3D ini adalah tinggi yang menunjukkan bahawa ianya mempunyai potensi untuk pengajaran dan pembelajaran anatomi manusia.

**Kata kunci** pendidikan anatomi, penilaian kebolegunaan, realiti maya, alat visualisasi, ICT dalam pendidikan

## INTRODUCTION

Modern science phenomena are often imbedded in visual representation that attempt to capture the complexity of structures, functions and process (Jones & Broadwell, 2008).

Mathewson's (1999) research has shown that visual representations are not only motivating but are also critical in the communication of science concepts. Thus, visualization learning tools are now widely used as knowledge sources for learning at all levels of science education and media to convey important and complex scientific information (Gobert, 2005). Visualization is important in three aspects of science learning, namely learning specific consensus or historical models, learning to develop new qualitative and quantitative models (Gilbert, 2008). In this regard, Uttal and Doherty (2008) defined visualization as any type of physical representations designed to make an abstract concept visible. These include but are not limited to concrete items, such as photographs, 2-D graphs, diagrams, charts and 3-D models.

Anatomy is the study of structures (McKinley & O'Loughlin, 2012). Tortora and Derrickson (2012) stated that the sciences of anatomy and physiology are the foundation for understanding the structures and functions of the human body. The word *anatomy* is derived from the Greek word meaning to cut apart. Human anatomy is an important subject in the life sciences, such as medical, biology, sport science, and nursing (Ma, Bale, & Rea, 2012). The study of human anatomy can be divided into two general categories, namely microscopic anatomy and gross anatomy. Microscopic anatomy examines structures that cannot be observed by the unaided eye (i.e., cell structure), while gross anatomy investigates the structure and relationships of large body parts that are visible to the unaided eye, such as the intestines, stomachs, brains, hearts, and kidneys (McKinley & O'Loughlin, 2012). In addition, the structure of human anatomy can be divided into several levels, which are chemical, cellular, tissue, organ, organ system and organism levels. The organ system level is the description of location and 11 major organ systems of the human body.

The primary purpose of learning anatomy is to recognize the body's normal structure and function so that when structures are altered by defects, trauma, or diseases, the knowledge of these deviations can be utilized in making clinical decisions (Moxham & Plaisant, 2007). Learning human anatomy is based on the ability of the student to visualize human anatomy structure. Visualisation in the context of anatomy can be defined as creating a mental picture of anatomical structure that is easily recalled (Meester, 2011). Currently, learning anatomical education is mainly assisted by learning aids, such as diagrams, images and physical models (Ma et al., 2012). These learning tools, which are 2D, are not effective to help students understand the spatial relationships and physical sizes of the various components of the body. Essentially, students using these tools will not be able to decipher the abstract representation of anatomical components. From the cognitive standpoint, the current tools lack the capability to help students construct appropriate mental models of 3D anatomical structures consisting of breadth, width and depth. Yeom (2011) stated that contemporary educational methods for teaching complex anatomical regions were considered inadequate as they typically lack the depiction of a 3D spatial tissue in a three dimensional configuration. More revealingly, students who face difficulty in visualizing complex anatomy structures are those with low spatial ability. In essence, spatial ability is the ability of humans to construct a 3D mental model from a 2D illustration or imagery.

Recently, virtual reality (VR) has become a prominent, popular technology used by many educators. VR prominence in education lies in its low total cost of ownership (TCO),

high computing performance, and fast delivery. VR is one of the promising technologies that has the potential to influence the way students learn complex microscopic structures of learning contents. Using VR, students are able to immerse in a three dimensional virtual environment, which engenders easy manipulation and visualization. For example, a VR learning tool enables students to rotate an anatomical structure about different axes and angles to gain several perspectives of the object. In theory, those perspectives should enable students develop a more complex 3D mental image of anatomy compared to the current methods (Jang, 2010). Despite its huge potential, VR has not been routinely employed in science teaching. One of the problems is the lack of a low cost 3D virtual reality applications for science learning. Recently, most of the current VR tools for anatomy education are based on immersive virtual environment or a semi immersive virtual environment. An immersive virtual environment is created using the high end VR technology, which is prohibitively expensive to be deployed at the school level. In view of this limitation, this research was carried out to develop and test a low cost 3D visualization tools for human anatomy learning.

