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## Design of a User Interface to Investigate the Role of 3D Spatial Reasoning in Surgical Training

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Graduate Program in Electrical and Computer Engineering  
A thesis submitted in partial fulfillment of the requirements for the degree in Master of Engineering Science  
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# **Design of a User Interface to Investigate the Role of 3D Spatial Reasoning in Surgical Training**

(Thesis format: Monograph)

by

Ladan Ashrafi

Graduate Program in Engineering Science  
Electrical and Computer Engineering

A thesis submitted in partial fulfillment  
of the requirement for the degree of  
Master of Engineering Science

The School of Graduate and Postdoctoral Studies  
The University of Western Ontario  
London, Ontario, Canada

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THE UNIVERSITY OF WESTERN ONTARIO  
The School of Graduate and Postdoctoral Studies

**CERTIFICATE OF EXAMINATION**

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The thesis by

**Ladan Ashrafi**

entitled:

**Design of a User Interface to Investigate the Role  
of 3D Spatial Reasoning in Surgical Training**

is accepted in partial fulfilment of the  
requirements for the degree of

**Master of Engineering Science**

Date \_\_\_\_\_

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# Abstract

In this thesis, a 3D interactive environment for measurement of spatial ability using Mental Rotation Test was designed and implemented. The spatial ability of two groups of participants (novices and experts) was evaluated using the implemented software and compared to the result from Embedded Figure Test. In Embedded Figure Test, only 15.63% of the experts' responses were incorrect (with score of  $6.75 \pm 1.50$  out of 8), compared to 57.00% for novices (with score of  $3.44 \pm 1.51$ ). No significant difference was found between scores of the two groups from Mental Rotation Test; however, experts responded significantly faster than novices ( $P < 0.05$ ). The response time found to be a more suitable metric to quantify the spatial ability of surgical trainees. Calot's Triangle Test was used to measure practical surgical knowledge of the candidates. Experts' surgical knowledge was found significantly higher than that of novices ( $P < 0.05$ ). Results from both spatial reasoning tests and Calot's Triangle test confirm the capability of the 3D Mental Rotation Test to measure the spatial ability of trainees, and therefore it may be used during the training to indirectly evaluate improvements in their practical surgical knowledge.

Keywords: Cognitive Psychology, Perceptual ability, Spatial reasoning ability, Three-dimensional; Minimally Invasive Surgery

*To my Husband, Reza*

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# Chapter 1

## Introduction

### 1.1 Overview

Spatial cognition is defined as a collection of mental skills involving the ability to perceive and manipulate a two-dimensional (2D) or three-dimensional (3D) figure, match different spatial representations of a figure, or analyze the spatial relationship between multiple figures or objects [1]. Spatial ability is involved in facilitating the mental manipulation of spatial information, and therefore it is heavily utilized in a number of professional areas including medicine, and in particular minimally invasive surgery.

Spatial ability has been the subject of extensive research in the area of cognitive psychology since 1970s. A number of tests have been developed to measure overall cognitive ability. Earlier research investigated the correspondence between spatial ability skills and achievement in mathematics, and engineering [2, 3]. The founding of this research also shows correlation between spatial reasoning and problem solving in engineers [4]. With recent increase in importance of spatial ability in different fields such as medicine, many of these tests have been used to explore the relationship between spatial cognition and surgical performance with the goal of improving training methods. However, the majority of these tests are aimed at measuring higher levels of spatial ability, and therefore, they are not suitable for identifying the visual-spatial abilities relevant to specific surgical tasks.

This work expands the 2D Mental Rotation Test developed by Metzler and Shepard [5] to three dimensions. It provides a configurable interactive environment for exploring the visual cues affecting spatial skills specific to surgical tasks commonly used in minimally invasive surgery.

This chapter begins with a review of commonly used spatial reasoning tests followed by reviewing the role of spatial thinking in medicine and in particular minimally invasive surgery (Sec. 1.2). Section 1.3 describes the motivation for designing an interactive 3D environment for measurement of spatial ability. The research objectives addressed by this thesis are outlined in Section 1.4.

## 1.2 Literature Review

Investigation of role of spatial cognition in performance of surgery has been the focus of a number of previous studies. Numerous tests have been developed to study the relationship between spatial ability and performance of individuals in surgical tasks [6-8]. Some of the tests include Visualization of Views [9], Perceptual Aptitude Test [10], Paper Folding Test [11], and touching blocks [12].

The scores on spatial cognition tests have been proposed to predict surgical performance of trainees [13]. In the following section, two of the most commonly used spatial cognition tests, Mental Rotation and Embedded Figures tests, are described.

### 1.2.1 Spatial Reasoning Tests

The Mental Rotation Test was originally developed by Shepard and Metzler in 1972 [5]. The test presented users with two 3D models with different representation views; half of the presenting pairs were similar (Fig. 1.1 A, B), and the rest were different (Fig 1.1.C). Score of the participants was evaluated based on the number of successful identification of similar pairs. Follow up studies of spatial ability using the Mental Rotation Test demonstrated good correlation between the score of participants and their surgical operative skills [14].

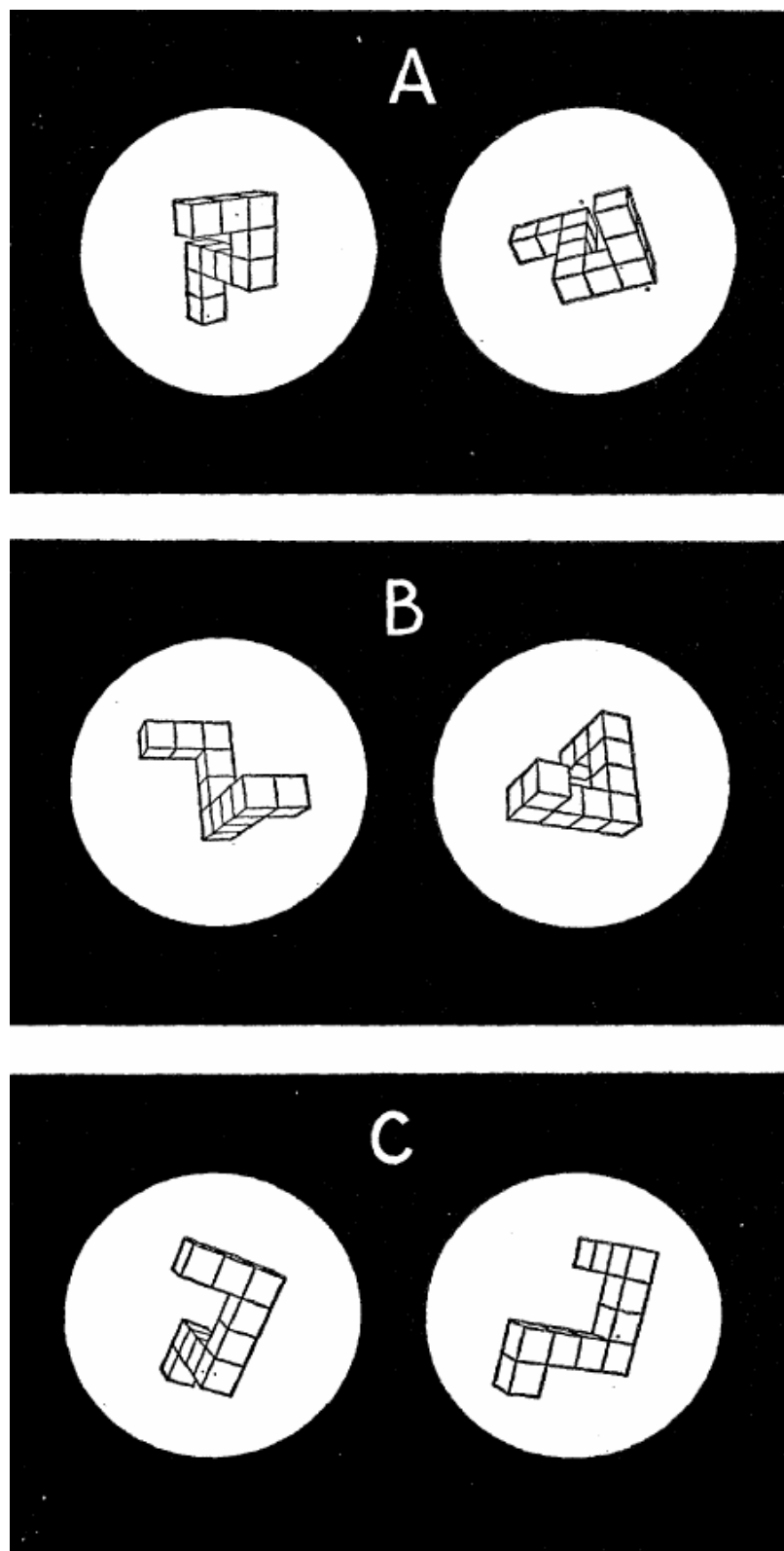


Figure 1.1. Shepard and Metzler 3D structures [5]. Half of the models were similar (A, B) and the rest were different models (C).

Another common test for evaluation of spatial ability skills is Embedded Figures Test. In this test, participants are presented with a simple two-dimensional figure (shown on the left in Fig. 1.2), and asked to find it in a more complex and cluttered figure [15]. As this task requires users to ignore distracting visual information in background, it is considered to reflect their ability to form mental representation of the original object that ultimately facilitates its identification. Similar to the Mental Rotation Test, the score of participants in Embedded Figures Test has been shown to correlate well with their surgical skills [6-8].

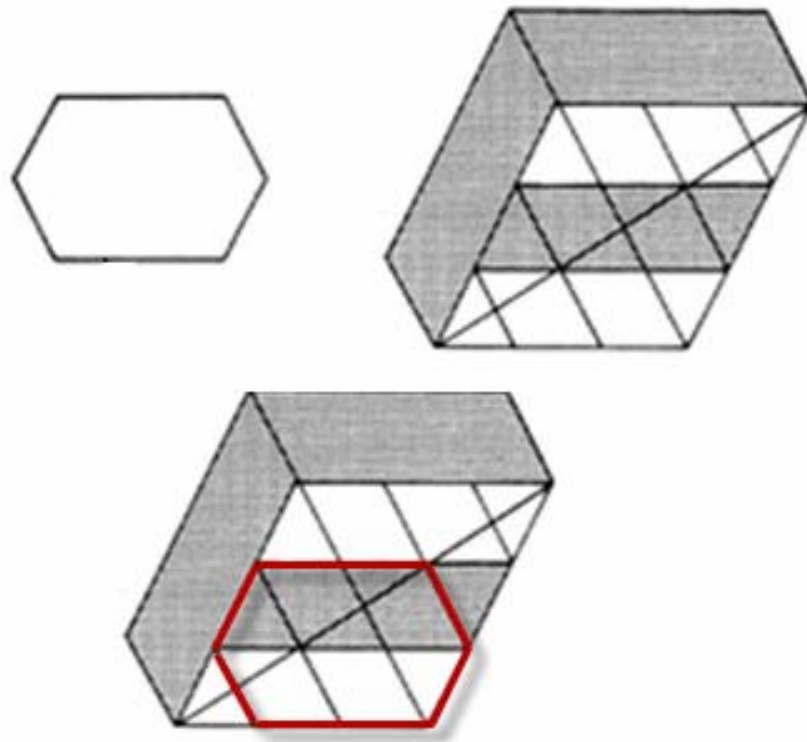


Figure 1.2. Finding a simple shape (upper left) in more complex figure(upper right). The result is shown in the bottom figure.



