Summer 8-2015

# Evaluate Students' Learning Effectiveness of HVAC System Using 3D Game Animation

Lalitha Devi Nandam
*University of Nebraska – Lincoln*, lalli.archidreamz@gmail.com

# Evaluate Students' Learning Effectiveness of HVAC System Using 3D Game Animation

By

Lalitha Devi Nandam

A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Construction Engineering and Management

Under the Supervision of Professor Zhigang Shen

Lincoln, Nebraska

August, 2015

# Evaluate Students' Learning Effectiveness of HVAC System Using 3D Game Animation

Lalitha Devi Nandam, M.S.

University of Nebraska, 2015

Advisor: Zhigang Shen

An important skill required for students in Construction Engineering and Architecture is to understand what the major components are and how the whole system and its components function. Students typically learn to understand HVAC equipment by reviewing two-dimensional (2D) CAD drawings, images and site visits. With latest developments in 3D game engines for facilitating interactive learning, it is now possible for students to experience three-dimensional (3D) environments of HVAC systems. While this technology is still at an early stage in learning application, it has the potential to significantly enhance the capability of students to study, comprehend and gain experience designing HVAC systems. While there were many studies on 3D game-assistant learning, systematic evaluation of the learning effectiveness of complex 3D engineering system is needed to further understand the students' learning mechanism.

In this thesis the author presented some preliminary results in learning of HVAC systems through the use of 3D modelling and game engines. For the purpose of the pilot study, a 3D game environment of an existing whole-building HVAC system was developed to enable students to interactively visualize and operate typical HVAC systems on computer monitors. The learning effectiveness of the developed 3D game was tested with two

groups of students, who were expected to learn the same knowledge on HVAC system: (a) an experimental group with 24 students using Unity 3D game environment; (b) the control group only used traditional 2D drawings. A questionnaire designed on the concepts of structure, behavior and function was distributed to and collected from the students right after the class. A descriptive analysis of results obtained from observations and quiz sessions showed a significant difference or improvement in behavioral and functional understanding of HVAC system when Unity 3D model was used compared to using 2D drawings only. However, the test also showed that the difference in structural understanding the HVAC system was not significant in the results from the two groups.

## ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my adviser Dr. Zhigang Shen for the guidance and support throughout my graduate schooling here at University of Nebraska-Lincoln. I am deeply indebted for his motivation, enthusiasm, and continuous support during my research. Without his support, this thesis would not have been possible.

Besides my advisor, I would like to thank the rest of my thesis committee: Professor Bruce Fischer, Professor Tim Wentz and Dr. Wayne Jensen, for their invaluable time. I extend my gratitude to Professor Tim Wentz for his permission to test the project within his classes and his valuable suggestions in framing quiz questions. I also owe a great deal to Professor Bruce Fischer who rendered a continuous professional support throughout my Masters Program.

I would like to take this opportunity to thank my husband Satyaprasad, for his valuable input and motivation throughout the Master's program. Without his support in helping me understand mechanical systems, I do not think I would have been able to complete this project.

Lastly, I would like to thank my parents Rama Prasada Rao & Satyavathi and my brothers Srinivas & Krishna Chandra for their encouragement, and for their belief in me.

# Table of Contents

# List of Figures

# List of Tables

# Chapter 1 Introduction

## 1.1 Background

Students of Construction and Architectural Engineering programs typically learn to analyze and understand mechanical systems by using 2D project drawings and site visits. A few 3-Dimensional Computer Aided Design (3D CAD), advanced visualization techniques have been successfully used in higher education. The use of 3D interactive gaming as an advantageous tool for training has gained wide acceptance in areas of pedagogy such as medical science, pure science (physics, chemistry and mathematics). Due to the extensive use of 3D modelling tools such as Revit, Google SketchUp and/or 3D Max, use of interactive game developments is beginning to gain traction in the building and construction industries.

Game engines are are typically graphical user interface (GUI), which allows user to operate or manipulate 3D objects through GUI. The technology in game engines typically consists of collisions, artificial intelligence, physics and a graphical user interface (Eberly, 2007). Almost all the game engines have a basic built-in library that supports interactive functions and the necessary concepts of physics that support such functions. A typical architectural design and visualization tools, on the other hand, do not offer sophisticated animation actions (e.g. smoke, fire, water flow, and etc.) like game engines.

Gaming tools for learning consist of a prescribed or pre-determined activity within the confines of a set of rules and regulations (Allery, 2004, p.504).Today gaming has developed into something more than its original function as a recreational system. Gaming tools are now considered as a viable tool for improving educational experience.

Visually intensive fields of pedagogy like engineering, science and mathematics have complex phenomena which can often be better understood through 3D visualization. Student learning experience can be enhanced through virtual reality learning environments (Herrington and Oliver, 1995) by allowing them to envision potential issues as and when they occur. The ability of teams of students to observe and discuss issues (as if in real-time) using 3D visualization may also be helpful in improving team interactions. Students can take such experience of mutual interaction in teams, and apply it in the real world (with multiple-stakeholders working together on a project). Research in determining the viability and impact of 3D Visualization on mechanical systems training and education in academia (and industry), and the development of necessary technology (software and hardware), is critical.

The design and engineering of HVAC systems is highly specialized. In addition it involves multiple stakeholders throughout the process of design, building and operation of HVAC systems. An inherent advantage of using game engines is that virtual environments created in game engines can be simultaneously explored and operated by numerous users located in multiple places. This allows real-time decision-making and reduced risk of design deficiencies. A game developed for learning or education is generally termed as “serious game”.

The major advantages of using 3D gaming for training are:

1. A user can operate and pre-visualize various types of mechanical systems in a building well-before construction and without disturbing the operations of the building.
2. To observe the working process of a HVAC system, students can essentially gain better understanding of the system without having to study and inspect real-world construction projects.

This thesis presents the development of a 3D game model of HVAC systems in a typical building using various 3D tools such as Unity 3D game engine, Autodesk Revit, SketchUp and 3D Studio Max. The effectiveness of the model in student learning experience is then evaluated.

## 1.2 Literature review

### Potential for enhanced learning:

The process of learning specialized systems can be improved with the use of 3D game engines as opposed to traditional learning methods of using images of equipment and 2D plans from contract documents. In recent years use of gaming and simulation, to aid in the development of social skills (Ravenscroft and Matheson, 2002) and cognitive skills (Prensky, 2001; Natale, 2002), has received a lot of attention in higher education.

Due to the growth in information technology in recent years, 3D learning has gained traction as a valuable tool. Researchers have explored the possibilities of utilizing 3D models as a replacement of actual scenarios. A study on developing a HVAC system within a virtual game environment, instead of onsite visits using BIM models showed that BIM and game technology can effectively be combined to create interactive web-based virtual environments.

Dede (2009) concluded that training could be more powerful with 3D gaming environments by allowing multiple viewpoints and situated learning. An online virtual world called “Second Life” created in 2003 was a significant step forward in the area, and confirmed the possibility of developing training scenarios tailored to academia (Warburton 2009). Despite the critical advancement afforded by Second Life, there are few key difficulties in using second life:

a. Its ability to use Building information models is a problem, and
b. Developing built scenarios as real scenarios is quite complicated using its limited library source.

**Interactive learning as opposed to mere observation:**

Previous studies have found that the use of virtual prototypes for designing various facilities is helpful in pre-visualizing and reviewing the design of complex systems such as systems needed for patient rooms in hospitals (Dunston et al., 2007). These studies have broadened the scope of virtual environments by heightening end user involvement; letting the end users to walkthrough the space; and also allowing users to explore finer details such as lighting and textures. However, a couple of challenges in using virtual prototypes are that (a) users cannot truly interact with the virtual prototype; and (b) it is a nonrealistic portrayal of space. With the use of game engines, users can interactively operate and also accomplish certain tasks within virtual prototypes (Sonali et al., 2011). This is clearly a step forward, since the user experience with the use of game engines is much more interactive and thereby conducive to learning.

The interactive nature of 3D gaming in a virtual environment helps users relate what they view in virtual environment to real world scenarios. While prescribed and pre-mapped walkthroughs are available in most architectural/visualization tools, game engines allow for user determined and operated walkthroughs in virtual environments. This ability of users to determine their own “walk-about”, within the 3D game engines, significantly improves their applicability in exploratory learning.

Gaming as a learning approach, provides students the privilege of self-directed learning (Peters, 2000). Learning is an experience of focusing on a topic without distraction, and gaming can make this experience interesting and entertaining (Kiili and Lainema, 2008). The interactivity afforded by gaming allows multiple users to “be on the same page” at all times and therefore it also strengthens teamwork skills (Wallin et al., 2007). In complex projects, where student designers and engineers navigate their ideas through the ayes and nays of multiple team members, interactivity afforded by gaming can prove highly effective.

**Learning by repetition without the excessive cost of on-site experience:**

The majority of learning happens by repetition. Repetition of a certain task multiple times helps master a skill and enhances clarity of subject matter. The number of “site-visits” that a student can be exposed to, during the period of study, is often limited. Gaming tools allows students to interact with and understand complex systems as many times as needed. Jones et al. (2007) indicated that repeated convenience to practice a skill, enhances performance, and gaming gives the opportunity of repetition.

**Student/staff perception of game engines as a viable learning tool:**

The viability of game engines as a learning tool is directly dependent on the readiness of the academic community in adopting them. Therefore student/staff perception of gaming engines as a valid learning tool is important to understand. Two studies were conducted by University of Ulster in 2007 to understand the perceptions of gaming as a learning tool based on a survey of students and staff. The results showed that 78% of students and 71% of staff perceived gaming tools as valuable in learning (Beggs, 2007).

**Limitations of on-site learning:**

A common practice in the education of mechanical systems is on-site training to demonstrate the working principles and structure of various HVAC systems. Beyond the disadvantage of limited on-site training, as discussed above, another challenge in onsite training is that students cannot substantially visualize the individual components of mechanical equipment and their functionality.

HVAC systems are functionally complex and a thorough understanding is essential for learners. Research strongly indicates that contact with physical environment has a great impact on learning and understanding. There is a need to develop more innovative tools to reduce the difficulty in design, building and operation of HVAC systems. Better visualization of these complex systems is essential in learning as well as and in real-world decision-making processes.

## 1.3 Three-Dimensional Modeling

In Architecture, Engineering and Construction (AEC) industry, Building Information Modeling has become important in the recent years. The initial use of BIM by the industry was limited to construction and design. At this point, the utilization of BIM has spread to life cycle management and facility management. While there have been significant advances in the utilization of BIM Models, their applications in game development are limited.

### 1.4 Structure, Behavior and Function

The theory structure, behavior and function were first introduced in 1971 by Rodenacker in which a design procedure was recommended as a guideline for amateur designers. According to this procedure, the complete function is figured out from the given specifications of a system. The function is later branched out into sub-functions, sub-functions into sub-sub- functions, and so on, up to the stage where sub-functions are accomplished by physical behaviors. From then a lot of research has been conducted by various branches on the concepts of function, structure and behavior. Function and structure concepts are also used in various fields including biology, where cellular behaviors are defined using the concepts. Further the function, structure and behavior theories are also utilized for flaw investigation and qualitative simulation in the artificial intelligence community.

In Structure Behavior and Function model, structure is expressed as components, the elements involved in the components, and the relation between the components. The characterization of a component consists of functional concepts, where each component contains numerous functions.

Function is described in various ways, however the common problem is the confusion and mixed used of behavior and function. Function can be defined as a design which indicates its pre and post conditions. The function design has an association to the behavior that realizes the function. The design may also indicate the factors under which the stated behavior accomplishes the given function.

Behavior is expressed as changeovers and states, and the relation amidst them. In behavior, every state is defined through the origins of the transition. Structural constraints, physical laws, subsystem functions, mathematical laws are some of the reasons for the state changeovers.

# Chapter 2 Problem Statement, Goal and Objectives

## 2.1 Problem statement

Building Information Modelling (BIM) and 3D modelling are commonly used in construction and many other industries. However, gaming combined with 3D visualization has not been used as a tool to learn mechanical systems.

This thesis attempts to test the hypothesis that “a 3D gaming model is a viable and valid tool in learning HVAC Systems”, and that “a 3D game is more useful for learners in visualizing and understanding HVAC Systems, compared to traditional teaching methods”.