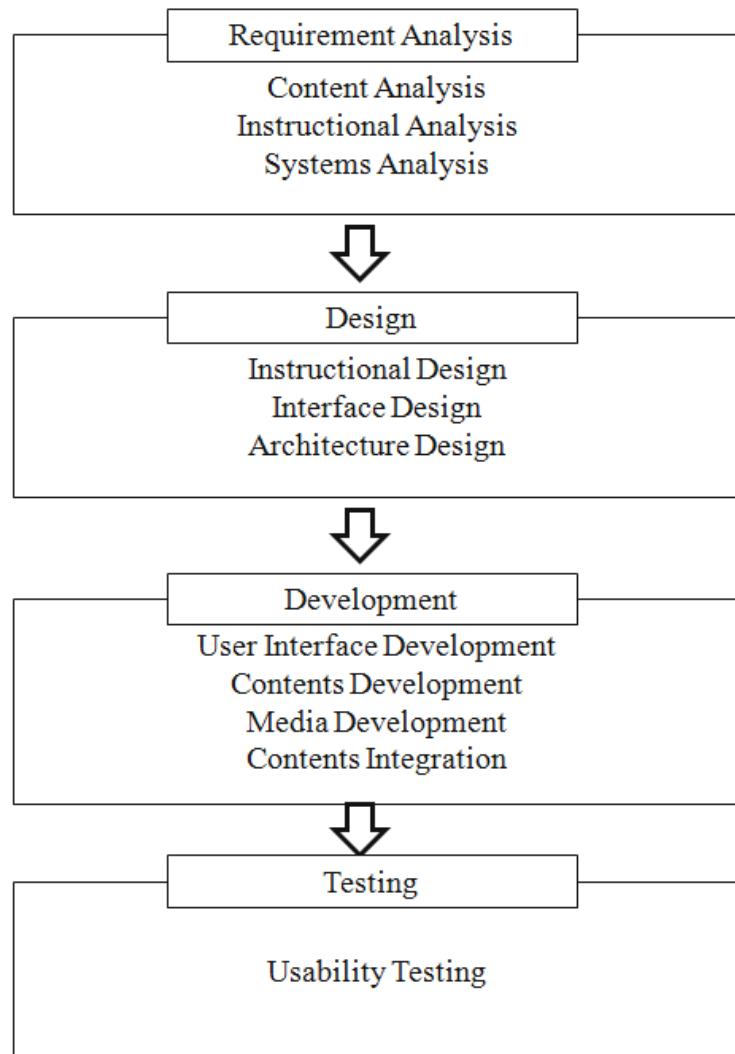
The objectives of these research are:

1. To develop a 3D visualization tool for human anatomy learning.
2. To evaluate the usability of the 3D visualization tool.
3. To evaluate students' satisfaction of the cognitive benefits of the 3D visualization tool.