### 1.2.2 Spatial Cognition in Medicine

During training, medical professionals develop an understanding of internal physical structures of human body including shape of organs, landmarks, and relative location and connection of structures. As direct access to the internal anatomy of patients often is not possible, physicians rely on their mental spatial representation of organs in many diagnostic methods (including the use of medical images) to identify abnormalities. Specifically, surgeries are pre-planned based on two-dimensional cross sections of three-dimensional structures of body represented in x-ray, CT and MRI images [16]. During operations, the surgeon must navigate to the site of interest by correlating the visible surface views with his or her mental spatial map of underlying structures.

Spatial cognition has a central role in minimally invasive surgery. In Laparoscopy (minimally invasive surgery of abdomen or pelvis), a small video camera attached to a tube (Laparoscope) as well as surgical instruments are inserted in patient's body through a number of small incisions [17]. The surgeon relies on the transmitted video images to view the operative site and indirectly control the surgical equipment to perform the procedure from outside the body [14]. Although Laparoscopy offers many benefits for patients (e.g. lower cost and faster recovery time), it requires a different skill set as surgeons mainly interact with a 3D environment based on 2D video images, and further they use different instruments and related motor skills compared to traditional surgery [14]. Many surgeons find Laparoscopy challenging since not only the operative space is not directly visible, but also the site cannot be explored with hands. Therefore due to lack of hand-eye coordination, the success of the procedure is more dependent on the

surgeon's interpretation of spatial information. As a result of these challenges, technical proficiency of surgeons for laparoscopic procedures has found to be highly inconsistent, and in many cases patients have been injured or faced complications [18, 19].

Spatial ability has been identified in several studies as a key predictor of performance in surgical procedures [8, 20]. Excellent correlation has been reported between surgical skills of residents and their performance on a number of 2D spatial ability tests including Embedded Figures Test and Mental Rotation test [13]. Given this close connection, one of the most discussed topics in surgical education is whether the performance on spatial ability tests should be used as a measure for selection of candidates, similar to Perceptual Aptitude Test (PAT) as an admission requirement in dentistry [21, 22].

Traditional methods for teaching surgical skills are based on apprenticeship model where trainees learn by observing mentors and gradually increasing their involvement in procedures to master the surgical techniques [23]. Teaching mediums available outside operating rooms have been limited to 2D textbooks that do not allow user interaction, or cadaver dissections labs with restricted access due to high maintenance costs [24].

With increase in number of MIS in recent years and heavier reliance of surgeons on their spatial abilities for these surgeries, there is a need for robust and reliable tools to monitor residents' progress during the training. Without knowledge of residents' skills at different stages of training, often residents with low spatial reasoning skills advance further along in the training programs and perform complex procedures on patients before achieving

the required level of visual-spatial abilities, resulting in high rates of complication or injury [25]. As many surgeons have called for the need for a paradigm shift in surgical education, virtual computer models are considered to be a safe alternative for improving trainee's knowledge of surgical anatomy outside operating rooms [26]. The integration of virtual models in training curriculums can help to identify and address deficiencies and reduce the risk of mistakes caused by limited experience of surgical trainees [27].

### 1.3 Interactive 3D Virtual Model

Recent introduction of three-dimensional computer models of anatomy has significantly improved education in medicine. Florance et al. studied the impact of 3D computer models on student learning, and demonstrated that the use of 3D models significantly enhanced the success in learning anatomy compared to traditional 2D models [28].

Garg et al. investigated the learning advantages of a user-controllable 3D model in comparison to a self-rotating 3D model of the wrist bones [29]. The anatomical knowledge of two student groups was tested after using the models. The group presented with the self-rotating views scored lower than students using the actively controlled 3D environment. Authors suggested that 3D objects are remembered as viewpoint-specific 2D projections. The controlled rotation of the models enabled selective access to key viewpoints, and therefore, improved their mental representation of the anatomical structures in three dimensions.

While efficacy of 3D virtual models in learning gross anatomy has been well studied [30], their underlying effect on spatial cognition has not been investigated [29]. Spatial

ability tests have mostly relied on comparing static two-dimensional representations of 3D objects. As a result, the potential learning benefits of 3D user controllable computer models in improving spatial abilities of trainees in surgical program are unknown.

The interactive 3D testing environment proposed in this work provides the opportunity to quantify spatial ability of users, and further allows obtaining insight into factors affecting decision-making process on spatial information. For example, representation angle of a 3D object is considered to be an important factor facilitating spatial ability [5]. A configurable 3D environment can be utilized to study patterns in user manipulation of 3D objects, and provide information on rotation patterns used to achieve optimal viewing angles by users with superior spatial abilities.

## 1.4 Research Objectives and Thesis Outline

The aim of this work was to design and implement a three-dimensional interactive environment for measurement of spatial ability of surgical trainees. The environment was designed as an evaluation tool to complement existing evaluation practices by monitoring improvements in spatial abilities of trainees and correlating the results to their surgical skills as they gain experience.

The capability of the designed 3D interactive model in measurement of spatial ability is evaluated in experienced surgeons and compared to the results of the Embedded Figures Test, an established 2D spatial ability test. Further, the effectiveness of the 3D interactive model in selection of candidates with superior spatial abilities is identified in an

experiment where spatial abilities of junior surgical residents as well as experienced surgeons are measured and correlated to their surgical skills (as measured by Triangle of Calot's Test).

The advantage of the 3D interactive model in identifying factors affecting spatial cognition is demonstrated by studying the effect of initial viewing angle of 3D objects in successful identification of objects for experts and novices, and relationship between identification time and viewing angle is explored.

Following the introduction presented in this chapter, the design detail of software and experimental methods for research objectives described above are addressed in Chapter 2. Results of the experiments and discussion of the results are presented in Chapter 3. Chapter 4 summarizes the thesis and explores future possible research avenues.

# Chapter 2

## Methods

An overview of methods used to design the 3D interactive Mental Rotation Test is presented in this chapter. The designed framework was tested in a number of experiments and the results were compared to spatial ability of the users measured using the standard 2D Embedded Figures Test. Further, the results were correlated with surgical knowledge of the users measured by Calot's Triangle Test.

Software design constraints and implementation methods are described in Section 2.1. Design parameters for Embedded Figures Test and Calot's Triangle Test are presented in Sections 2.2 and 2.3, respectively. Details of experimental procedures such as selection of participants and number of images presented for each test are provided in Section 2.4.

### 2.1 Interactive 3D Mental Rotation Test

The interactive 3D model presented in this thesis was designed based on Shepard and Metzler Mental Rotation Test [5]. In this framework, user is presented with two 3D objects; the 'static object' positioned on the right side and the 'mobile object' on left (Fig. 2.1). The user is asked to rotate the mobile object as necessary in around X and Y axes before deciding whether the two objects are similar or different.

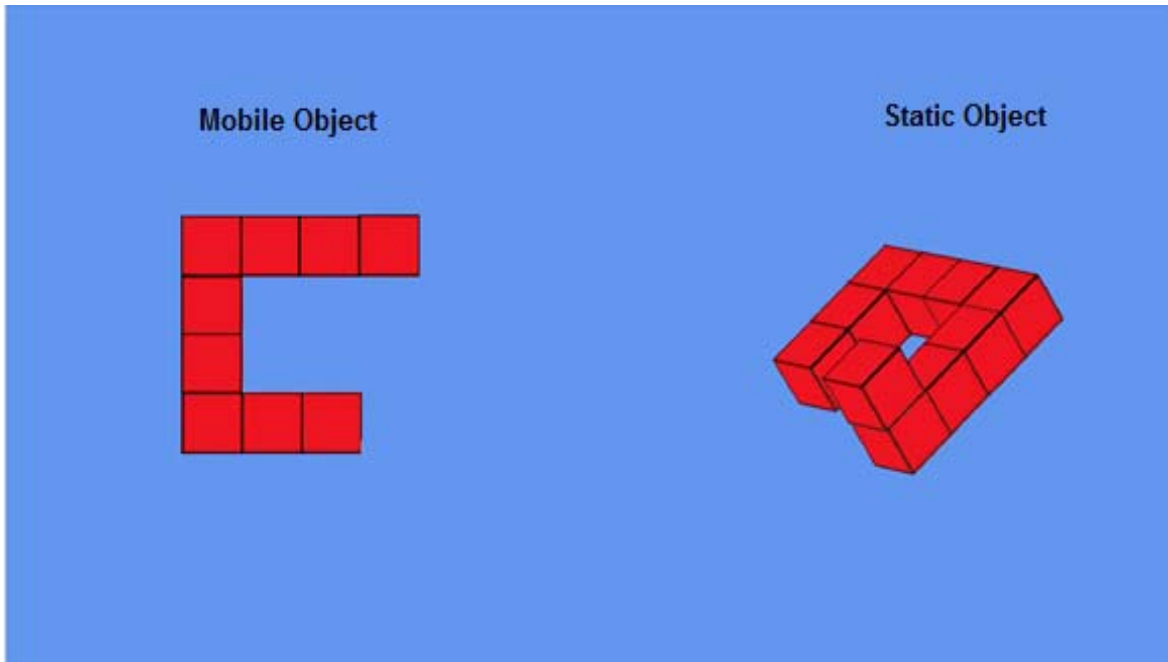


Figure 2.1. A representation of workspace presented to users. The mobile object on left is designed to be rotated around X and Y axes.

An important objective of this framework was to examine the different factors that can affect spatial reasoning skills such as response time and visual affects. The environment was designed specifically to enable testing of the visual factors that may affect spatial cognition such as shape and texture of the objects.

### 2.1.1 Structure of the 3D models

A total of 18 unique 3D objects were designed using simple cubes (Fig. 2.2). Each object constructed from 10 cubes attached face to face to form structures with one or two elbows. The objects were designed such that no two structures were isomers (i.e. one object resembling the mirror view of another object).