## 2.2 Goals

- To develop an HVAC 3D game, which allows learners (students and/or professionals) to understand the system thoroughly, just as they would in a physical setting.
- To test and evaluate the HVAC 3D game in a classroom setting, to understand the effectiveness of its use in learning.

Game engines in combination with 3D modeling tools have been used in areas such as science, engineering and technology; have proven useful in improving the learning process.

There are many advantages of using 3D models over 2D drawings.

- The 3D models which are closer to real world scenarios help to better understand the mechanical systems.
- 3D models can be used in larger scale of audience at different places.
- It can be understandable to anyone with minimum knowledge of the interface.

### 2.3 Objectives

The objectives of this thesis are:

- To understand the use of 3D game engines as a learning tool.
- To develop a 3D game model of UNL Multicultural center with mechanical systems using the tools Autodesk Revit 2014, Trimble SketchUp, Autodesk 3Ds Max and Unity 3D.
- To evaluate the effectiveness of the 3D game model in learning HVAC systems - using student presentations followed by a structured quiz.

# Chapter 3 Methodology

## 3.1 Selection of Software

There are a lot of 3D modeling and gaming tools available today, each with its own advantages. The selection of gaming tool was an important step in achieving the goals and fulfilling the objectives of this thesis.

Tools selected for this thesis are:

- A three dimensional modeling tool with the ability to model a building and its mechanical system (duct system) in detail; Autodesk Revit was selected to develop the three dimensional model.
- A tool to model mechanical equipment with all of the components in its internal structure. Trimble SketchUp and Autodesk 3ds Max were chosen to model the internal components in detail and lastly,
- A tool to develop the necessary interactive environment and implement the concept of gaming within the 3D model. Unity 3D was selected as a gaming tool, since prior studies have identified that it has the capabilities of 3D, cross platform functionality in BIM exporting models, and it supports multiple operating systems (SHEN et al. 2012).

The following sections outline the capabilities/advantages of the tools that were selected for this thesis.

### 3.1.1 Autodesk Revit

- Offers the capability to design a building with its structure and components such as Mechanical, Electrical and Plumbing (MEP) in 3D.
- A vigorous collaboration tool among various disciplines and software tools.
- Existing or imported geometric models can be used as part of modeling the structure, such as ducts and equipment.
- User has the ability to create and manipulate system families, and loadable families.

### 3.1.2 Trimble SketchUp

- Very simple to use and can be learned in a short amount of time.
- Software is “free to use” and downloads of the program are easy accessible.
- Has Google 3D warehouse with community sharing of user built models.
- Import and export of the SketchUp models is easy and fast.

### 3.1.3 Autodesk 3ds Max

- Has the necessary capabilities of 3D modeling and polygon size of the model created in Revit can be reduced using a plugin called Polygon cruncher.

### 3.1.4 Unity 3D

- The game engine is meant for cross-platform game creation system, and can be utilized to create games for mobiles, consoles, desktops and websites.
- Programming the game engine can be mastered quickly.
- There are inbuilt "assets", such as character control, which make the workflow easy to handle.
- Scripting can be conveniently done using JavaScript (JS) or C Sharp (C#).

## 3.2 Workflow

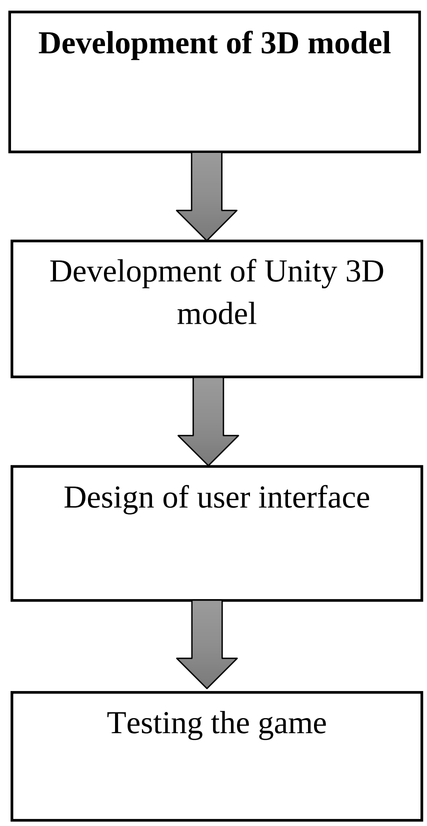



Figure 3.1 – The Workflow

### 3.2.1 Step 1 – Development of 3D model

The first step in developing a 3D game is to create multiple 3D models including: a 3D architectural and mechanical model of a building with all the architectural and mechanical elements and individual equipment. The detail to which the building was modeled depended upon the level of details available such as contract documents. It also depended on what was a “good enough” level of detail for gaming visualization.

The individual equipment models were modelled with all the major components within the equipment structure, so that the working mechanism of the equipment may be effectively demonstrated. An example of an air handling equipment with its major components is shown in figure 3.2.


Figure 3.2 – Air handling unit with Components.

### 3.2.2 Step 2 – Development of Unity 3D model

The second step in the workflow is to create a single robust model in Unity3D by combining: the architectural model, mechanical model and models of individual equipment. Unique graphical representations have been used to simulate functional effects in the model. To achieve this, several different methods in Unity 3D were used to design and simulate the operational conditions of equipment individually and as a whole. For instance, Particle System and iTween was used to simulate air movement within the equipment and duct system of the building. An example of an air handling equipment included with iTween effect to show the air movement is shown in figure 3.3.

Several simulations were designed to demonstrate the operational conditions of equipment: water, steam, flue, fire etc. The graphical effects for all of these conditions were selected with the intention of achieving differentiation that is understandable at a glance.

Figure 3.3 – Air Handling Unit showing air movement with particle effects using iTween.

### 3.2.3 Step 3 – Design of user interface

The third step of the workflow was to design an interactive user interface. This was the last and most critical step in making game a learning tool. Demonstration of equipment with all of its internal components was essential, and was achieved by simulating multiple (camera) views of the model such as: front and side elevations; lateral and orthogonal views; as well as location based perspectives. The 3D building model as a whole needed user-controlled walkthroughs that allowed movement within the building (so the user could move from one place to another). This was achieved by the use of character controllers and multiple camera views. Call-out and display text was used to indicate multiple camera and user options that allow a user to control the system. Typical user interface in the Unity 3D game is shown in figure 3.4.


Figure 3.4 – Variable Air Volume (VAV) unit scene user interface.

### 3.2.3 Step 4 – Testing the game

Once the 3D game and a user-operable interface were in place, the game was then tested with two selected group of students using Unity 3D model and 2D presentations followed by a structured quiz. This was the final step in testing the hypothesis of the thesis that a 3D game is more useful for learners in visualizing and understanding HVAC Systems, compared to traditional teaching methods”.

#### 3.2.3.1 Quiz design and content

The questions in the quiz were designed to evaluate subject’s understanding of (a) function (b) structure and (c) behavior. It was essential to understand the viability and validity of the 3D game, as it specifically relates to a learner’s understanding of:

- The equipment, its primary components and their interrelationship,
- The primary purpose of the system, and of its individual components,
- The functional mechanisms of the system and individual components.

Each test subject was asked to answer a total of thirteen (13) questions: consisting of four (4) functional questions, four (4) structural questions, and five (5) behavioral questions. The quiz format consisted of (a) multiple choice questions, (b) Input and Output questions, and (c) flowchart questions.

**Questions based on understanding of function:**

The first four questions of the quiz (Questions 1 – 4) were designed to evaluate (subject's understanding of) function, with each question carrying eight points. These questions are based on concept of an "Input and Output model", and subjects were expected to answer the possible Inputs and Outputs of given mechanical equipment.

- Questions 1 & 2: had eight answers each, and evaluated (subject's understanding of) the Variable Air Volume (VAV) unit and the Air Handling Unit (AHU). Each correct answer was recorded as one point, for a total of eight points.
- Questions 3 & 4: had four answers each and evaluated (subject's understanding of) the cooling tower and the boiler. Each correct answer was recorded as two points, for a total of eight points.

**Questions based on understanding of structure:**

The next four questions (Questions 5 – 8) were designed to evaluate (subject's understanding of) structure, with each question carrying six points. These questions were designed based on the concepts of a "flow chart model" or "concept map model", and subjects were asked to draw flow charts for given mechanical equipment, its major components, their inter-connectivity, and source of input/output.

- Question 5: had six answers and evaluated (subject’s understanding of) the VAV unit, which consists of three components, two sources and a single connectivity. Each correct answer was recorded as one point.
- Question 6: had six answers and evaluated (subject’s understanding of) the air handling unit (AHU), which consists of six major components. Each correct answer was recorded as one point.
- Question 7: had six answers and evaluated (subject’s understanding of) the makeup air unit (MAU), which consists of five major components. Each correct component was recorded as one point and accurate identification of connectivity is recorded as one point.
- Question 8: had six answers and evaluated (subject’s understanding of) the cycle of cold water supply to the AHU, which has a total of five components. Each correct answer for each component was recorded as one point; and an accurate identification of circulation loop was recorded as one point.

**Questions based on understanding of behavior:**

The next five questions (Question 9-13) were designed to evaluate (subject’s understanding of) behavior, with each question carrying three points. These five questions were “multiple choice” questions.

- Questions 9 & 11 & 13: had one answer each and evaluated (subject's understanding of) system behavior. Each correct answer was recorded as three points.
- Questions 10 & 12: had three answers each and evaluated (subject's understanding of) system behavior further. Each correct answer was recorded as one point.

Data gathered from the quiz was subjected to descriptive analysis. The methods employed for analysis were "Determination of Group Means" and "Independent T-test".

**Questions to evaluate prior knowledge of test subjects:**

In addition to the structured Quiz, each student was given a set of background questions prior to the presentations, to understand each subject's prior knowledge of mechanical systems. Specifically:

- Working experience with HVAC systems, be it designing HVAC systems or installing the systems.
- Subject's own rating of individual knowledge about the HVAC systems as excellent, very good, good, fair and poor.

Background questions were further analyzed to understand for any margin of error in results, due to the subject's prior knowledge.

Further, at the end of presentation and test with Group 1 – Unity 3D group, subjects were asked to rate their general experience using the 3D game as a learning tool for HVAC systems. Rating for this question was based on a scale of 1 – 5, 1 being "least" and 5 being "best".

# Chapter 4 Implementation

As discussed in Chapter 3, a total of four major steps were involved in fulfilling the objectives of this thesis: Development of 3D model; Development of Unity 3D model; Design of a user interface; and testing the model. This Chapter elaborates further on these four steps from an implementation standpoint.

## 4.1 Development of 3D model

The first step in the workflow was to create the 3D architectural and mechanical models of the Jackie Gaughan multicultural center of University of Nebraska, which is located in Lincoln, Nebraska. The location of the building is shown in figure 4.1. Figure 4.2 shows the front view of the building.

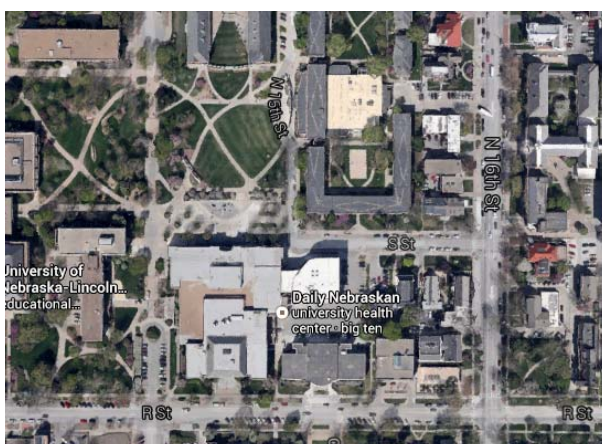



Figure 4.1 – Location of the Multicultural center.


Figure 4.2 – Picture showing the Multicultural center.

Contract documents were utilized to model the building in Revit 2014. This building is a mixed (Business & Assembly) occupancy group, four level structure including basement. It has three levels with an actual area of 34,313 square feet and allowable area of 166,500 square feet. Cold water for mechanical equipment is pumped by a central chiller plant and steam is generated by a central steam plant. To show the inter-connectivity of mechanical equipment, the game was modelled with boiler and chiller unit within the building in place of central chiller plant and steam plant. The architectural (figure 4.3) and mechanical (Figure 4.4) models were created in Revit 2014.

Figure 4.3 – Model of the building created in Revit.