## **METHODOLOGY**

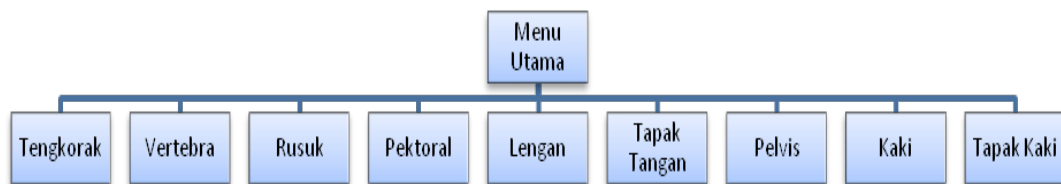
The development of 3D visualization tool for human anatomy learning was based on a modified software development life cycle (SDLC), namely the waterfall model. The waterfall model involves four stages, namely requirement analysis, design, development, and testing (see Figure 1). Requirement analysis is the most important, crucial part in software development process. In this study, a field interview was conducted with three science teachers and four students. The finding from the interview revealed that majority of the students faced difficulties in understanding human anatomy. Part of this problem is due to the limitations of 2D illustrations in explaining the 3D structure of the human anatomy. They also stated that human anatomy was a complex subject containing complex information. In order to gain a deeper understanding of the teaching process of human anatomy, a class observation was conducted. It was found that one of the most effective instructional strategies in teaching human anatomy was the tutorial method. Contents analysis was conducted with the guidance of science teachers. Related literature pertaining to anatomy education and anatomy contents were also reviewed. Based on the interviews, class observations, discussion with the science teacher, and literature reviews, the instructional strategies, media elements and contents for the new, novel 3D tool were specified. In addition, the researchers also reviewed current virtual anatomy applications, such as VisibleBody (<http://www.visiblebody.com/index.html>), BioDigital Human (<https://www.biodigital.com/>) and InnerBody (<http://www.innerbody.com/>). The architecture of the 3D visualization tool was determined through the evaluation of the current anatomy application. Most the applications were web-based applications that could be viewed using

a normal web browser. Input from the analysis of the current virtual anatomy applications helped the researchers to specify the architecture of the 3D tool.



**Figure 1** Waterfall development methodology

The main objective of the designing phase was to design a 3D visualization tool that was based on sound instructional design principles and multimedia design principles. The tutorial approach was adopted as the instructional strategy in 3D visualization tool as it permitted the user to explore the learning material based on their preferences. Figure 2 shows the instructional model of a 3D visualization tool with a feature that enables the learners to navigate each individual module based on their preferences. Multimedia design principle, such as multimedia principle, modality principle, and redundancy principle were also used in designing the contents layout and delivery.



**Figure 2** Instructional model of 3D visualization tool

Figure 3 shows the design of the 3D visualization tool based on the multimedia and modality principles. The focus of the multimedia design was to design a multimedia presentation that was aligned with students' cognitive load. For the 3D visualisation tool, navigation tools allowed the learners to view the textual information based on their preferences. These features helped students to read the information without constraining their limited cognitive resources. User interface design was an important factor that contributed significantly to the effectiveness of the 3D visualization tool. In this research, a user interface design that could contribute significantly to the effectiveness was used as a guideline in designing a user interface for the 3D visualization tool.

The development of this 3D visualization tool was based on the web virtual reality technology. The web virtual reality technology is a set of low cost virtual reality technologies that enables the developer to build a web VR application. In this project, HTML, CSS and VRML programming language were used as the core technology. Autodesk 3D Studio Max was used for developing 3D anatomy structure. Graphic elements, such as buttons and illustrations, were developed using the graphic editor software GIMP. The development process consisted of three important steps, namely the development of a 3D anatomy model, the development of a VRML file, and the development of the web VR application. The 3D designer was employed to develop a three dimensional anatomy model. The development of the 3D anatomy models was carried out under the supervision of the science teachers. This supervision was vital to help minimise the development time and to ensure accurate 3D models.



**Figure 3** Multimedia Message Design

The last activity in 3D visualization tool development was testing. Usability testing was conducted when the software development were complete. The ISO 9241 standard defines usability as “*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use*”. From this point of view, the purpose of usability testing is to evaluate the effectiveness, efficiency and satisfaction of the particular software. In this study, the usability evaluation was conducted to evaluate four element of usability, namely effectiveness, efficiency, satisfaction, and learnability. An experiment was conducted to evaluate the usability of the 3D visualisation tool involving 18 students in a multimedia computer laboratory. Each of the respondent was given two hours to explore this tool. Each participant was provided with printed instructions that explained every task that they must complete. In this experiment, the respondent must complete three tasks, namely exploring the main menu, exploring each of 3D anatomy models using the exploration and manipulation tools, and navigating the textual information in each module. After the completion of the experiment, all respondent were administered with the usability instrument. The usability instrument was a questionnaire that was based on a 5-point Likert scale, consisting of 21 items to evaluate the four dimensions of usability.