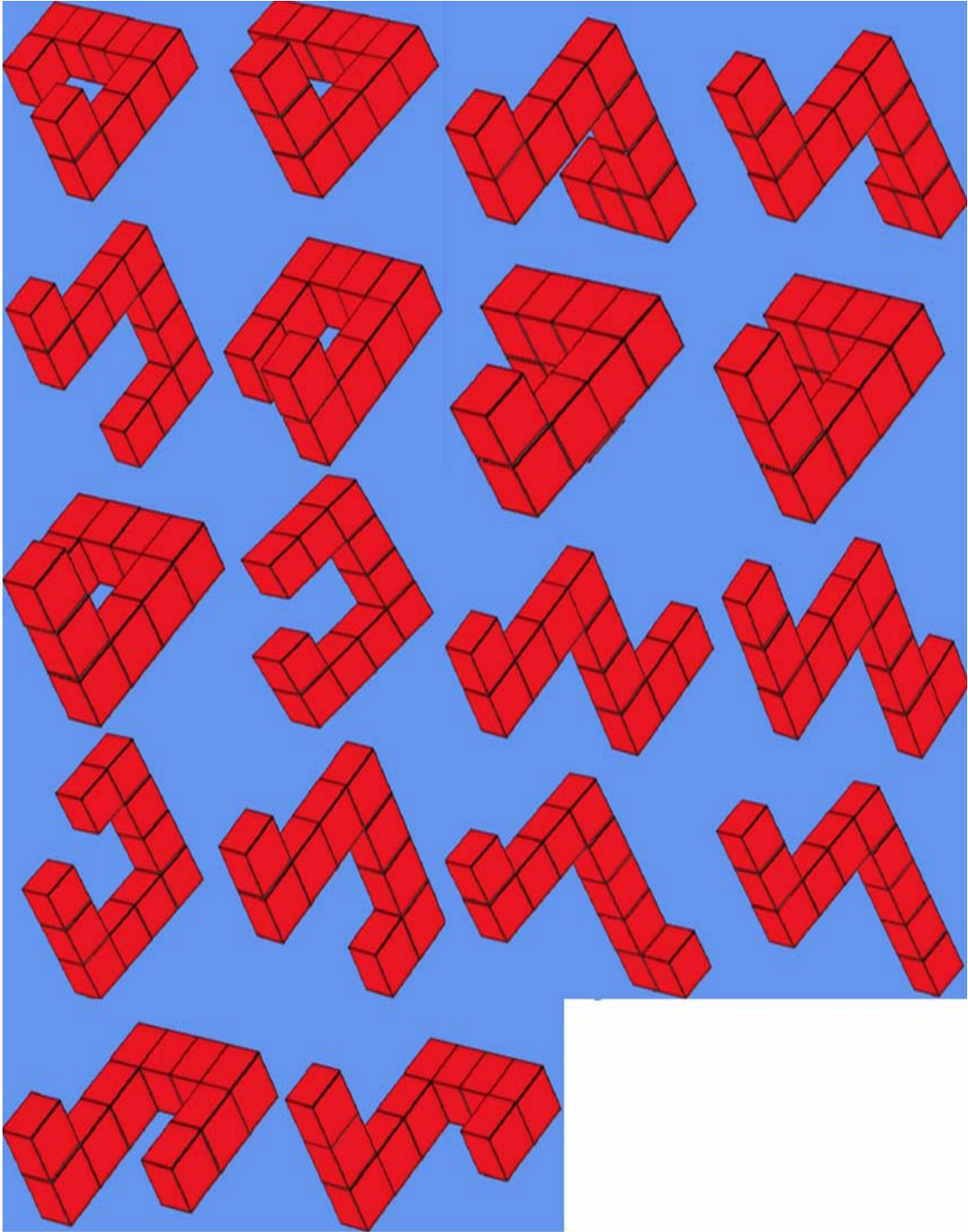


Figure 2.2. 3D objects implemented for 3D Mental Rotation Test. The models are based on the 3D figures developed by Shepard and Metzler [5].



The 3D structure of each shape defining arrangement and attachment of the connected cubes was developed in Blender environment. Blender is an open source tool that helps the developer to design a complex 2D or 3D shapes in gaming environments [31]. A simple  $2 \times 2 \times 2$  unit cube was used as the building block as shown in Fig. 2.3. The cubes were attached together to construct a 3D structure (Fig. 2.4).

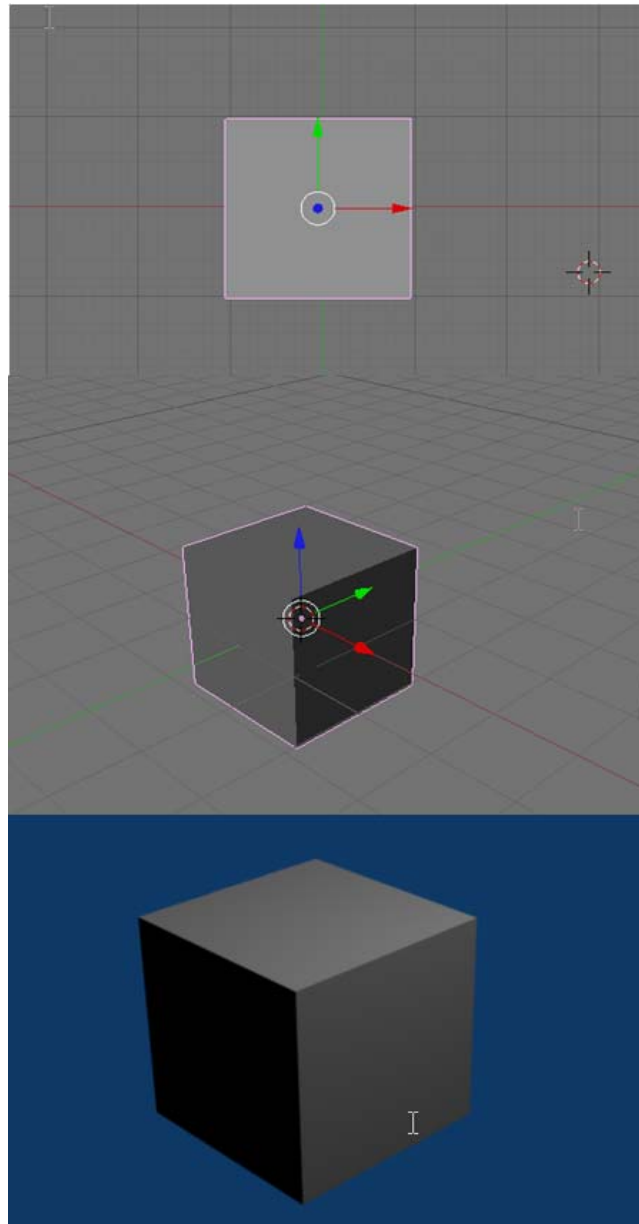


Figure 2.3. Presentation of a 3D cube in Blender environment from Top view (top image) , camera view (middle image) and rendered view (bottom image).

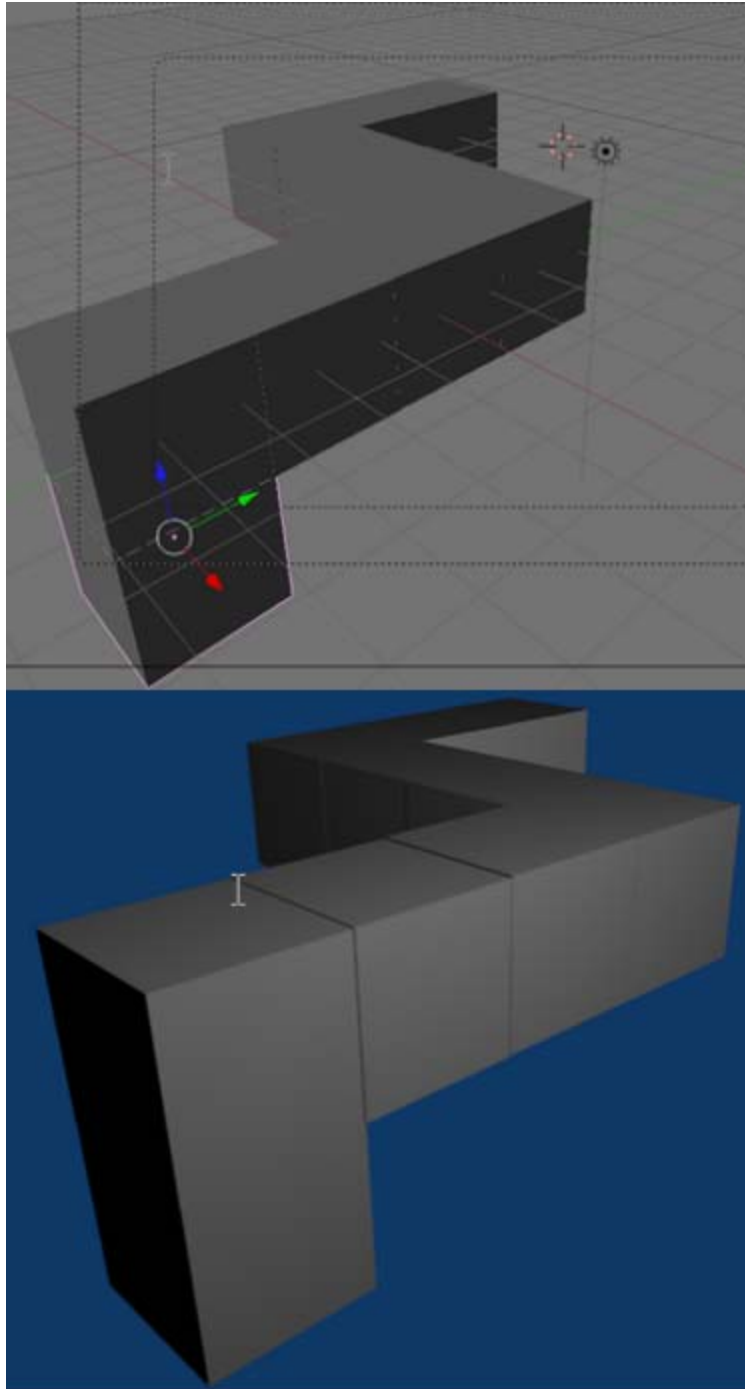


Figure 2.4. Presentation of a complex 3D model (consisting of 10 similar cubes), with camera view (top) and rendered view (bottom) in Blender environment.

The surface texture and color for each unit cube was designed in Photoshop environment. The six faces of a unit cube were unwrapped onto a flat surface and painted uniformly with red, and the edges were highlighted in black (Fig. 2.5). The implemented texture was then imported back to Blender as an image and applied to each of the constructing cubes.