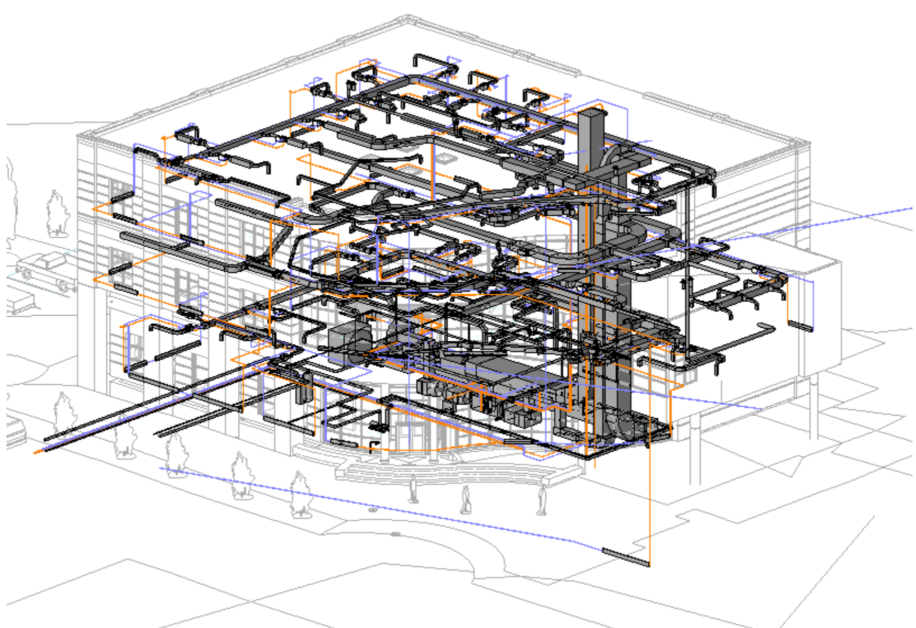


Figure 4.4 - Model of the mechanical system in the building created in Revit.

The mechanical model created in Revit consists of the entire duct system of the building including supply ducts, return ducts, outside air duct with air terminals and variable air volume (VAV) units. For the 3D game, major mechanical equipment's were selected as a representation of the overall mechanical system in a typical building. These systems include air handling unit (AHU), makeup air unit (MAU), rooftop unit (RTU), VAV unit (Heating only), cooling tower, chiller, and boiler. These individual equipment models were developed in SketchUp, since SketchUp consists of a vast models library. These models are further developed in 3D max with all the components necessary for the 3D game. Many equipment models with necessary components were developed directly in 3D Max. Figure 4.5 shows a block model of MAU developed in SketchUp.

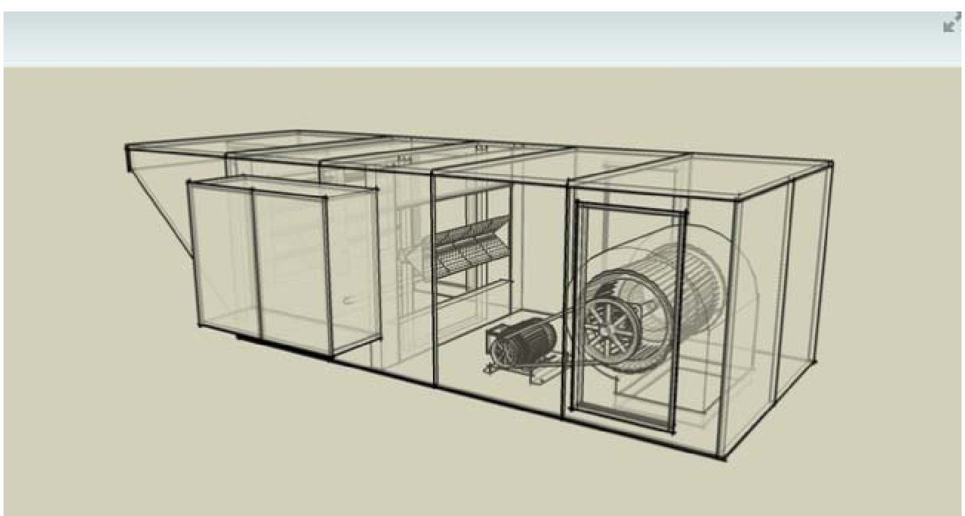


Figure 4.5 - Makeup air unit developed in SketchUp.

### 4.2. Development of Unity 3D model

In Unity 3D, each object or model is measured by polygon count. Polygon count is the number of polygons or faces rendered per object. For web based games, most gamers prefer a maximum of 40,000 polygons. The Revit models (architecture and mechanical models) approximately had 200,000 polygons – a very high polygon count to develop further in Unity 3D. For this reason, the Revit models were exported to 3DS Max to reduce polygon count using a plugin called Polygon Cruncher - a plugin that reduces the number of polygons without reducing visual quality. The plugin reduced Polygon count by 40% to 120,000 pixels! The tools used in simulating the operational mechanism of the system are discussed below.

#### 4.2.1 Particle Systems

In Unity 3D, Particle system was used to simulate the effects of fluidity such as smoke, flames, clouds, and flowing liquids. Particles are small images or objects circulated in huge numbers to achieve a realistic simulation. Particle system is utilized to simulate flue and air movement in mechanical equipment and ductwork of the game model. Figure 4.5 shows the air movement using particle system in a VAV unit.

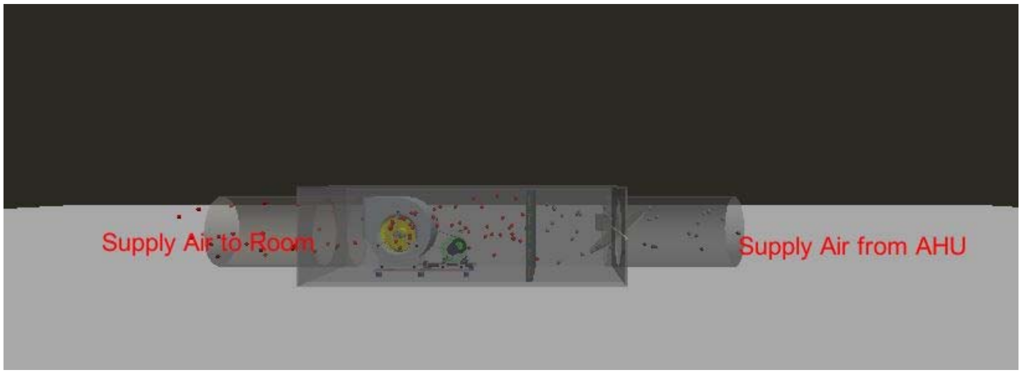



Figure 4.5 - VAV unit displaying the particle system.

### 4.2.2 Default water package

To realistically simulate the effect of water flowing through pipe lines connected to the equipment, a default prefab water package was used in Unity 3D. Hot and cold water is then differentiated with the use of colored red (for hot) and blue (for cold) textures. Figure 4.6 shows the simulation of hot and cold water pipes connected to chiller.

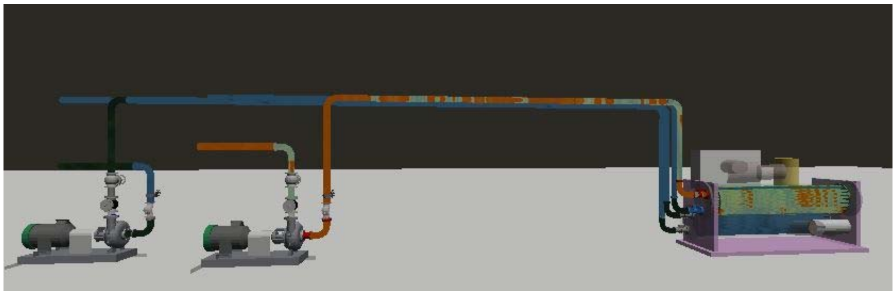


Figure 4.6 - Chiller unit pipe line displaying water package effect.

### 4.2.3 Skybox

The skybox rendering component is used to simulate clouds over the building. Skybox is a rendering component within Unity 3D, which creates an envelope of clouds over the entire scene. Figure 4.6 shows the exterior of the building with clouds.

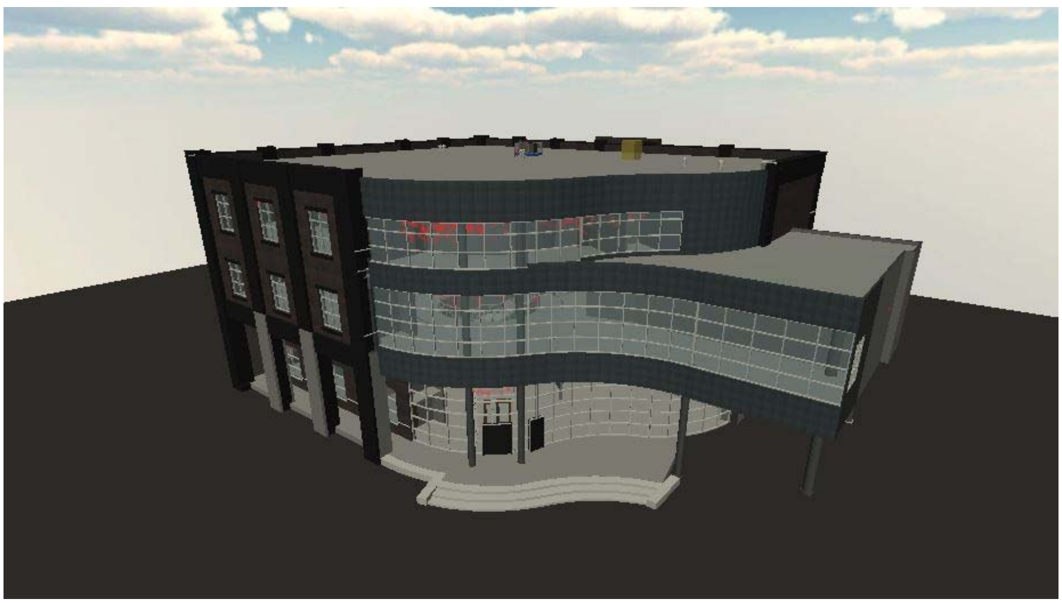


Figure 4.7 - Exterior building view displaying the cloud effect.

## 4.3 Design of User Interface

The interface of the game is designed to allow users complete access to the model, and to keep it user friendly and easy to learn. The options available to users are categorized into five segments: operation, cameras, details, buildings and text. Operations tab allows users operate equipment in multiple modes. Cameras tab is provided to view the equipment at multiple elevations with a provision for walkthroughs. Details tab allows users to view images and flow charts related to the equipment. Building tab is used to access and select other related equipment. Text tab is used to display the technical details of equipment. These options and menus were developed using GUI text option in Unity 3D. GUI text is a 2D text used to display text on screen and is controlled by scripting. Figure 4.8 shows the user interface of the game.

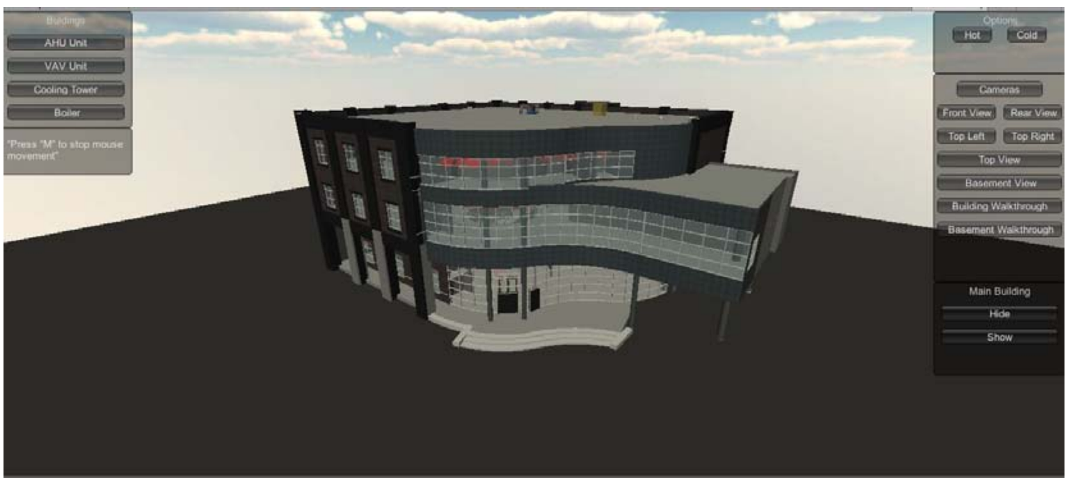



Figure 4.8 – The user interface of the game.