## RESULTS

The purpose of software evaluation was to measure the students’ perception of the usability and to evaluate the students satisfaction on the cognitive benefit of the three dimensional visualization tools. An experiment was conducted to evaluate the 3D Visualisation tool usability. Table 1 shows the result of the usability evaluation that was carry out in this research. From the table, the respondents give a good evaluation on the learnability, satisfaction, efficiency, and effectiveness.

**Table 1** Average score and standard deviation on each dimensions of usability evaluation

Usability Dimension	Mean Scores	Standard Deviations
Learnability	4.25	0.81
Effectiveness	4.10	0.72
Efficiency	4.08	0.73
Satisfaction	4.16	0.71
Overall dimension	4.15	0.74

The mean scores (and standard deviations) for rated learnability, satisfaction, efficiency and effectiveness were 4.25 (.81), 4.10 (.72), 4.08 (.73), and 4.16 (.71), respectively. Clearly, all these dimensions of usability were highly rated by the respondents. The learnability aspect (dimension) of the VR tool was of great importance because it clearly defined the perceived easiness (or difficulty) in learning anatomy using the learning tool. To achieve such a high rating for this dimension, the VR tool could become a prominent

learning aid in future anatomy learning by complementing or replacing existing learning tools that have been reportedly less effective. Likewise, the satisfaction aspect of the VR tool was also highly rated by the students, thus suggestive of their sense of contentment. This dimension plays an important role by making students more engaged and motivated to use such a learning tool. If such a dimension were to receive poor rating, the likelihood of frustration or disinterest in using such a novel tool will increase (Rafi & Samsudin, 2010; 2009). In addition, the dimensions effectiveness and efficiency were also highly rated, indicating that the VR tool provided them with meaningful learning experiences as searching, examining or focusing on relevant pieces of learning information was carried out almost effortlessly.

Moreover, these findings further contributed to a high rating of the overall usability of the 3D VR tool, which attained a mean score of 4.15. These findings suggest that, in general, the 3D VR tool has achieved its intended purpose, i.e. helping students to learn and attain greater understanding of anatomy structure. All the four dimensions of usability have, in unison, created a learning environment that helped improved students' cognition when learning the subject matter. This particular finding is not unexpected as ample evidence from the literature shows that learning materials or contents that have been properly crafted, seamlessly assembled, and timely delivered could facilitate better construction of knowledge (Jamilah, Nor Hasbiah, Aslina & Samsudin, 2013; Rafi & Samsudin, 2009; 2010). To enhance further learning experience, accessing appropriate part(s) or section(s) of the presented learning contents could be achieved by using appropriate navigation features. Otherwise, the learners might meander aimlessly or miss important information. In this study, the VR tool was equipped with the appropriate navigation features to help ease the exploration of the learning contents. Another novel feature of the VR tool was that relevant, important information was displayed on an appropriate section of screen as the students navigated to a certain part of the anatomy structure on the adjacent section (Figure 3). The juxtaposition of the 3D anatomy structure and textual information helped students to process information optimally, without undue cognitive load. From the multimedia learning perspective, the design of this information display helped the students to channel both verbal and visual inputs into their minds to be processed accordingly, thus creating a coherent model of knowledge being learned (Samsudin et al., 2014). Integrating this newly constructed model with their prior knowledge helped realize a meaningful understanding, thus learning became effective.

## CONCLUSION

Overall, the findings from this study strongly suggest that 3D VR tool offers a practical, affordable solution to help students learn complex anatomy structures. More specifically, using this tool, students were able to visualize an anatomy structure to form a holistic 3D model from multiple perspectives. More profoundly, learning aided by the VR tool was found to be far more effective, in comparison to current practices, which relies on 2D approach, in helping students to examine and understand the intricacies of anatomy structure. From the implementation standpoint, the use of VR tool in anatomy learning could be carried out in almost all schools in Malaysia, given the relatively low costs associated with the development, deployment, and maintenance of such a novel tool, which

runs on desktop platform. Moreover, this type of learning tool is not only effective and affordable, but it is also widely accessible when deployed over the web.

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