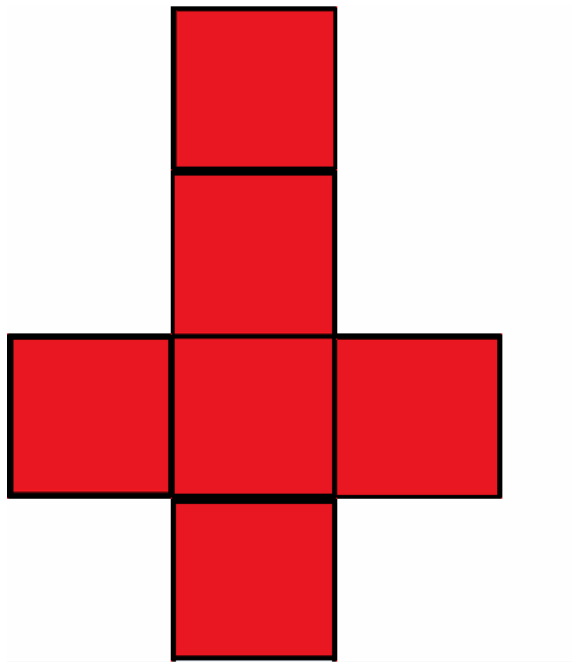


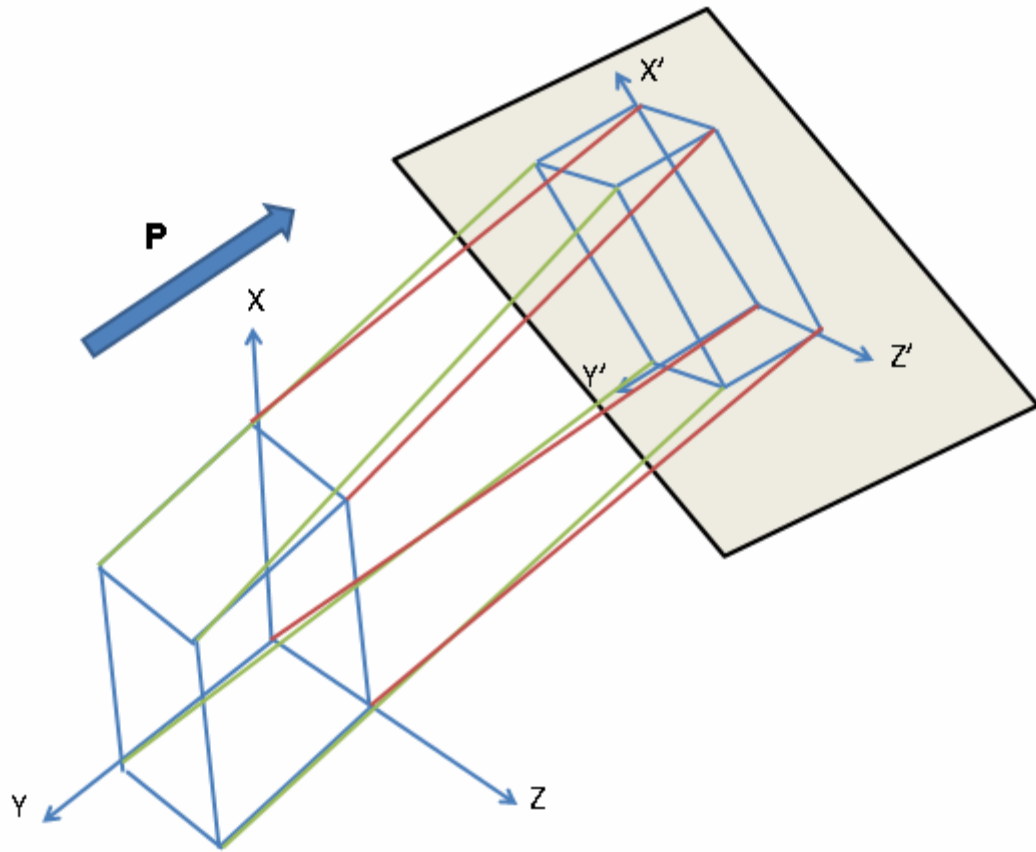
Figure 2.5. The texture, edges and color of cube faces were designed in Photoshop.

The designed environment allows developer to choose any texture for cube faces depending on the objectives of an experiment and the related design requirements (e.g. investigating the relationship between spatial ability and object texture as an added visual cue). For the scope of experiments implemented in this thesis, same texture was applied to all cube surfaces, and the edges were marked clearly to focus users' attention only to identifying the differences in shape of objects rather than differences in cube size, texture, or color.

### 2.1.2 Three-Dimensional space in Microsoft XNA User Interface

As it was mentioned in Chapter 1, providing user with opportunity to freely interact with the mobile object can improve user's mental representation of the object by enabling access to key viewpoints of the 3D model. Microsoft XNA was employed as a host for the designed objects to create a robust and controllable 3D environment allowing users to interact with objects seamlessly by mouse movement. Microsoft XNA is an extension to Microsoft Visual Studio that facilitates the process of game design.

The first step in the design of this framework was to present the two 3D models to user. To present a 3D model on a 2D screen, 3D points in space need to be transformed to 2D plane. This was achieved by multiplying the 3D position with a Projection Matrix. Figure 2.6 demonstrates the transformation of an object from 3D space to a 2D surface determined by the Projection Matrix.



$$\begin{bmatrix} b_x \\ b_y \end{bmatrix} = \begin{bmatrix} P_x & 0 & 0 \\ 0 & 0 & P_z \end{bmatrix} \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix}$$

Figure 2.6. Transformation of the 3D point to 2D screen. The equation projects the transformation of three points  $(a_x, a_y, a_z)$  to two points  $(b_x, b_y)$  using the Projection Matrix  $P$ .

The location of the object within XNA environment is defined by the World Matrix. The multiplication of Projection Matrix and World Matrix defines the coordinates required to draw every point of the object onto the 2D screen.

The code below demonstrates the attributes of Field of View (FOV) required to define the Projection Matrix.

```
effect.Projection = Matrix.CreatePerspectiveFieldOfView(
    MathHelper.ToRadians(5.0f), aspectRatio, 1.0f, 100000.0f);
```

The first argument determines the viewing angle of the camera. The second argument sets the aspect ratio between the width and height of the screen. The third argument defines the focal length (i.e. view range) of the camera. Any object that is closer than 1f (with f describing a floating point) to camera will not be shown. The farthest distance in this frame work is defined as 100000f.

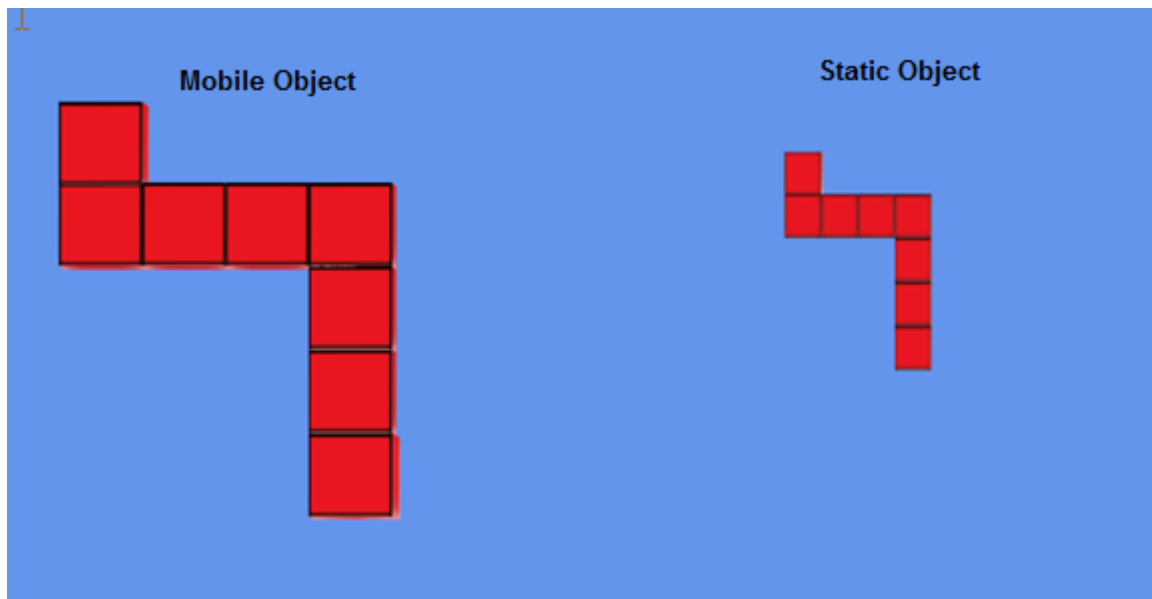


Figure 2.7. Presenting the object in different distance from camera . In this figure the viewing angle is 15.0f for mobile object and 5.0f for static object.

The screen in this framework was divided in half to create left and right panels for mobile and static objects, respectively, as shown in the code below. The aspect ratio is used as the second argument in the definition of Projection Matrix described above.

```

defaultViewport = GraphicsDevice.Viewport;
leftViewport = defaultViewport;
rightViewport = defaultViewport;
leftViewport.Width = leftViewport.Width / 2;
rightViewport.Width = rightViewport.Width / 2;
rightViewport.X = leftViewport.Width + 1;
i = 1;

GraphicsDevice device = graphics.GraphicsDevice;
device.Viewport = defaultViewport;
device.Viewport = leftViewport;

float aspectRatio = (float)device.Viewport.Width /
device.Viewport.Height; float modelRotation = 0.0f;

```

View Matrix defines the position and orientation of the camera in XNA environment. The View matrix is defined as:

```

effect.View = Matrix.CreateLookAt(new Vector3(3.0f, 1.0f, 250.0f),
Vector3.Zero, Vector3.Up);

```

The first argument defines the position of the camera in 3D space. For all rendered scenes the camera was positioned at +250 on Z axis. The second argument sets the target of the camera. The target was set to (0, 0, 0) the origin of World Matrix. The first two arguments set the viewing axis. The third argument specifies the reference direction for the camera (here set to Up).

### 2.1.3 Rotation Angle

To draw the 3D object and create a movement in the object presenting in XNA screen, the World matrix was defined as:

```
effect.World = transforms[mesh.ParentBone.Index]*  
Matrix.CreateRotationY(0.52f)*  
Matrix.CreateRotationX(0.52f)*  
Matrix.CreateRotationZ(0.52f);
```

The rotation can be around single axis or multiple axes. Here, as an example, the rotation around each axis has been set to 30 degrees (0.52 f) as used for representation of the static object.

Figure 2.8 demonstrates the X, Y, Z axes defined in World matrix.

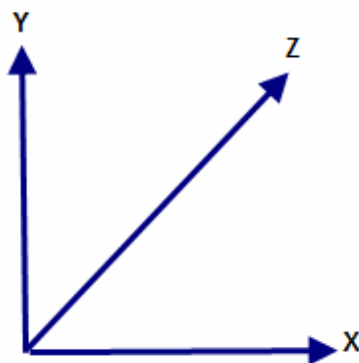


Figure 2.8. X, Y, and Z axes defined in World matrix.



Examples of  $90^\circ$  rotation around X, Y, and Z axes are illustrated in Fig 2.9.