Access and navigation from one place to another was necessary to view mechanical equipment at different areas of the building. This was achieved by the use of "First Person Controller" of the character controller game component. First person controller is a capsule shaped collider that can be directed to move in any direction using a background script.

### 4.4 Testing – Participants and Methodology

The main purpose of the test is to understand if the game is more useful for the learners, in visualizing and understanding equipment compared to traditional teaching methods.

#### 4.4.1 Participants

A total of 45 students (in two separate sessions) in Construction Engineering Program "Course CNST-305 – Building Environmental Technical System – I" participated in this study. During the course period, students learned about various topics related to mechanical systems. The evaluation was conducted in fall 2014 from August to December. The sections related to mechanical systems covered from August to the date of quizzes conducted are human comfort; indoor air quality (IAQ) fundamentals and strategies; ventilation; psychrometrics; heat loss calculation methods, ventilation & infiltration; heat gain – conduction, solar & ventilation; air conditioning systems – refrigeration, direct expansion, chilled water, constant volume, variable air volume, split systems, central systems.

The learning objectives of the above sections are to:

1. Learn how to conduct a site visit.
2. Predict and solve air – water problems.
3. Understand the terms of air-conditioning systems.
4. Comprehend how and why air-conditioning systems operate.

5. Identify the various types of air-conditioning systems and understanding the advantages and disadvantages of each system.

### 4.4.2 Methodology

Two groups of students are selected to test the game. The first group (Group 1) of 24 subjects was introduced to the 3D game. The presenter showed how to access the game for ten minutes and then the students accessed the 3D game in the laptops provided for each individual for the next ten minutes. Later a structured quiz was conducted to understand the results. The second group (Group 2) of 21 subjects learnt about the systems using traditional classroom teaching methods. A PowerPoint presentation about all the systems was designed using flow diagrams and presented to the class for twenty minutes and later quiz was conducted.

An initial set of background questions were used to determine prior knowledge of HVAC systems in both the groups. Subjects with “poor” or “fair” prior knowledge were further divided into separate groups to evaluate if Unity 3D presentation and 2D presentation have an impact on the students with little or no amount of knowledge of HVAC systems.

In Group 1 – Unity 3D Group, 15 out of 24 subjects rated themselves as having “poor” or “fair” knowledge of HVAC systems. In Group 2 – 2D Presentation Group, 18 out of 21 subjects rated themselves as having “poor” or “fair” knowledge of HVAC systems. An

Independent T-Test was conducted on all the three aspects of function, structure and behavior to evaluate the learning effectiveness using 3D vs. 2D presentations.

# Chapter 5 Results

The results from testing are outlined in this chapter.

**Questions Based on Understanding of Function:**

Questions 1–4 evaluated understanding of function and purpose of mechanical equipment. Each correct answer was recorded as 8 points. The mean score of all four questions is compared between both the groups as shown in Figure 5.1. The mean of scores of subjects in questions based on understanding of function was higher in Group 1 (3.58) compared to Group 2 (3.13). Although the difference seems minimal, it does support the primary hypothesis.

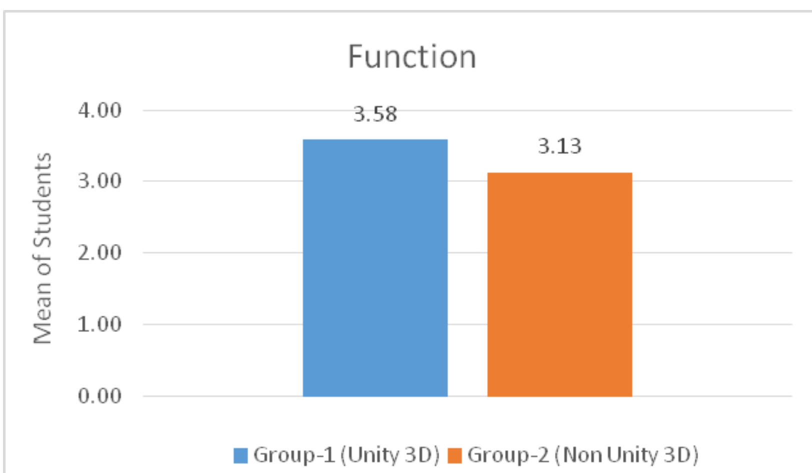



Figure 5.1. - Mean of student responses to function questions.

It should also be noted that, as shown in Figure 5.2, the performance of subjects in Group 1 was slightly better on questions that were designed to test the understanding of system function. The frequency of subjects scoring 3 or fewer points was about the same in both the Groups. However, the frequency of subjects scoring 4 or greater points was substantially higher in Group 1.

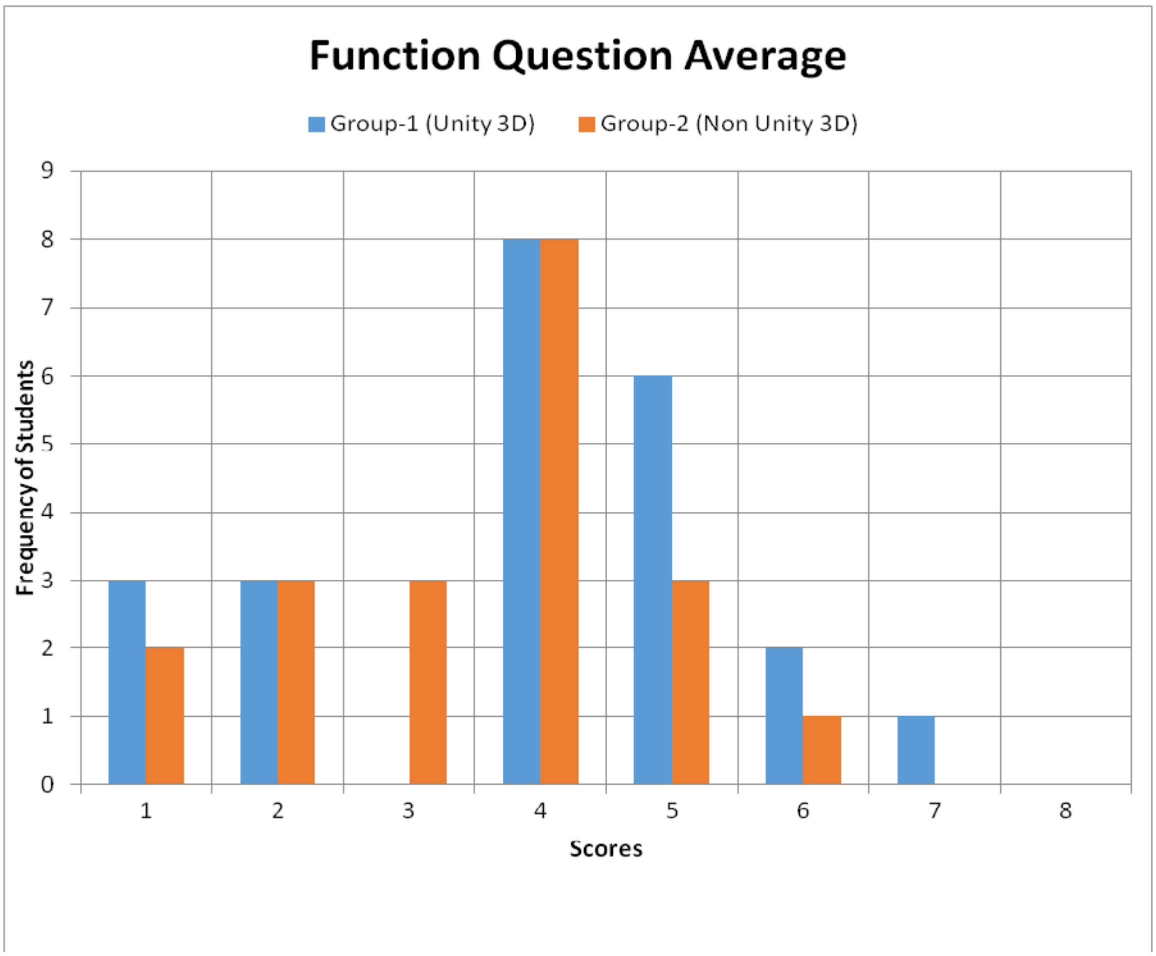



Figure 5.2. – Frequency of scores for function questions average

**Questions based on Understanding of Structure:**

Questions 5–8 evaluated understanding of structure, components and inter-relationship of mechanical equipment's. Each correct answer was recorded as 6 points. The mean of the four questions is compared between both the groups, as shown in Figure 5.3. . The mean of scores of subjects in questions based on understanding of structure was higher in Group 1 (2.10) compared to Group 2 (1.72). Although the difference seems minimal, it does support the primary hypothesis.

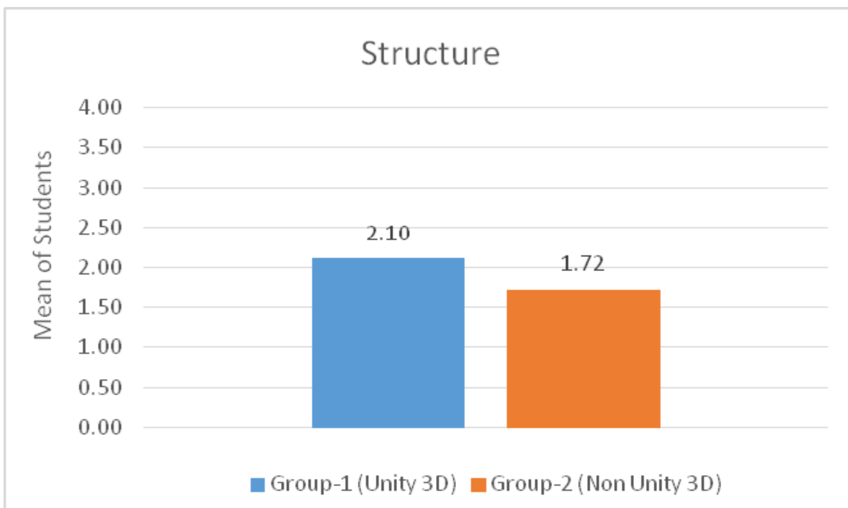



Figure 5.3. - Mean of student responses to structure questions.

The frequency scores of structure questions are shown in Figure 5.4. The graph shows that in both Group 1 and Group 2 most subjects secured one point. Subjects in Group 1 (Unity 3D Group) had higher scores - four and five points out of six points. In comparison, subjects in Group 2 (2D Presentation Group), the highest score was four points.

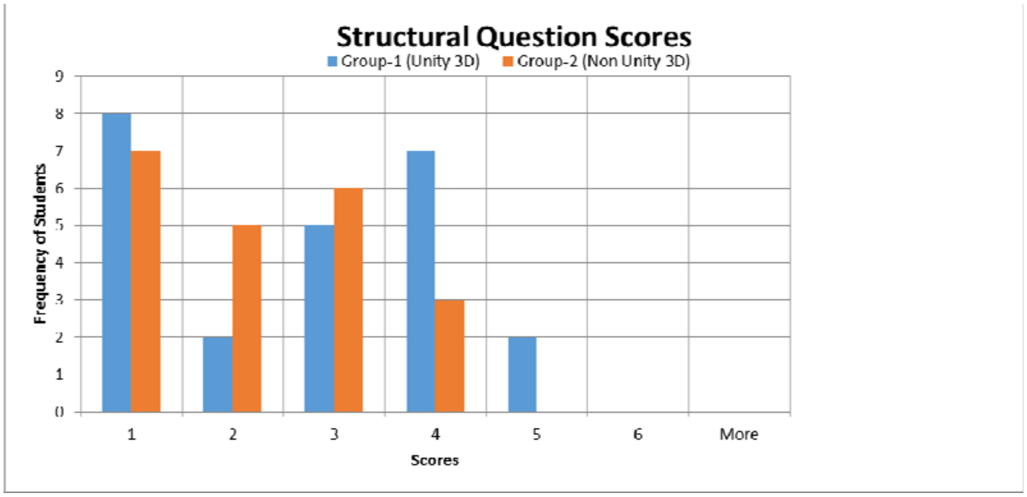



Figure 5.4. – Frequency of scores for structure questions average

**Questions Based on Understanding of Behavior:**

Questions 9–13 evaluated understanding of system behavior – functional mechanism of mechanical equipment. Each correct answer was recorded as 3 points. The mean of the five questions is compared between both the groups, as shown in Figure 5.5. . The mean of scores of subjects in questions based on understanding of behavior was higher in Group 2 (1.00) compared to Group 1 (0.93).

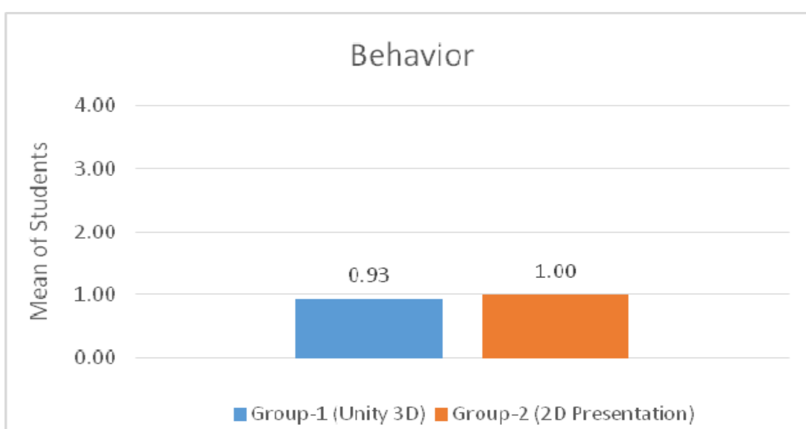



Figure 5.5. - Mean of student responses to behavior questions.

The frequency scores of behavior questions are shown in Figure 5.6. The graph shows that in both Group 1 and Group 2 most subjects secured one point. While subjects in Group 1 (Unity 3D Group) secured two/three, no subject in Group 2 (2D Presentation Group) secured the highest score of 3 points.

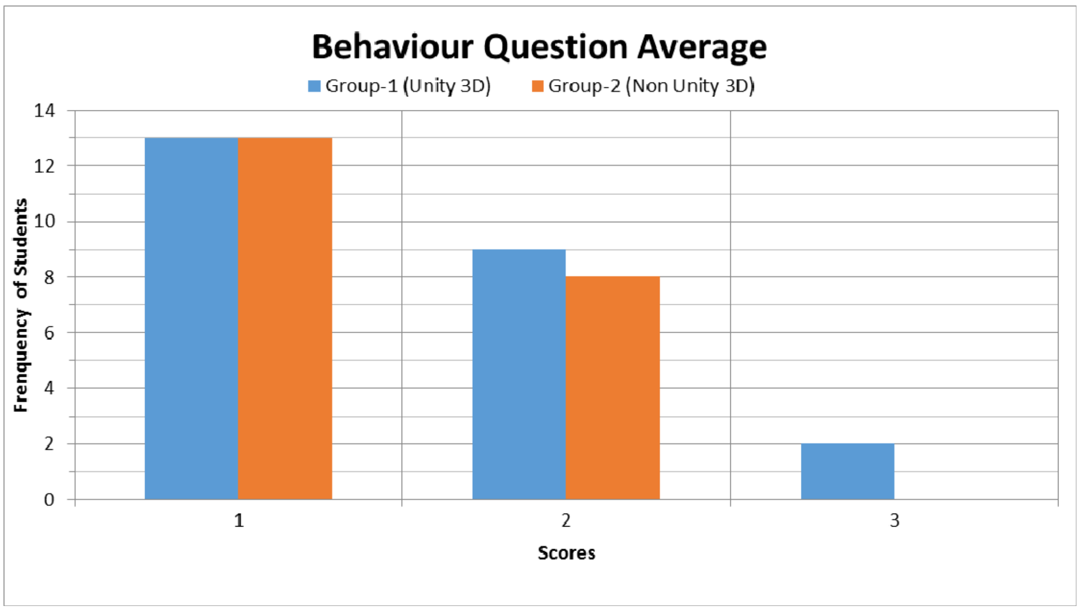



Figure 5.6. – Frequency of scores for behavior questions average

In the first test, an Independent T-test for all the three models “Function, Structure and Behavior” is conducted using both the groups. The statistics of both the groups are shown in Table 5.1. Results of Independent T-test are shown in Table 5.2.

TABLE : 5.1 - Test 1 - Statistics of Two Groups

| | Group | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Q1to4Average | 1 | 24 | 3.583 | 1.602 | .327 |
| | 2 | 21 | 3.130 | 1.286 | .280 |
| Q5to8Average | 1 | 24 | 2.104 | 1.572 | .321 |
| | 2 | 21 | 1.719 | 1.233 | .269 |
| Q9to13Average | 1 | 24 | .933 | .684 | .139 |
| | 2 | 21 | 1.000 | .529 | .115 |

TABLE : 5.2 – Test 1 - Independent T-test Results

| | | Levene's Test for Equality of Variances | | T-test for Equality of Means | |
|---|---|---|---|---|---|
| | | F | Sig, (p-Value) | t | df |
| Q1to4Average | Equal variances assumed | 1.079 | .305 | 1.034 | 43 |
| | Equal variances not assumed | | | 1.050 | 42.708 |
| Q5to8Average | Equal variances assumed | 1.793 | .188 | .904 | 43 |
| | Equal variances not assumed | | | .919 | 42.529 |
| Q9to13Average | Equal variances assumed | 2.876 | .097 | -.362 | 43 |
| | Equal variances not assumed | | | -.368 | 42.402 |

By analyzing the group means of all the three variables - function, structure and behavior, there is a variance in function and structure groups where the mean score of subjects in Group 1 (Unity 3D Group) is higher than those of subjects in Group 2 (2D Presentation Group). Where as for behavior questions, the mean score of Group 2 (2D Presentation Group) is higher than Group 1 (Unity 3D Group).

In testing the hypothesis, P-values of the Independent T-test prove that there was no significant difference or improvement in scores when a class was taught with Unity 3D model. One reason for insignificant results could be a low sample size, with 24 student subjects in Group 1 (Unity 3D Group) and 21 student subjects in Group 2 (2D Presentation Group). Another reason could be that these were controlled groups of Construction and Architectural Engineering students – student subjects already had a fair amount of knowledge about HVAC systems. If the test were conducted again with a random group of students with bigger sample size, there may be a difference in the results.

A second independent T-test was conducted based on background questions where two different groups were selected consisting of 15 student subjects (from Group 1) and 18 student subjects (from Group 2) who rated themselves as having “poor” or “fair” prior knowledge of the HVAC systems. The Independent T-test for all the three variables (Function, Structure and Behavior) was conducted using both these new groups. The statistical results of both the groups are shown in Table 5.3. Results of Independent T-test are shown in Table 5.4.

TABLE: 5.3 – Test 2 - Statistics of Two Groups

| Group | | N | Mean | Std. Deviation | Std. Error Mean |
|---|---|---|---|---|---|
| Q1to4Average | 1 | 15 | 3.350 | 1.841 | .475 |
| | 2 | 18 | 3.055 | 1.376 | .324 |
| Q5to8Average | 1 | 15 | 2.200 | 1.648 | .425 |
| | 2 | 18 | 1.736 | 1.214 | .286 |
| Q9to13Average | 1 | 15 | 1.000 | .807 | .208 |
| | 2 | 18 | .966 | .554 | .130 |

TABLE: 5.4 – Test 2 - Independent T-test Results

| | | Levene's Test for Equality of Variances | | t-test for Equality of Means | |
|---|---|---|---|---|---|
| | | F | Sig. | t | df |
| Q1to4Average | Equal variances assumed | 3.693 | .064 | .525 | 31 |
| | Equal variances not assumed | | | .512 | 25.513 |
| Q5to8Average | Equal variances assumed | 2.626 | .115 | .930 | 31 |
| | Equal variances not assumed | | | .904 | 25.281 |
| Q9to13Average | Equal variances assumed | 4.282 | .047 | .140 | 31 |
| | Equal variances not assumed | | | .136 | 24.097 |

The independent T-test results show that there is significant difference or improvement in scores when the test is done with student subjects with “minimum knowledge” of HVAC systems. In the case of behavior questions (questions 9 – 13), there was a 95% confidence interval when a class was taught using 3D Unity model. For functional questions (questions 1 – 4), even though P- value is greater than 0.05, it is really at the ending of the value, which could be considered as significant enough, at 90% confidence interval, considering the sample size. The test did not show any significant improvement or difference in scores on structure questions (questions 5 – 8) when a class was taught using Unity 3D model. These results indicated that there is a significant improvement in understanding of system function and system behavior, when a class is taught with Unity 3D model compared to traditional teaching using 2D presentations. However, the no significant difference was found between the two groups on system structure knowledge.

The results of the review question that asked subjects to rate their experience using Unity 3D as a learning tool showed an average of 3.5 (1 being least and 5 being best). This shows that students believe Unity 3D gaming tool is a “viable” learning tool for mechanical systems.

# Chapter 6 Conclusions

## 6.1 Summary conclusions

Due to recent growth in gaming technology, it is now possible to take advantage of game engines and improve the visual learning approach in educational training. Prior Research has shown that virtual environments can enhance the student learning experience. Building Information Modelling (BIM) and 3D modelling are commonly used as learning and professional tools in the construction industry. However, gaming combined with 3D visualization has not been used as a tool to learn mechanical systems.

This thesis attempts to test the hypothesis that “a 3D gaming model is a viable and valid tool in learning HVAC Systems”, and that “a 3D game is more useful for learners in visualizing and understanding HVAC Systems, compared to traditional teaching methods”. A 3D game of HVAC system in a building was developed, primarily using Revit, 3D Max and Utility 3D, for the purpose of testing this hypothesis. Two controlled groups (Group 1, was taught using Utility 3D as a learning tool; and Group 2 was taught using Traditional 2D Presentations) were tested to verify the hypothesis.

The two Groups were tested for understanding of core concepts presented to them. Three key variables of subject understanding were measured – understanding of structure, function and behavior of HVAC system.

The following is a bulleted list of key conclusions:

**Results from the Test - Analysis of All Subjects**

An initial analysis of all subjects (inclusive of subjects that declared prior knowledge of systems) that took the test was conducted to see how the Groups performed overall on the test.

- **Performance Based on Understanding of Function:** Subjects in Group 1 performed substantially better on quiz questions about understanding of function. In Group 1, 7 out of 24 subjects scored full points (8 Points) for at least one question out of the four questions. In Group 2, 3 out of 21 subjects scored full points (8 Points) for at least one question out of the four questions. Based on an average score, 9 out of 24 subjects scored more than 4 points in Group 1 whereas 5 out of 21 subjects in Group 2 scored more than 4 points.

- **Performance Based on Understanding of Structure:** Subjects in Group 1 performed substantially better on quiz questions about understanding of structure. In Group 1, 8 out of 24 subjects scored full points (6 points) for at least one question out of the four questions. In Group 2, 1 out of 21 subjects scored full points (6 points) for at least one question out of the four questions. Based on an average score, 9 out of 24 subjects scored more than 3 points in Group 1 whereas 4 out of 21 subjects (6 points) scored more than 3 points.

- **Performance Based on Understanding of Behavior:** Subjects in Group 2 performed slightly better on quiz questions about understanding of behavior. In Group 1, 17 out of 24 subjects scored full points (3 points) for at least one question out of the five questions. In Group 2, 17 out of 21 subjects scored full points (3 points) for at least one question out of the five questions. Based on an average score, 6 out of 24 subjects scored more than 1.5 points in Group 1 whereas, 4 out of 21 subjects in Group 2 scored more than 1.5 points.

- **Performance Overall:** On the whole, analysis of controlled Groups (inclusive of subjects that had prior knowledge of HVAC systems) showed an inconclusive difference in overall subject understanding. The results based on subject's performance, however, showed a substantial improvement in subject learning of function and structure using Unity 3D game, as compared to using traditional teaching methods using 2D Presentations.

- **End Statement for Practical Applications:** An important conclusion is that teaching using Unity 3D seems to contribute significantly to subject understanding of function and structure. A scenario where the teacher feels it important for students to learn function and structure of a system, a 3D game would be a better teaching tool compared to traditional methods.

**Results from the Test - Analysis of Subjects without Prior Knowledge**

A second analysis was conducted factoring in prior knowledge of test subjects. This independent T – test was conducted on student subjects that rated their prior knowledge of HVAC systems as “poor” or “fair”.