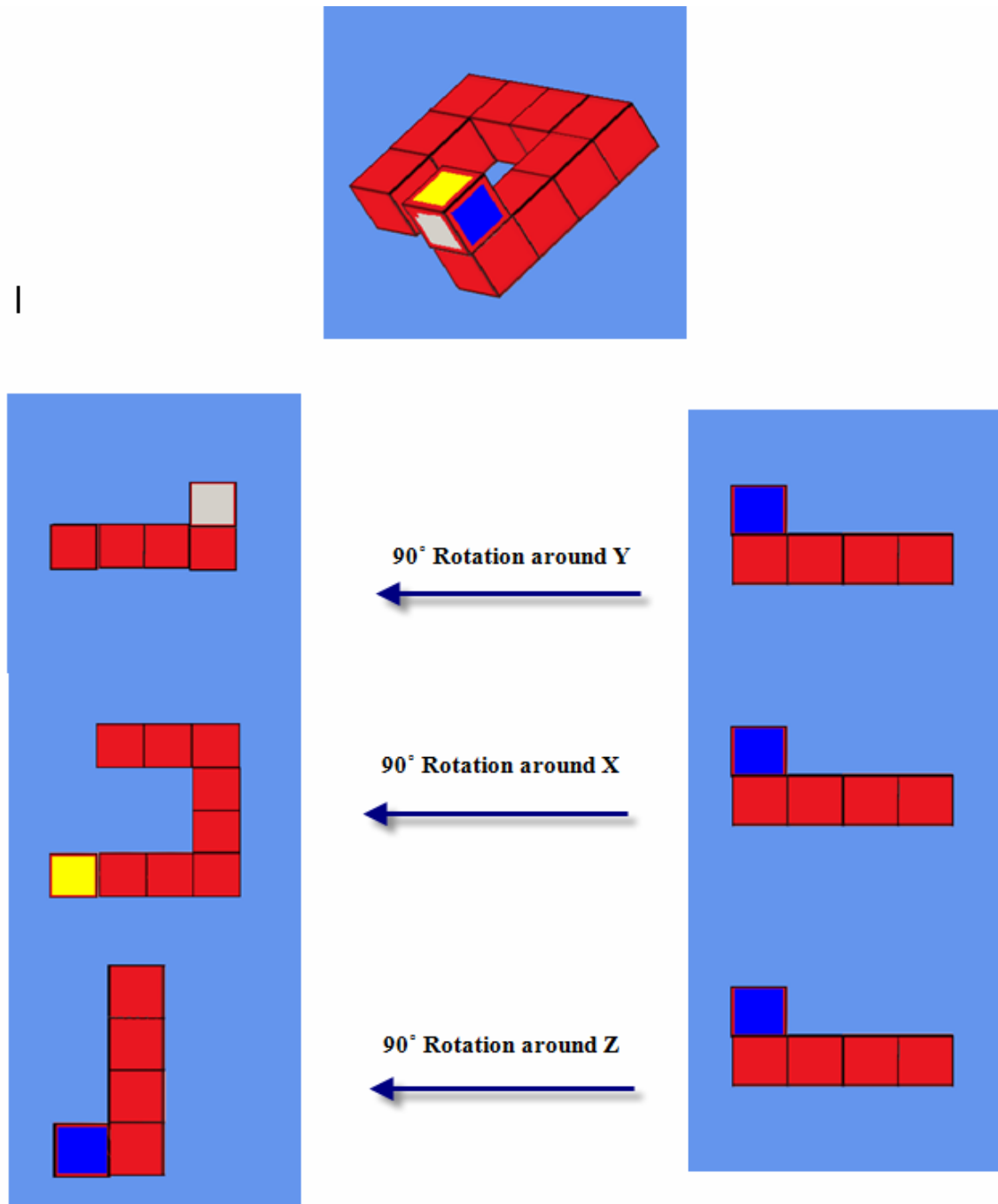


Figure 2.9. The effects of rotation around X,Y,Z axes. The static object is illustrated at top of the figure with initial angle of 30 degrees for all axes.

At the beginning of each trial, both 3D models were presented to the subject with initial presenting angles. The static model always appeared with a 30° rotation in the X, Y, and Z axis to adequately show all sides of the object. However, the initial angle for the left model was randomly selected in the 30°-180° range with 30 degrees increments (Figure 2.10, 2.11, 2.12).

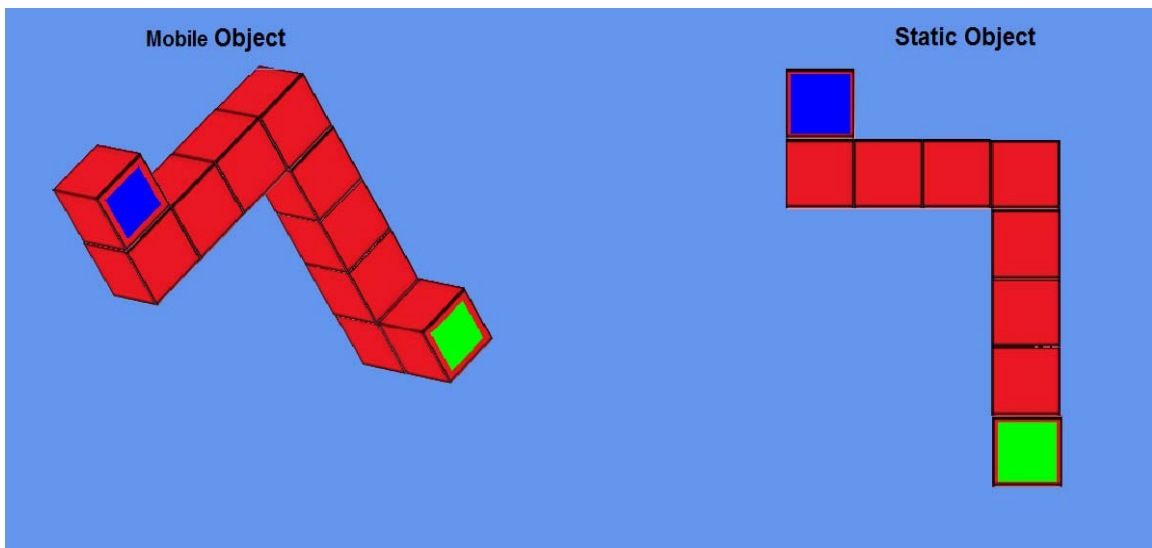


Figure 2.10. The effects of rotation around X,Y,Z axes. The static object is illustrated with initial angle of 0 degrees for all axes and mobile object is presented with 30 degree for all axes.

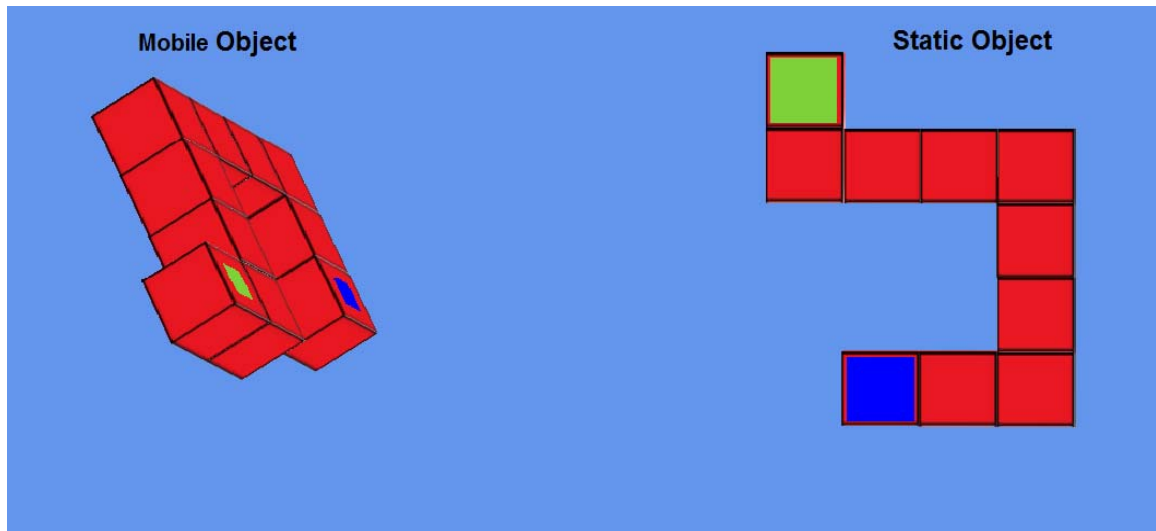


Figure 2.11. The effects of rotation around X,Y,Z axes. The static object is illustrated with initial angle of 0 degrees for all axes and mobile object is presented with 60 degree for all axes.

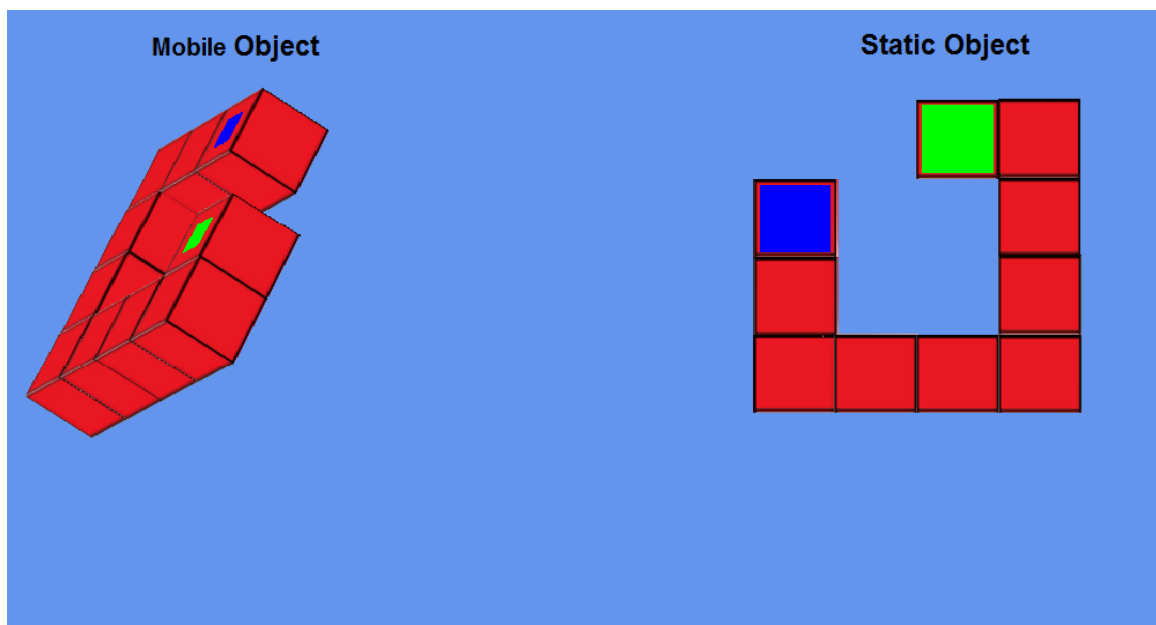


Figure 2.12. The effects of rotation around X,Y,Z axes. The static object is illustrated with initial angle of 0 degrees for all axes and mobile object is presented with 120 degree for all axes.

### 2.1.4 Moving 3D shape

Movement of the mobile object was achieved by transforming the movement of the mouse to the object in XNA world.