- **Performance Based on Understanding of Function:** Subjects in Group 1 performed substantially better on quiz questions about understanding of function. In Group 1, 6 out of 15 subjects scored full points (8 points) for at least one question out of the four questions. In Group 2, 3 out of 18 subjects scored full points for at least one question out of the four questions. Based on an average score, 7 out of 15 subjects scored more than 4 points in Group 1 whereas 5 out of 18 subjects in Group 2 scored more than 4 points.

- **Performance Based on Understanding of Structure:** Subjects in Group 1 performed substantially better on quiz questions about understanding of structure. In Group 1, 5 out of 15 subjects scored full points (6 points) for at least one question out of the four questions. In Group 2, 1 out of 18 subjects scored full points (6 points) for at least one question out of the four questions. Based on an average score for the four questions, 7 out of 15 subjects scored more than 3 points in Group 1 whereas 3 out of 18 subjects in Group 2 scored more than 3 points.

- **Performance Based on Understanding of Behavior:** Subjects in Group 1 performed well on quiz questions about understanding of behavior. In Group 1, 10 out of 15 subjects scored full points (3 points) for at least one question out of the five questions. In Group 2, 14 out of 18 subjects scored full points (3 points) for at least one question out of the five questions. Based on an average score for the five questions, 6 out of 15 subjects scored more than 1.5 points in Group 1 whereas 3 out of 18 subjects in Group 2 scored more than 1.5 points.

- **Performance Overall:** The results from this analysis (of subjects without prior knowledge of systems) conclusively showed that use of Unity 3D as a learning tool significantly improved subject understanding of HVAC systems, compared to the use of traditional 2D presentations as a teaching method. The results specifically showed a significant difference or improvement in subject understanding of function and behavior of HVAC systems, when taught using the Unity 3D tool. However, subject understanding of structure showed little difference.

- **End Statement for Practical Applications:** An important conclusion from the second analysis is that teaching using Unity 3D seems to contribute significantly to subject understanding of function and behavior. A scenario where the teacher feels it important for students to learn function and behavior of a system, a 3D game would be a better teaching tool compared to traditional methods.

## 6.2 Recommended Direction for Future Research

The following are a few recommended directions for future research in the area, base on the experience derived from this thesis:

- Researchers in this area should test the model with more precise testing methods, a larger sample size, and a random selection of test subjects (with limited or no knowledge of HVAC systems) to accurately understand whether 3D games are better learning tools (compared to traditional learning methods such as 2D presentations and/or on-site lectures and demonstrations).

- It would be a valid next step to analyze construction-engineering curricula (both with the University of Nebraska) and elsewhere in order to determine the "right" subjects and courses that might be conducive to 3D game based learning.

- As computing software and hardware advances are made, there might be more 3D and game development tools that might be used in developing learning games for the construction industry. This tangent of research may also involve development of web-based 3D games.

# References

Allery, L.A., (2004). Educational games and structured experiences. *Medical Teacher* 26 (6), 504–505.

Autodesk Revit. In *Wikipedia*. Retrieved October 10, 2014 from http://en.wikipedia.org/wiki/Autodesk_Revit

Autodesk 3ds Max. In *Wikipedia*. Retrieved October 16, 2014 from http://en.wikipedia.org/wiki/Autodesk_3ds_Max

Beggs, R., (2007). What women want: Investigation into games based learning and serious gaming needs. *Submitted in fulfillment of requirements for MSc in eLearning; Interactive Teaching Technologies*, Jordanstown: University of Ulster.

Cook, N.F., McAloon, T., O'Neill, P., and Beggs, R. (2011). "Impact of a web based interactive simulation game on nursing students' experience and performance in life support training –A pilot study." *Nurse Education.*

Choo, SY., and Phan, VT. (2010). "A combination of Augmented Reality and Google Earth's facilities for urban planning in idea stage. *International Journal of Computer Applications* , 4 (3):26-34, July.

Dede, C. (2009). "Immersive Interfaces for Engagement and Learning". *Science*, 323 (5910), 66-69.

Dunston, P.S., Arns, L.L. & McGlothin, J.D. (2007). An Immersive Virtual Reality Mock-Up for Design Review of Hospital Patient Rooms. In: CONVR 2007.

Eberly, D. (2007). 3D Game Engine Design: A Practical Approach to Real-time Computer Graphics. 2nd ed. San Francisco CA; Oxford, Morgan Kaufmann; Elsevier Science.

GUI Text. Retrieved October 15, 2014 from http://docs.unity3d.com/Manual/class-GuiText.html

Google sketchup. Retrieved October 12, 2014 from http://wikid.eu/index.php/Google_sketchup#Advantages

Goel, A., Rugaber, S., Vattam, S. Structure, behavior and function of complex systems: The SBF modeling language.

Gordon, C.J., Buckley, T., (2009). The effect of high-fidelity simulation training on medical– surgical graduate nurses' perceived ability to respond to patient clinical emergencies. *Journal of Continuing Education in Nursing* 40 (11), 491–498.

Herrington, J., and Oliver, R. (1995). "Critical characteristics of situated learning: Implications for the instructional design of multimedia." ASCILITE '95: *The 12th Annual Conference of the Australian Society of Computers in Learning of Tertiary Education*, University of Melbourne, Melbourne.

How do I use water. Retrieved October 15, 2014 from http://docs.unity3d.com/Manual/HOWTO-Water.html

Jones, I., Handley, A.J., Whitfield, R., Newcombe, R., Chamberlain, D., (2007). A preliminary feasibility study of a short DVD-based distance-learning package for basic life support. *Resuscitation* 75 (2), 350–356.

John I. Messner, David R. Riley, and Michael J. Horman, (2005). AN interactive visualization environment for construction engineering education. *Construction Research Congress* 2005, 1-10.

Messner, J.I., Yerrapathruni, S.C.M., Baratta, A.J., Whisker, V.E., (2003). Using Virtual Reality to Improve Construction Engineering Education. *Proceedings of the 2003 American Society for Engineering Education. Annual Conference & Exposition, American Society for Engineering Education.*

Kiili, K., Lainema, T., (2008). Foundation for measuring engagement in educational games. *Journal of Interactive Learning Research* 19 (3), 469–488.

McLellan, H. (1991). "Situated learning: continuing the conversation." *Educational Technology* 34(10), 39-45.

Natale, M.J., (2002). The effect of a male-oriented computer gaming culture on careers in the computer industry. *Computers and Society* 32 (2), 24–31.

Particle Systems. Retrieved October 15, 2014 from http://docs.unity3d.com/Manual/ParticleSystems.html

Peters, M., (2000). Does constructivist epistemology have a place in nurse education? *Journal of Nursing Education* 39 (4), 166–172.

Polygon (Computer graphics). In *Wikipedia*. Retrieved October 14, 2014 from http://en.wikipedia.org/wiki/Polygon_(computer_graphics)

Polygon Cruncher for 3ds Max. Retrieved October 14, 2014 from http://www.mootools.com/plugins/us/polygoncruncher/3dsmax.htm

Prensky, M., (2001). Digital natives, digital immigrants. *On the Horizon* 9 (5), 1–6.

Ravenscroft, A., Matheson, M.P., (2002). Developing and evaluating dialogue games for collaborative e-learning. *Journal of Computer Assisted Learning* 18 (1), 93–101.

Ricketts, B., (2010). The role of simulation for learning within pre-registration nursing education: A literature review. *Nurse Education Today* 31 (7), 650–654.

Rieber, L. P. (1994). "Visualization as an aid to problem-solving: examples from history." *Proceedings of the National Convention of the Association for Educational Communications and Technology*, Nashville, TN.

Shen, Z., JIANG, L., Grosskopf, K., Berryman, C., (2012). Creating 3D web-based game environment using BIM models for virtual on-site visiting of building HVAC systems. *Construction research congress 2012.*

Unity (game engine). Retrieved October 17, 2014 from http://en.wikipedia.org/wiki/Unity_(game_engine)

Durvasula, V.K. (2012). Integrated 3D visualization to facilitate component-based bridge condition rating.

Wallin, C.J., Meurling, L., Hedman, L., Hedegård, J., Fellander-Tsai, L., (2007). Target-focused medical emergency team training using a human patient simulator: effects on behaviour and attitude. *Medical Education* 41 (2), 173–180.

Warburton, S. (2009). Second life in higher education: Assessing the potential for and the barriers to deploying virtual worlds in learning and teaching. *British Journal of Educational Technology*, 40(3), 414.

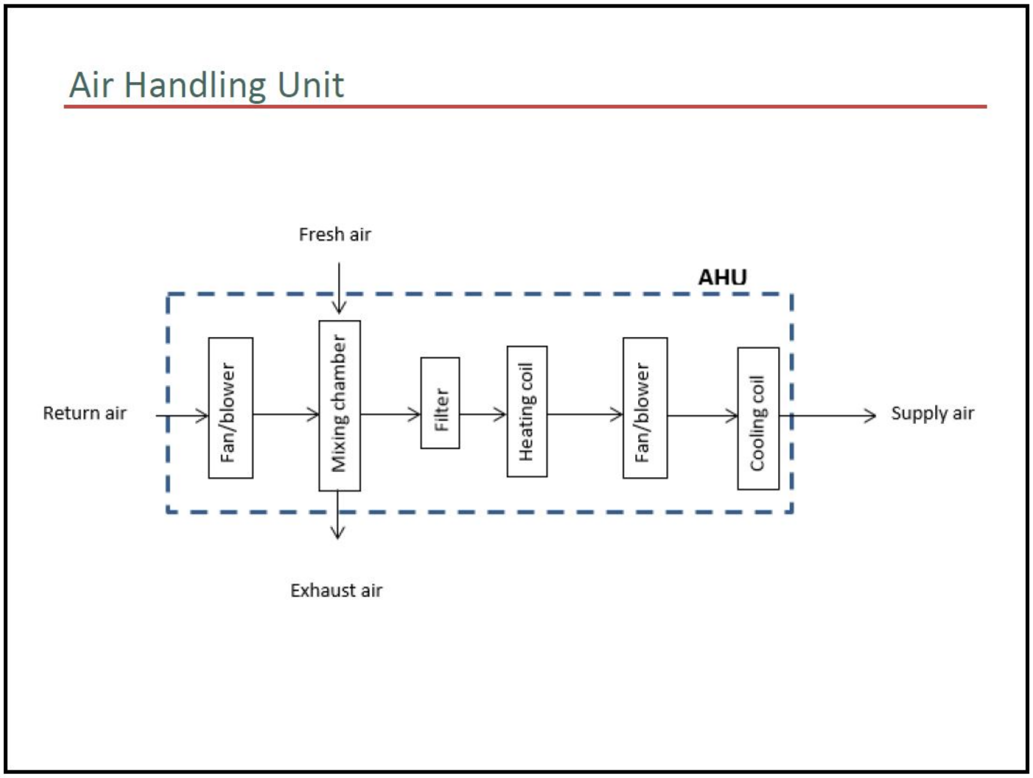
What are the pros and cons of unity game engine. Retrieved October 10, 2014 from http://forum.unity3d.com/threads/what-are-the-pros-and-cons-of-unity-game-engine.240802/

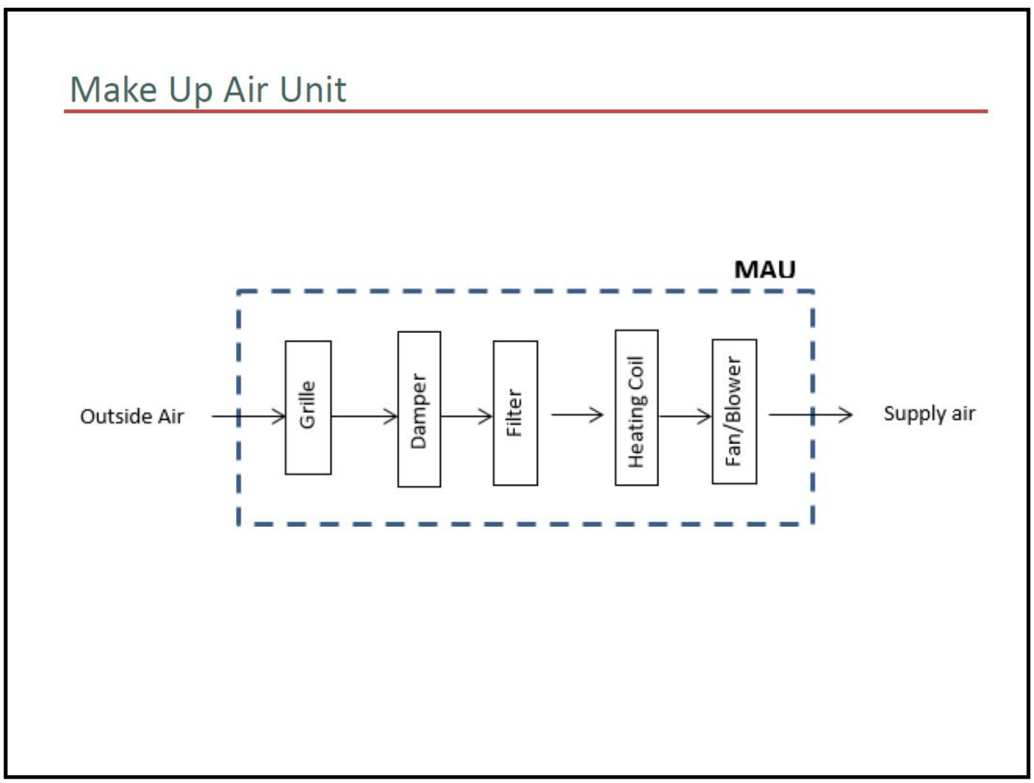
W. Rodenacker. (1971). Methodisches Konstrueieren. Springer Verlag. Berlin.

Zhang, W.J., Lin, Y., Sinha, N., On the function–behavior-structure model for design.

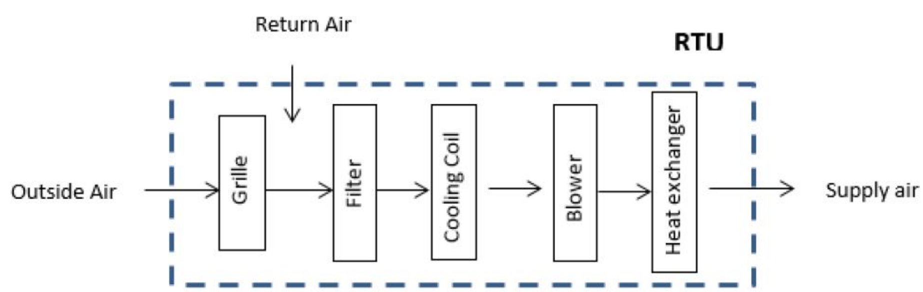
Zhu, Y., Shen, Z., Applying Structure, Behavior and Function (SBF) and discrete event modelling to construction education: a Pilot Study.

# Appendix 1 – 2D presentation slides

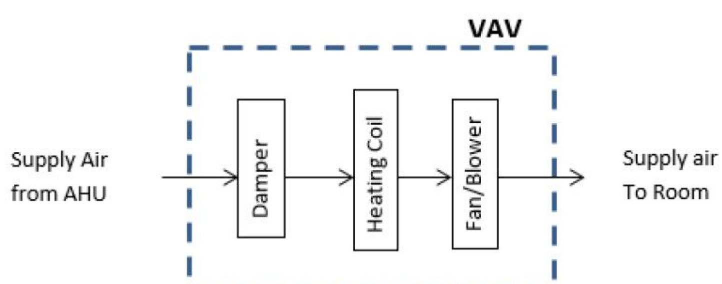


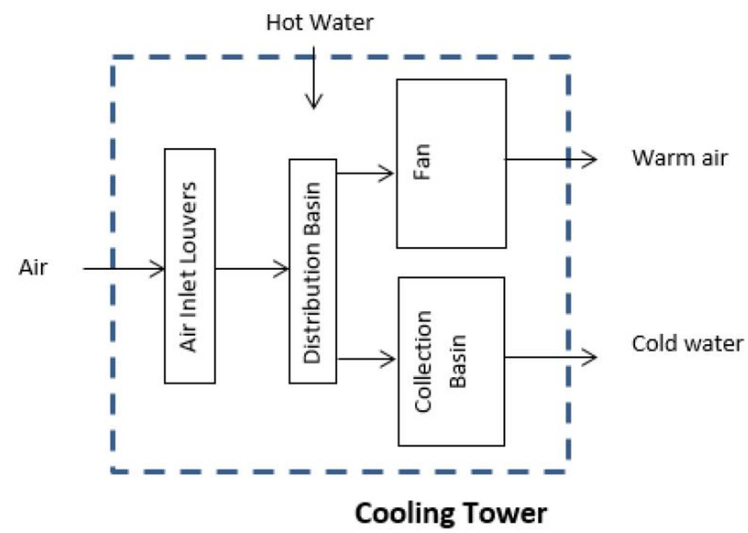
## Rooftop Unit



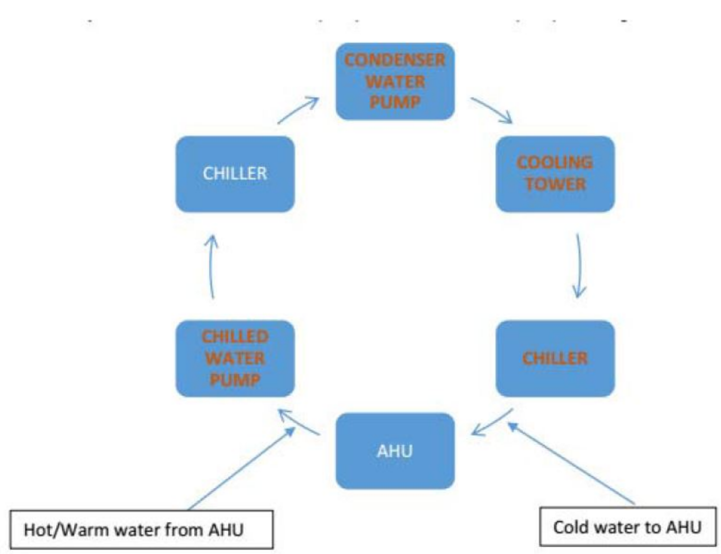

## Variable Air Volume Unit



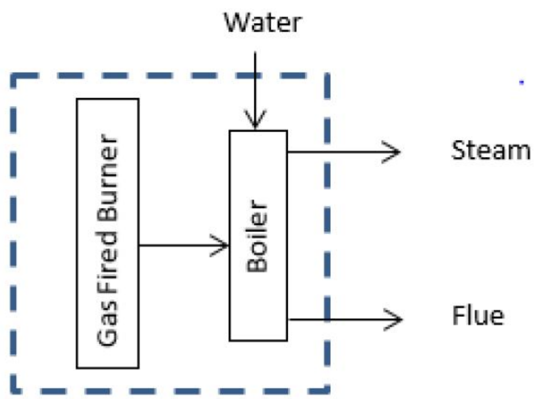
## Cooling Tower



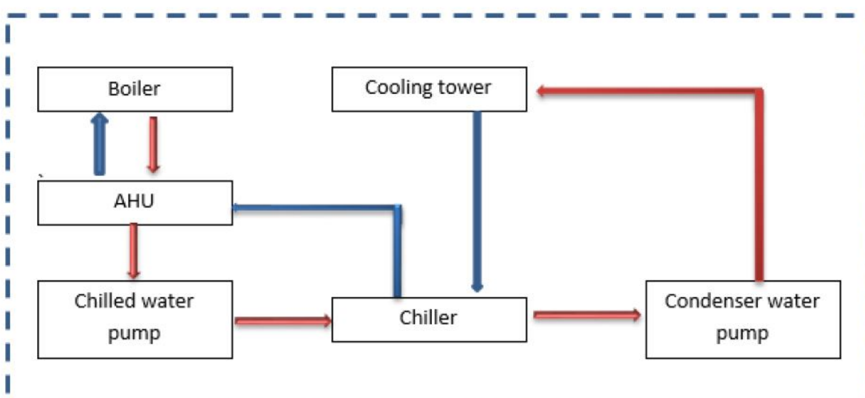

## Chiller



## Boiler




## Overall system



# Appendix 2 – Questionnaire

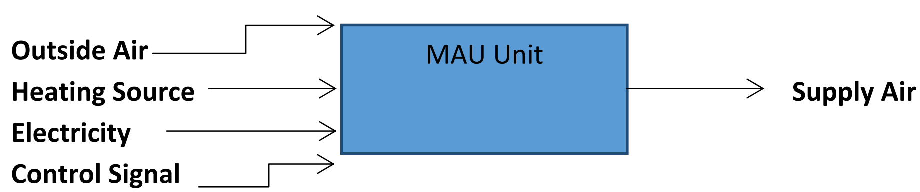
**FUNCTION:**

**Example:** Makeup Air Unit (MAU) Input and output model.

Direction: Please fill out the Input and output sources that are correct for a MAU unit from the list of options below.

**Options:** Heating source, cooling source, desired temperature, desired volume, Supply air, Return air from building, Return air from Air handling unit, Supply air from Air handling unit, Supply air to room, Fresh air, Electricity, Control signal, Outside air, Relief air, Fresh air in, Condenser water in, Condenser water to chiller, warm air out, Flue/smoke, Steam, Fuel source, water, Gas oil

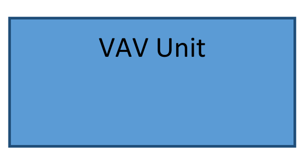
**Solution:**




1. Variable air volume (VAV) Input and output model.

Direction: Please fill out the Input and output sources that are correct for a typical VAV unit (heating only) from the list of options below. The number of inputs and outputs might vary.

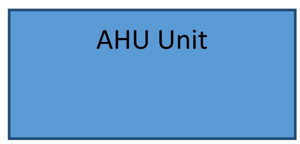
**Options:** Heating source, cooling source, desired temperature, desired volume, Supply air, Return air from building, Return air from Air handling unit, Supply air from Air handling unit, Supply air to room, Fresh air, Electricity, Control signal, Outside air, Relief air, Fresh air in, Condenser water in, Condenser water to chiller, warm air out, Flue/smoke, Steam, Fuel source, water, Gas oil



Air handling unit (AHU) input and output model.

Direction: Please fill out the Input and output sources that are correct for a typical AHU unit from the list of options below. The number of inputs and outputs might vary.

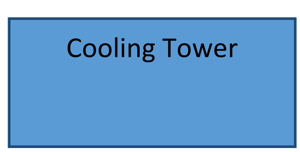
**Options:** Heating source, cooling source, desired temperature, desired volume, Supply air, Return air from building, Return air from Air handling unit, Supply air from Air handling unit, Supply air to room, Fresh air, Electricity, Control signal, Outside air, Relief air, Fresh air in, Condenser water in, Condenser water to chiller, warm air out, Flue/smoke, Steam, Fuel source, water, Gas oil




2. Cooling tower input and output model.

Direction: Please fill out the Input and output sources that are correct for a cross flow type design cooling tower from the list of options below. The number of inputs and outputs might vary.

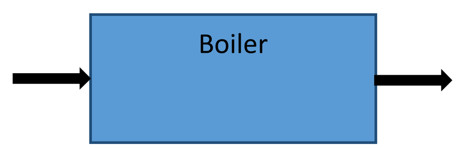
**Options:** Heating source, cooling source, desired temperature, desired volume, Supply air, Return air from building, Return air from Air handling unit, Supply air from Air handling unit, Supply air to room, Fresh air, Electricity, Control signal, Outside air, Relief air, Fresh air in, Condenser water in, Condenser water to chiller, warm air out, Flue/smoke, Steam, Fuel source, water, Gas oil



3. Boiler input and output model.

Direction: Please fill out the Input and output sources that are correct for a typical combustion Boiler unit from the list of options below. The number of inputs and outputs might vary.