By default, the XNA window only displays the object, and the mouse location is not visible. In order to establish a connection between the two environments, the current mouse position needs to be rendered on the XNA screen. Microsoft.Xna.Framework.Input library provides the methods required to activate the mouse and transform mouse coordinates to World matrix coordinates in XNA. By Using *IsMouseVisible* property of the current window the mouse will appear on the XNA screen:

```
this.IsMouseVisible = true;
```

After activating the mouse, the mobile object can be selected by pressing and holding the left mouse button:

```
GraphicsDevice device = graphics.GraphicsDevice;
MouseState newMouse = Mouse.GetState();

if (newMouse.LeftButton == ButtonState.Pressed)
{
    flag = 1;
    if (!mouseDown)
    {
        mouseDown = true;
        lastMousePoint = new Point(newMouse.X,
            newMouse.Y);
    }
}
```

The mouse coordinates and its current state are saved to be use later in the moving functionality.

```
mouseX = newMouse.X;
mouseY = newMouse.Y;
mouseX = mouseX - device.Viewport.Height / 2;
mouseY = mouseY - device.Viewport.Width / 2;
```

Rotation along each axis is achieved by identifying the mouse direction vector. This vector is obtained by subtracting the current position of the mouse from its previous value. Movement of the mouse relative to X and Y rotation axes is determined as follows:

```
bool MoveUp, MoveDown, MoveLeft, MoveRight;  
  
MoveUp = lastMousePoint.Y > newMouse.Y ? true : false;  
MoveDown = lastMousePoint.Y < newMouse.Y ? true : false;  
MoveLeft = lastMousePoint.X < newMouse.X ? true : false;  
MoveRight = lastMousePoint.X > newMouse.X ? true : false;
```

A rotation around X axis is generated when the mouse moves up and down. Similarly, a rotation around Y axis when the mouse moves to the left or right. In addition, the combination of up (+x direction) combined with left (-y) and right (+y), as well as down (-x direction) with left and right are covered (Appendix A).

### 2.1.5 Storing Time and User Selection

A total of 170 pairs of 3D objects were presented to users. Users selected Y or N key on the keyboard to determine if the two models were similar or different.

The program randomly selected two objects and presented them to user. After selection of either Y or N on the keyboard, this method determined whether the two objects were the same, and recorded the lapsed time as well as the user response:

User selection on the keyboard and response time was stored in a log-file generated with the name of user at beginning of each experiment (Appendix D). Timer was restarted after presenting each pair and storing the response time and user selection.

## 2.2 Embedded Figures Test

For the Embedded Figures Test, participants were asked to locate a 2D shape in a cluttered background using pencil and paper (Fig 2.13). This test was used to measure spatial ability of the user. The score of participants was calculated based on the number of successful identification of the simple image.

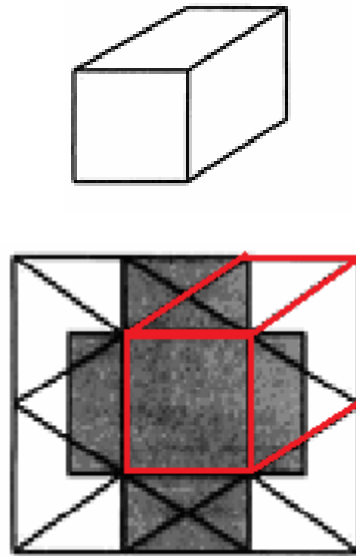


Figure 2.13. An example from Embedded Figures test. The users were asked to identify a simple object (above) hidden inside a complex figure.

## 2.3 Calot's Triangle Test

The Cystohepatic Triangle, also known as Calot's Triangle, is the area bordered by common hepatic ducts, the cystic duct, and the cystic artery. Identifying Calot's Triangle has been a conceptual tool for teaching about open gall bladder removal. Triangle of Calot's Test in this thesis was designed in Microsoft Visual Studio using images from simulated cholecystectomy procedures. Images with different perspective, lighting condition, and obstructed of view (due to fatty tissues) were presented to participants.

Users were presented with a form to enter their names, and a log-file was generated on the system. Then, participants were asked to place 3 different points on the image to form the Calot's Triangle. The paint method in windows form used the 3 points to create the triangle.

Users were provided with the option to modify the location of the triangle after the initial drawing. The time which user took to draw the final triangle was recorded along with the triangle coordinates (Appendix B).

After drawing each triangle, users were asked to navigate to the next image by pressing the NEXT button on the form. The SKIP button was used to skip an image if the user could not identify the proper position of the triangle.

Pressing the NEXT or SKIP button stopped the timer, and recorded the time and triangle coordinates on file (Appendix C).

The number of skipped images was used to calculate the score for each user.



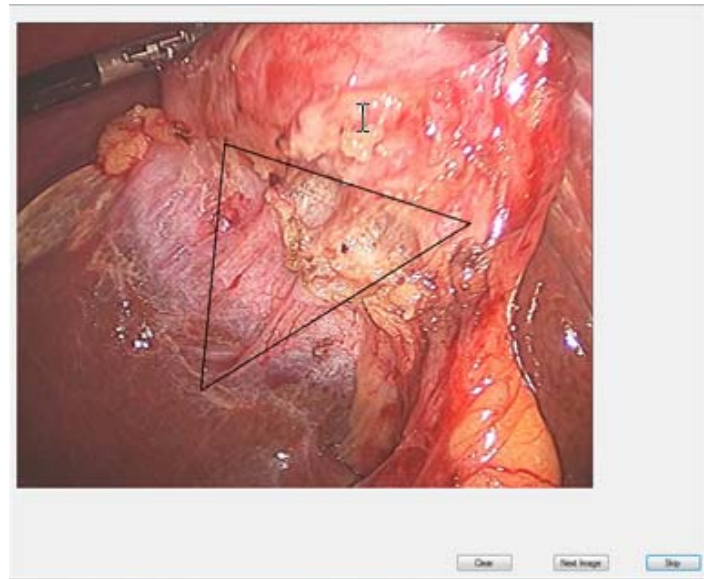
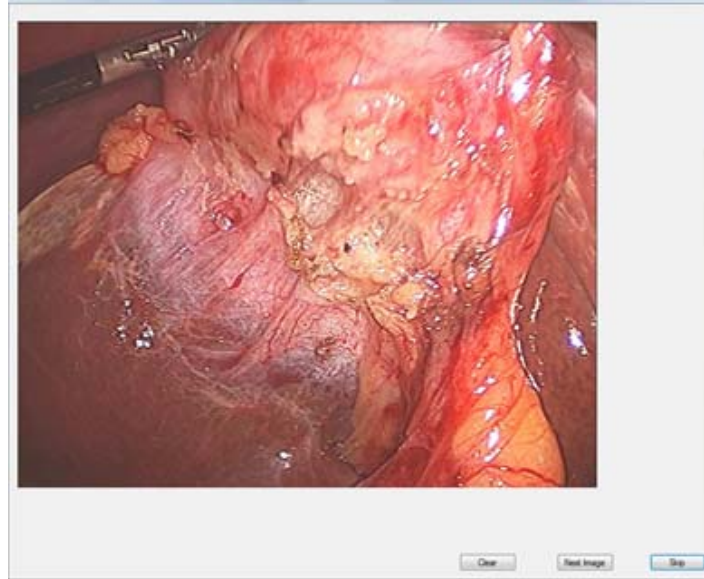


Figure 2.14. Representative Cholecystectomy image used in Calot's Triangle Test (Top). Users were asked to specify the location of triangle using 3 points (Bottom) or skip the image if they could not identify the triangle.

## 2.4 Experimental Methods

Participants were divided into two groups of novices ( $n = 8$ , first year surgical residents with no experience in surgery) and experts ( $n = 5$ , surgeons or senior surgical residences who at least preformed 300 surgeries). In the 3D Mental Rotation Test, participants were presented with 170 pairs of objects with randomly selected viewing angles, and asked to indicate whether the objects were the same. The time that each participant took to make a decision (reaction time) and number of correct answers were recorded.

Spatial ability of the participants was measured with the Embedded Figures Test where they presented with 8 images and asked to identify a simple figure within a cluttered background. The results were compared to performance of the candidates on the 3D Mental Rotation Test. Further, the results were compared to surgical knowledge of the candidates using Calot's Triangle Test.

# Chapter 3

## Results and Discussions

This chapter presents the experimental results of 3D Mental Rotation Test for junior surgical residents (novices) as well as experienced surgeons (experts). These results are compared to participants' practical surgical knowledge quantified by Calot's Triangle Test. The advantages of the presented 3D framework are highlighted in the final section.

### 3.1 Measurement of Spatial Reasoning Skills

The spatial ability of participants was measured using the implemented 3D Mental Rotation Test and compared to results obtained from the two-dimensional Embedded Figures Test.

The number of correct answers to Embedded Figures Test questions was used to calculate the score for each participant. Only 15.63% of the experts' responses were incorrect (with score of  $6.75 \pm 1.50$  S.D out of 8), compared to 57.00% for novices (with score of  $3.44 \pm 1.51$  S.D). The higher Embedded Figures Test score of the experienced surgeons compared to the residents reported in this experiment was in line with a number of previous studies.

To evaluate the implemented 3D interactive model, participants were presented with pairs of objects with randomly selected viewing angles. The participants were allowed to rotate

the movable object, compare it to the static object, and asked to indicate whether the objects were the same.

For the 3D Mental Rotation Test, the score of each candidate was calculated based on successful identification of similar objects. The mean score of novices and experts was  $163.00 \pm 3.25$  S.D and  $164.8 \pm 1.48$  S.D, respectively (Fig 3.1). The score of the two groups was found to be not significantly different ( $P > 0.05$ , unpaired  $t$  test).

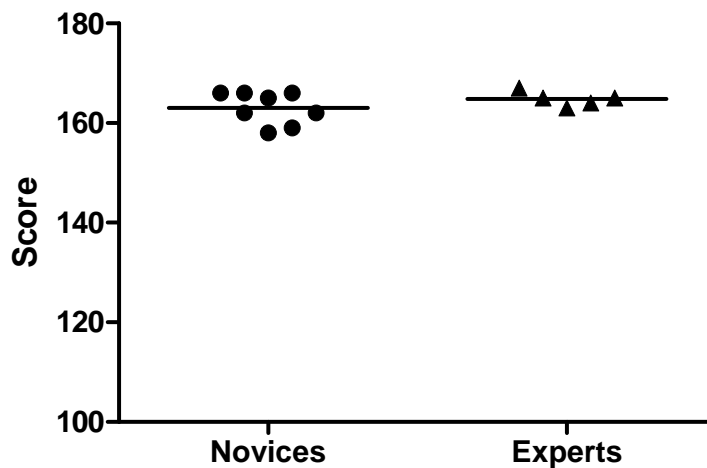


Figure 3.1. Mean score of novices and experts obtained from 3D mental rotation test.

The mean response time for novices and experts was  $10.35 \pm 3.26$  S.D and  $6.16 \pm 1.26$  S.D (Fig 3.2).

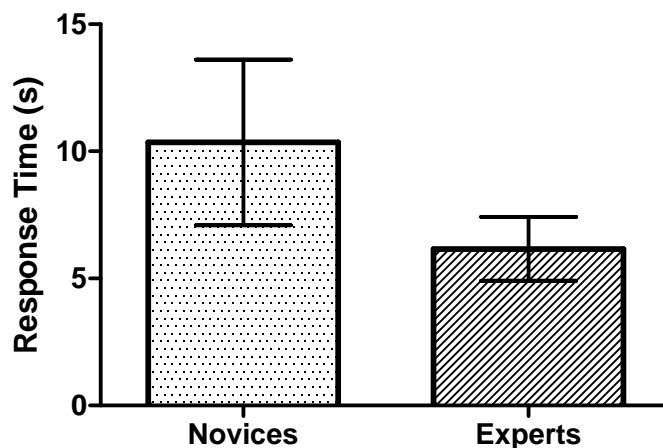


Figure 3.2. Mean response time of users to 3D mental rotation test. Experts responded significantly faster than novices ( $P < 0.05$ , unpaired  $t$  test).

As indicated in Fig 3.1 and 3.2, the majority of novice users who scored lower in the Embedded Figures Test, and considered to have inferior spatial ability compared to the experts, were able to identify the correct answers in the 3D environment when interacted with the figures for a longer period of time. The results suggest that the response time maybe a more suitable metric compared to candidates' scores for quantifying the spatial ability and monitoring the effect of surgical training on the spatial ability as trainees advance in the program. Further, incorporating response time in evaluation of spatial ability helps trainees to consider the importance of time limitations typically present in operating rooms, and therefore they can better prepare themselves for making fast decisions during the surgical procedures.

## 3.2 Spatial Ability and Surgical Experience

Practical surgical knowledge of the candidates was evaluated using Calot's Triangle Test. Subjects were asked to either identify the Triangle of Calot's on each image or skip the image if they couldn't recognize the position of the triangle. The score of each candidate was calculated base on the number of images that subjects could successfully identify Calot's Triangle. Experts achieved the score of  $68.20 \pm 22.4$  S.D out of 100 (31.8% of the images was skipped), compared to  $39.66 \pm 23.90$  S.D out of 100 for novices (60.33% of the images was skipped). Experts' surgical knowledge was significantly higher than that of novices ( $P < 0.05$ , unpaired *t* test).

Considering experts' superior response time in 3D Mental Rotation Test, as demonstrated in Sec 3.1, time might have a relation with experience so as junior surgical residents gain surgical experience; their response time in spatial reasoning tests is reduced. Previous research has established that spatial ability can be improved by practice and training [4, 32-34]. The 3D Mental Rotation Test may be used during the training program to monitor candidates' response time and provide an indirect measure of improvements in their practical surgical skill.

## 3.3 Advantages of 3D Interactive Model

The advantage of 3D environment as a training tool is that it mimics real life interaction of surgeons with the laparoscope to navigate to the site of interest and often manipulate the angle of view to recognize key structures. Aside from the time management skills mentioned above, the consistent use of this tool during the training can help translate the acquired cognitive skills more efficiently to clinical environment.

Spatial ability is a collection of mental skills involving the ability to perceive and manipulate spatial properties of objects such as location, extent, shape, and connectivity [24]. There are several different visual cues that are involved in formation of perceived scene geometry by the viewer. The role of available visual information from the objects (e.g. surface textures, lighting variations, edge contrasts, dept cues, etc.) has not been explored in details. The virtual environment designed in this work provides a test bed to study the role of visual cues in formation of spatial specific components and explore interdependency of these factors. As an example, the effect of initial viewing angle on user's response times is explored in Sec 3.3.1.

### 3.3.1 Effect of Initial Viewing Angle on Response Time

Spatial disorientation has been identified as a key element in many unsuccessful laparoscopic procedures [25]. After navigation to the operation site, most surgeons spend time to orient the camera view such that it matches their mental representation of known landmarks obtained during training or by experience.

To showcase the capabilities of the designed framework, the effect of variation in initial viewing angle of objects on participants' response time was investigated. The response time of experts and novices was recorded in a number of experiments where the mobile objects' angle of view was varied from 30 to 180 in 30 degree increments. The object pairs were not presented to users in any particular order. The mean reaction time for both groups at each representation angle is shown in Fig 3.4.

Linear regression analysis of mean reaction time and initial viewing angle for experts yielded a slope of  $0.024 \pm 0.008$  (SE) and 95% confidence interval of 0.002 to 0.045 ( $r^2 = 0.708$ ). As the initial viewing angle increased, more time was required to recognize the differences between the two objects. This result highlights the importance of presenting angle in identifying the 3D model in the surrounding environment.

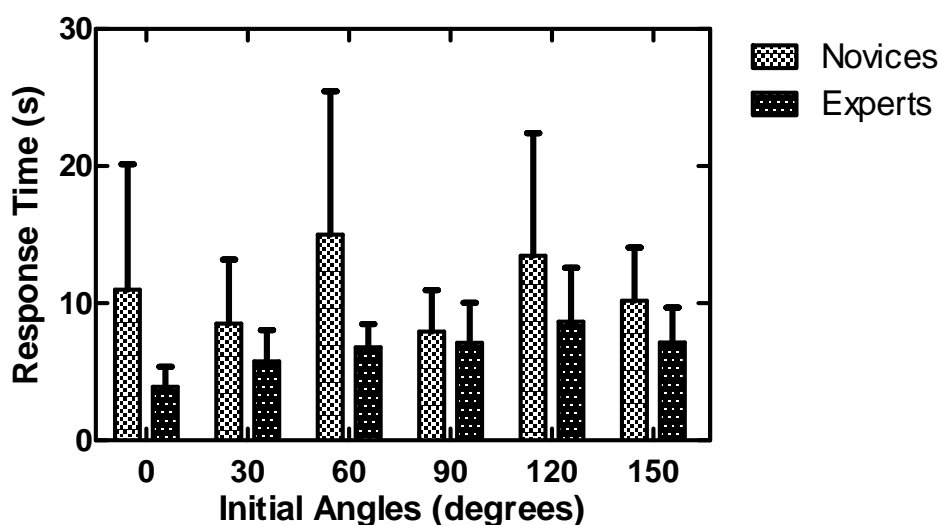


Figure 3.3. Mean reaction time for same pairs vs. angle of rotation in experts.

No correlation was found between the initial angle and response time for novices ( $r^2 = 5.32 \times 10^{-3}$ ). However, novices' response times for certain angles were comparable to that of experts. A closer look at these angles reveals that these representation angles provide a visual advantage. For example at 0 degree difference, experts were able to compare the two models and make their selection very fast (Fig 3.4) on the other hand, novices weren't confident enough to make their selection right away despite the fact that both



models were the same and presented with the same initial angle. At 90 degrees difference, subjects were able to see all sides of the mobile object before they started interacting with them, and therefore, they required less time to identify the similarities and differences between the two shapes (Fig 3.6). Conversely, novices found it more challenging to determine the differences between the two models for presenting angles with 60° difference where initially not all parts of the mobile object were visible (Fig 3.5).

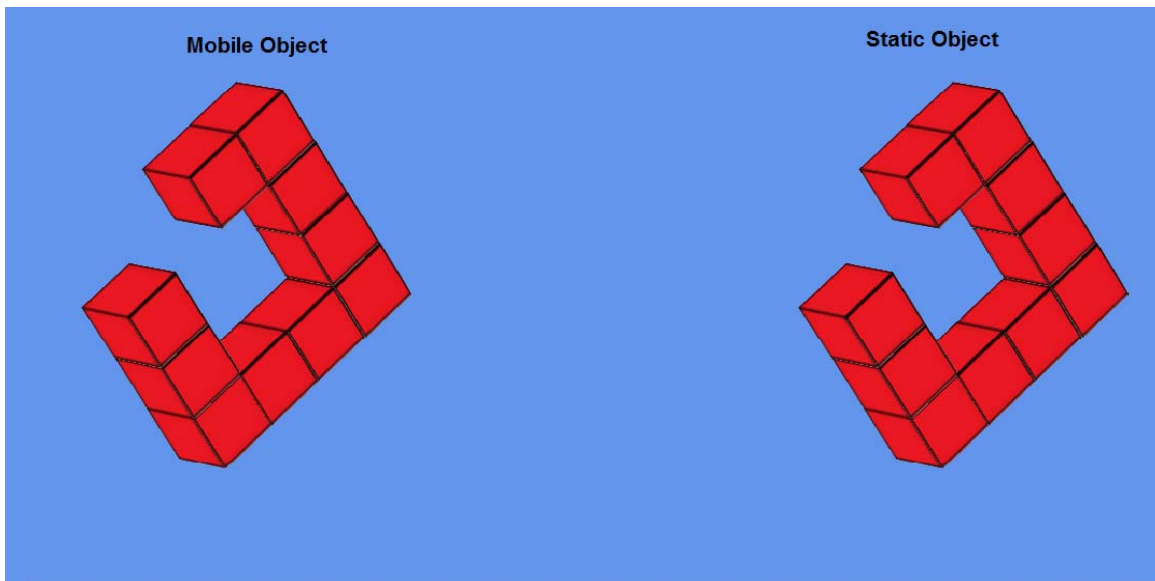


Figure 3.4. Presenting the two shapes on the screen with 0° different in initial angle. The left model is presented with 30° angle rotation on X,Y,Z.

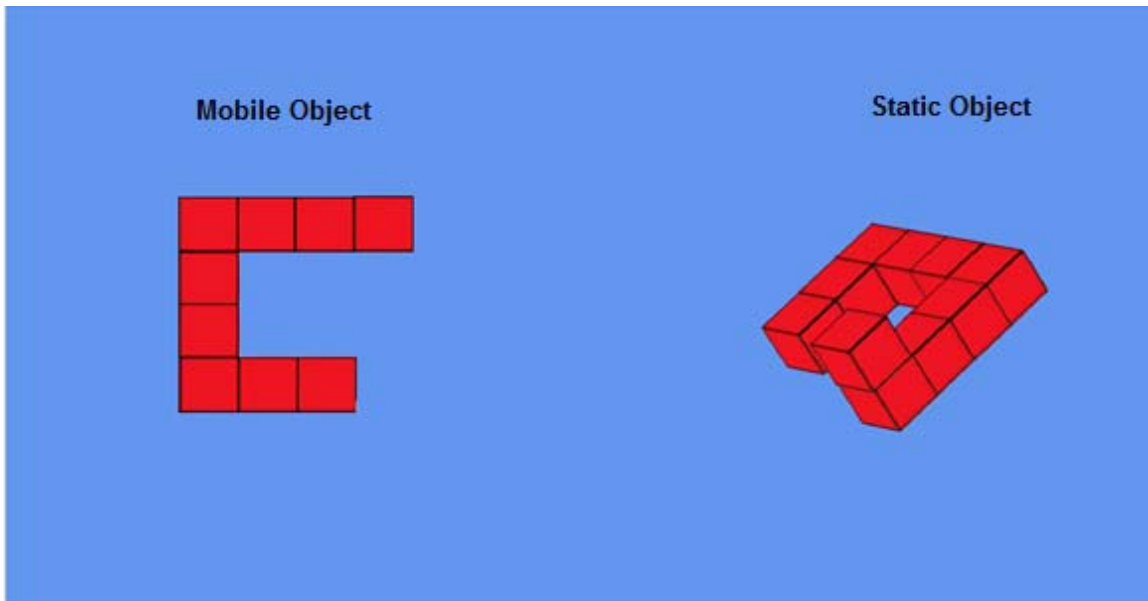


Figure 3.5. Presenting the two shapes on the screen with  $60^\circ$  different in initial angle. The left model is presented with  $90^\circ$  angle rotation on X,Y,Z.