**Options:** Heating source, cooling source, desired temperature, desired volume, Supply air, Return air from building, Return air from Air handling unit, Supply air from Air handling unit, Supply air to room, Fresh air, Electricity, Control signal, Outside air, Relief air, Fresh air in, Condenser water in, Condenser water to chiller, warm air out, Flue/smoke, Steam, Fuel source, water, Gas oil



**STRUCTURE:**

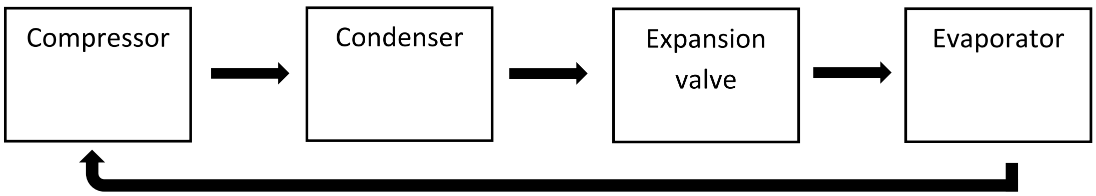
**Choose the options from below to sketch a schematic layout of structure for different equipment's in the questions 5, 6 and 7**

| | | | | |
|---|---|---|---|---|
| Compressor | Fan | Expansion Valve | Condensing Coil | Heating Coil |
| Reheat Coil | Grille | Radiator | Damper | Evaporator |
| Mixing Chamber | Condenser | Cooling Coil | Humidifier | Dehumidifier |
| Compressor | Heater | Heat exchanger | Filter | Condenser Fan |

**Example:** Major components of chiller.

Direction: Choose the correct symbols from the list of options above to form the structural layout of a typical chiller unit.

**Solution:**




4. Variable air volume (VAV) unit layout

Direction: Choose the correct symbols from the list of options above to form the structural layout of a typical VAV unit.

5. Air handling unit layout.
Direction: Choose the correct symbols from the list of options above to form the structural layout of a typical AHU unit.

6. Makeup air unit (MAU) Layout.
Direction: Choose the correct symbols from the list of options above to form the structural layout of a typical MAU unit (Heating only).

7. Cycle of cold water supply to Air handling unit (AHU).

Direction: Choose the correct symbols from the list of options to show the circulation loop between systems for cold water supply and place them in the sectional elevation below and show the interrelation with arrows.

| | | | | |
|---|---|---|---|---|
| AHU | Chilled water pump | Chiller | Cooling Tower | Condenser water pump |

**BEHAVIOR:**

8. Scenario: On a 90° F day, a user in a room lowers the temperature set point of the room on the thermostat from 78°F to 70 °F. Choose the following correct reaction of a VAV to accommodate the request. Mark the best possible option

    A. Damper opens wider
    B. Increase in the blower speed
    C. Activates the heating coil
    D. Activates the chiller and Boiler
    E. Activates the cooling coil
    F. Activates heating coil in AHU
    G. All the above

9. Scenario: The user in a room reduces the temperature set point on the thermostat from 80 °F to 70°F. The user did not see any difference in the change of temperature after reducing the temperature to 70°F. The CFM to the room did not change. What could be the possible reason? Choose all the right answers.

    a. Failed VAV unit
    b. Failed heating coil in AHU
    c. Failed Chiller
    d. Failed Blower in Rooftop unit
    e. Failed Chilled water pump
    f. Activated condenser water pump
    g. All the above

10. Scenario: The owner of a 3 story building would like to maximize energy efficiency while maintaining good user controllability, Mark the best possible option

    a. Single constant volume AHU ducted to zones
    b. (3) constant volume AHUs ducted to Zones
    c. Single AHU with VAV boxes for each zone
    d. (3) AHU with VAV boxes for each zone
    e. (3) Standard Roof top units in place of AHUs

11. Scenario: A user in office room wants to increase the temperature set point in the room from 65°F to 78°F. The user did not see any difference in the change of temperature after increasing the temperature set point to 78°F. The VAV unit and the Air handling unit are in good condition. What could be the reason? Choose all the right answers. Mark all the correct answers.

    a. Failed Condenser water pump.
    b. Failed heating coil in the makeup air unit
    c. Failed burner in the boiler
    d. Failed condenser fan in boiler
    e. Failed water pipe connected to boiler.
    f. Failed Chiller.
    g. Failed reheat coil.
    h. All the above.

12. Scenario: In a typical patient room, air pressure shall always remain active. Choose the following correct reaction of a VAV to accommodate the request. Mark the best possible option.

    a. Damper opens wider
    b. Activates cooling coil
    c. Damper opens narrower
    d. Increase in blower speed
    e. Activates heating coil
    f. Activates chiller

# Appendix 3 – Quiz Results

## Group 1

| NO. | Function (8 Each) | | | | Structure (6 Each) | | | | Behavior (3 Each) | | | | | Academic Status | Working experience | HVAC Design/Installing Experience | Rank | Review |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 | Q13 | | | | | |
| | | | | | | | | | | | | | | | | | | |
| 1 | 2 | 4 | 4 | 8 | 2 | 1 | 2.4 | 4.8 | WA | 1 | WA | WA | WA | Senior | No | - | Fair | - |
| 2 | 4 | 4 | 4 | 8 | 6 | 6 | 2.4 | 4.8 | WA | 3 | 3 | 3 | WA | Senior | No | - | Fair | 3 |
| 3 | 3 | 4 | 2 | 4 | 4 | 2 | WA | 3.6 | 3 | WA | 3 | WA | WA | Junior | No | - | - | - |
| 4 | 5 | 4 | 4 | 6 | 6 | 4 | 2 | 3.6 | 3 | 1 | 3 | 1 | 3 | Junior | No | - | Fair | 3 |
| 5 | 4 | 3 | 6 | 6 | 6 | 4 | 1.2 | 1.2 | WA | 3 | WA | WA | WA | Senior | No | - | Good | 3 |
| 6 | 4 | 6 | 8 | 8 | 2 | 4 | 2.4 | 1.2 | 3 | WA | WA | WA | WA | Senior | No | - | Good | 4 |
| 7 | 3 | 4 | 2 | 4 | 6 | 6 | 3.6 | 2.4 | 3 | 1 | WA | 2 | WA | Senior | No | - | Good | 3 |
| 8 | 5 | 3 | 4 | 8 | 4 | 5 | 4.8 | WA | WA | WA | WA | WA | WA | Junior | No | - | Fair | 3 |
| 9 | 2 | WA | 4 | 8 | 6 | 6 | NA | 1.2 | WA | 1 | 3 | 1 | 3 | Junior | No | - | Poor | 4 |
| 10 | 2 | 2 | 4 | WA | 4 | 4 | 3.6 | 3.6 | WA | WA | 3 | WA | WA | Senior | No | - | Fair | 5 |
| 11 | 4 | 3 | 4 | 6 | 2 | 2 | 2.4 | 1.2 | 3 | WA | WA | WA | WA | Junior | No | - | Good | 2 |
| 12 | 6 | 5 | 6 | 6 | 2 | 5 | 3.6 | 2.4 | 3 | 2 | WA | 3 | WA | Junior | No | - | Fair | 4 |
| 13 | 6 | 2 | NA | NA | 4 | 6 | NA | 2.4 | 3 | 1 | WA | WA | WA | Junior | Yes | Design | Fair | 2 |
| 14 | WA | 3 | NA | NA | 4 | 3 | NA | NA | WA | 3 | 3 | 2 | 3 | Junior | No | - | Fair | 1 |
| 15 | 4 | 5 | 4 | 8 | NA | 4 | NA | NA | 3 | 1 | WA | 2 | WA | Junior | No | - | Fair | 4 |
| 16 | 2 | 3 | 4 | 4 | 6 | NA | NA | 4.8 | 3 | 2 | WA | 1 | WA | | | | | 4 |
| 17 | 1 | 3 | 4 | 6 | NA | NA | NA | NA | WA | WA | WA | WA | WA | Junior | No | - | Fair | 1 |
| 18 | 2 | NA | NA | NA | NA | NA | NA | NA | WA | 1 | WA | WA | WA | Junior | No | - | Fair | 5 |
| 19 | 3 | 4 | NA | 6 | NA | NA | NA | WA | WA | 2 | 3 | 2 | WA | | | | | 3 |
| 20 | 4 | 5 | 4 | 2 | NA | NA | NA | NA | WA | 1 | WA | 1 | WA | Senior | No | - | - | 3 |
| 21 | 3 | 5 | 4 | 8 | NA | 6 | NA | 2.4 | WA | 3 | 3 | 2 | WA | Junior | No | - | Poor | 4 |
| 22 | 2 | NA | NA | 2 | NA | NA | NA | NA | WA | 1 | 3 | 1 | WA | Junior | No | - | Fair | - |
| 23 | 1 | NA | NA | 6 | NA | NA | WA | WA | WA | WA | WA | WA | WA | Senior | No | - | Fair | 1 |
| 24 | 4 | 4 | 2 | 4 | NA | 2 | NA | NA | WA | 1 | WA | WA | WA | Junior | No | - | Good | 5 |

NA: Not Answered

WA: Wrong Answer

## Group-2

| NO. | Function(8 Each) | | | | Structure (6 Each) | | | | Behavior(3 Each) | | | | | Academic Status | Working experience | HVAC Design/ Installing experience | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Q1 | Q2 | Q3 | Q4 | Q5 | Q6 | Q7 | Q8 | Q9 | Q10 | Q11 | Q12 | Q13 | | | | |
| 1 | 2 | 4 | 4 | 6 | 4 | 2 | WA | 1.2 | WA | 2 | WA | 2 | WA | Junior | No | - | Poor |
| 2 | 2 | 2 | WA | 8 | 2 | 4 | 3.6 | 2.4 | WA | 1 | 3 | 1 | WA | Junior | No | - | Poor |
| 3 | 1 | 2 | 6 | 4 | 2 | 2 | 2.4 | WA | WA | 1 | 3 | 1 | WA | Senior | No | - | Good |
| 4 | 4 | 3 | 2 | 6 | 4 | 3 | 3.6 | 2.4 | 3 | 2 | WA | 3 | WA | Junior | No | - | Good |
| 5 | 3 | 3 | 6 | 6 | 2 | 3 | 2.4 | 2.4 | 3 | 1 | WA | WA | WA | Junior | No | - | Fair |
| 6 | 2 | 3 | 4 | 4 | 4 | 4 | 3.6 | NA | 3 | 1 | WA | 3 | WA | Senior | Yes | Design | Fair |
| 7 | 2 | 3 | WA | 6 | 2 | 3 | 3.6 | WA | WA | 1 | 3 | WA | WA | Junior | No | - | Fair |
| 8 | 1 | 3 | 2 | 2 | 2 | 1 | 4.8 | NA | WA | WA | WA | WA | 3 | Junior | No | - | Fair |
| 9 | 2 | 4 | 8 | 8 | 4 | 4 | 2.4 | 2.4 | 3 | WA | WA | 3 | WA | Junior | No | - | Fair |
| 10 | 3 | 5 | 2 | WA | 2 | 3 | 2.4 | WA | 3 | 1 | WA | WA | 3 | Junior | No | - | Fair |
| 11 | 1 | 3 | WA | 2 | 2 | 2 | 1.2 | 4.8 | WA | 1 | 3 | WA | WA | Junior | No | - | Fair |
| 12 | 3 | 5 | 4 | 6 | 2 | 3 | 2.4 | WA | 3 | 3 | WA | 3 | WA | Junior | No | - | Fair |
| 13 | 4 | 3 | 4 | 4 | 6 | 4 | 4.6 | WA | 3 | 3 | WA | 3 | WA | Junior | No | - | Fair |
| 14 | 4 | 2 | 4 | 4 | 4 | 3 | 1.2 | 2.4 | 3 | 1 | WA | WA | WA | Senior | No | - | Fair |
| 15 | 2 | 2 | NA | 4 | WA | 2 | WA | WA | WA | WA | 3 | WA | WA | Junior | Yes | Design | Fair |
| 16 | 4 | 4 | 4 | 2 | WA | WA | WA | 1.2 | WA | WA | WA | WA | WA | Junior | No | - | Fair |
| 17 | 3 | 5 | WA | 6 | WA | 2 | WA | WA | 3 | 1 | WA | 3 | WA | Junior | No | - | Poor |
| 18 | NA | NA | NA | NA | NA | NA | NA | NA | WA | 3 | 3 | 3 | NA | Junior | No | - | Fair |
| 19 | 5 | 2 | 2 | 8 | NA | NA | NA | NA | NA | 1 | WA | WA | WA | Senior | No | - | Fair |
| 20 | 2 | NA | NA | 2 | NA | NA | NA | NA | WA | 1 | WA | WA | WA | Junior | No | - | Fair |
| 21 | 3 | 4 | 4 | 4 | WA | NA | NA | WA | 3 | 1 | WA | 1 | WA | Junior | No | - | Good |

NA: Not Answered

WA: Wrong Answer