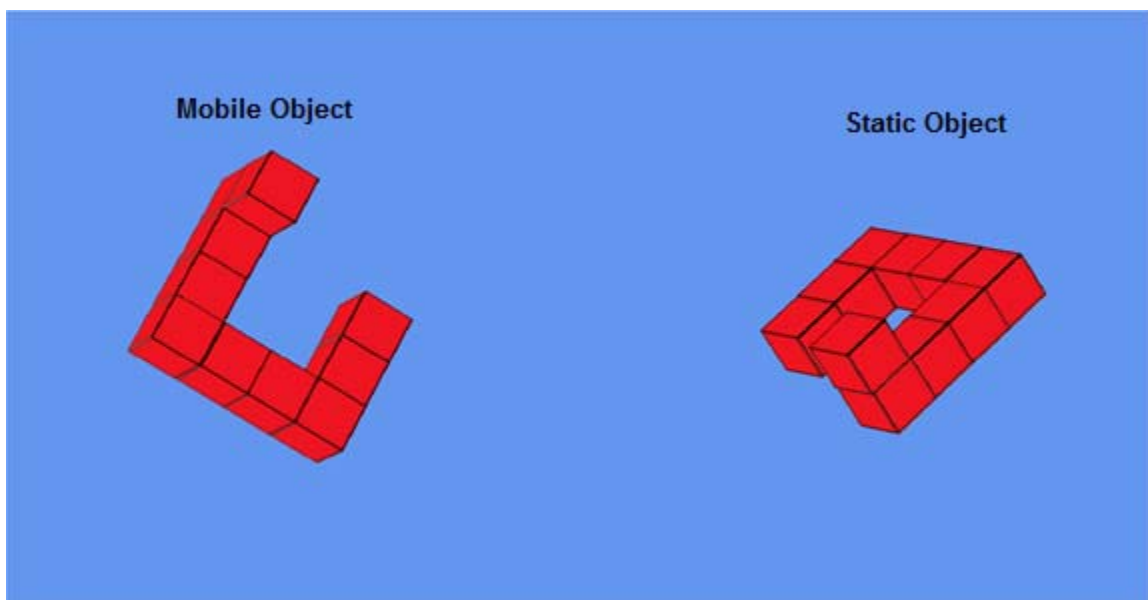


Figure 3.6. Presenting the two shapes on the screen with  $90^\circ$  different in initial angle. The left model is presented with  $120^\circ$  angle rotation on X,Y,Z .

The results indicate that experts exhibited superior mental rotation capabilities as they consistently identified the correct pairs faster than the novices for all viewing angles. Further, experts were able to mentally manipulate the mobile objects significantly faster even when parts of the objects were concealed for some of the viewing angles.

Translation of the results to clinical settings may suggest that when surgeons face a landmark of interest from an angle that does not visually match their mental spatial representation, experts can manipulate camera angle in a shorter amount of time and orient themselves faster than novices. This can partially explain the reason many junior surgical residents find it far simpler to perform laparoscopy after an experienced surgeon makes small adjustments in camera angle and instrument placement to obtain proper exposure to the surgical site [24].

The framework provided in this work can be utilized by investigators to explore the vast possibilities of recognizing factors affecting individual components of spatial ability, their interdependencies, and relationship of each to specific surgical tasks used in MIS.

# Chapter 4

## **Summary and Future Directions**

With recent increase in number of minimally invasive surgeries and given the important role of spatial reasoning required for this type of surgery, it is evident that the spatial reasoning skills of the surgical trainees must be monitored as they progress during the training program.

The standard spatial ability tests do not explore the factors affecting decision-making process on spatial information. The interactive 3D testing environment designed in this work is capable of quantifying user's spatial ability, and further provide a configurable environment for investigators to study the underlying visual elements that may affect spatial cognition.

The designed framework was tested in an experiment with participants including experienced and novice surgeons. A summary of the findings is presented in this chapter, and avenues for future research on this topic are discussed in the following sections.

## 4.1 Thesis Summary

- The designed 3D environment allowed user to interact with the mobile object. This interaction assisted users to have selective access to key viewpoints, and ultimately assisted the mental reconstruction of the two 3D objects as well as understanding the spatial relation between different parts of 3D models.
- A comparison of scores of expert and novice users from 3D Mental Rotation Test and Embedded Figures Test suggested that response time might be a better evaluation variable for measurement of the spatial ability than score. The response time of experts was significantly lower than that of novices.
- Calot's Triangle Test was used to evaluate general surgical knowledge of participants. Lower score of novices on Calot's Triangle Test along with their longer response on 3D Mental Rotation Test suggested that spatial ability of junior surgical residents can be improved as a result of training.
- The importance of the presenting angle for 3D models as one of the visual cues involve in spatial ability was discussed. Presenting angle may provide additional contrast and enable users to spend less time rotating the model to identify the similarities and differences between the two shapes.

## 4.2 Future Directions

The presented 3D interactive model identified the initial angle as one of the visual cues that may affect spatial cognition. This work can be extended by investigating the effect of the highlighted edges and non-uniform surface texture of the 3D objects as other visual cues that can affect spatial reasoning [35]. For example, the transparent cubes may help users to visualize the differences in the planes and edges easier and therefore shorten the reaction time. The difficulty level of the 3D Mental Rotation Test also can be extended by using a transparent cube that includes another 3D object inside. Additionally, we can extend the experiments by designing a trial in which each participant has to detect the differences between each pair of 3D object in a set amount of time so we can ensure that time limitation does not affect the participant's score.

Further, given the influences of experience on spatial reasoning skills, future work can be focused on creating a gold standard based on the responses of experienced surgeons. The response of junior surgical residents can be evaluated against this gold standard to monitor their progress as they advance in the surgical training program.

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# Appendix A

The Code for moving the 3D model with the mouse movement:

```

GraphicsDevice device = graphics.GraphicsDevice;
MouseState newMouse = Mouse.GetState();
if (newMouse.LeftButton == ButtonState.Pressed)
{
    flag = 1;

    int updown, leftright;
    updown = lastMousePoint.Y - newMouse.Y;
    leftright=lastMousePoint.X -
    newMouse.X;_worldRotationX*=Matrix.CreateRotationX((float)(updown
) / (float)(100.0f));
_worldRotationY*=Matrix.CreateRotationY((float)(leftright)/
(float)(100.0f));

    lastMousePoint = new Point(newMouse.X, newMouse.Y);
    mouseDown = true;
}
else
{
    mouseDown = false;
}

```

## Appendix B

Sample code to present the three points to form a Calot's Triangle on an image and modifies the triangle after the initial draw:

```

mouseDown = true;
stopwatch.Start();
if(_firstLocation == Point.Empty)
{
    _firstLocation = new Point(e.X, e.Y);
    return;
}

if (_secondLocation == Point.Empty)
{
    _secondLocation = new Point(e.X, e.Y);
    return;
}

if (_lastLocation == Point.Empty)
{
    _lastLocation = new Point(e.X, e.Y);
    pictureBox1.Image = img;
    return;
}
if(firstTriangle && mouseDown)
{
    double toFirstPoint =Math.Sqrt(Math.Pow(Math.Abs(e.X
- _firstLocation.X), 2) + Math.Pow(Math.Abs(e.Y -
_firstLocation.Y), 2));
    double toSecondPoint=Math.Sqrt(Math.Pow(Math.Abs(e.X
- _secondLocation.X), 2) + Math.Pow(Math.Abs(e.Y -
_secondLocation.Y), 2));

    double toLastPoint =Math.Sqrt(Math.Pow(Math.Abs(e.X -
_lastLocation.X), 2) + Math.Pow(Math.Abs(e.Y -
_lastLocation.Y), 2));

    if(toFirstPoint<toSecondPoint&&toFirstPoint<toLastPoi
nt)
    {
        _firstLocation = new Point(e.X,e.Y);
    }
    elseif(toSecondPoint<toFirstPoint && toSecondPoint <
toLastPoint)
    {
        _secondLocation = new Point(e.X,e.Y);
    }
    else
    {
        _lastLocation = new Point(e.X,e.Y);
    }
}
}

```

## Appendix C

Sample code for recording the time and triangle coordinates on each image in Calot's Triangle Test:

```
private void button2_Click(object sender, EventArgs e)
{
    int randomIndex = 0;
    Random random = new Random();

    randomIndex = random.Next(0, imageNames.Count);
    string strFirstLoc =
        _firstLocation.X.ToString()+","+_firstLocation.Y.ToString()
    ;
    string strSecondLoc = _secondLocation.X.ToString() + "," +
        _secondLocation.Y.ToString();
    string strLastLoc = _lastLocation.X.ToString() + "," +
        _lastLocation.Y.ToString();

    if (randomIndex == 0 && imageNames.Count != 0)
    {
        img =Image.FromFile(path +imageNames[0]);
        pictureBox1.Image = img;
        ts = stopwatch.Elapsed;
        String elapsedTime = String.Format("{0:00}.{1:00}",
            ts.Seconds, ts.Milliseconds);
        tw.WriteLine(temp + "," + imageNames[0] +","+strFirstLoc + "," + strSecondLoc +","+ strLastLoc +
            "," + elapsedTime);
        imageNames.Remove(imageNames[0]);
        tw.Flush();
    }
    else if (randomIndex != 0 && imageNames.Count != 0)
    {
        img =Image.FromFile(path +imageNames[randomIndex]);
        pictureBox1.Image = img;
        ts = stopwatch.Elapsed;
    }
}
```

```
String elapsedTime = String.Format("{0:00}.{1:00}",
    ts.Seconds, ts.Milliseconds);
tw.WriteLine(temp + "," + imageNames[randomIndex]
    +","+ strFirstLoc + "," + strSecondLoc + "," +
    strLastLoc + "," + elapsedTime);

    imageNames.Remove(imageNames[randomIndex]);
    tw.Flush();
}
else
{
    img =Image.FromFile(path+"Done.jpg");
    pictureBox1.Image = img;
    ts = stopwatch.Elapsed;
    tw.Flush();
}
_firstLocation = Point.Empty;
_lastLocation = Point.Empty;
_secondLocation = Point.Empty;
stopwatch.Stop();
stopwatch.Reset();
pictureBox1.Refresh();
}
```

# Appendix D

The sample stored log file from Interactive 3D model

<b>Time</b>	<b>User selection</b>	<b>Models Comparison</b>	<b>Model 1</b>	<b>Model 2</b>	<b>Presenting Angle</b>
8.25	N	NO	9CubesShape3Right	9CubesShape8	3.14
11.158	N	NO	9CubesShape5	9CubesShape1	2.61
10.791	Y	YES	9CubesShape4	9CubesShape4	2.61
8.879	N	NO	9CubesShape7	9CubesShape1	0.52
17.455	Y	YES	9CubesShape8	9CubesShape8	0.52
6.479	N	NO	9CubesShape5Right	9CubesShape3Right	1.04
5.495	N	NO	9CubesShape4Right	9CubesShape7	1.57
18.15	N	NO	9CubesShape3Right	9CubesShape9	1.04
4.799	N	NO	9CubesShape5Right	9CubesShape2	0.52
3.887	N	NO	9CubesShape4	9CubesShape2	3.14
13.367	N	NO	9CubesShape8	9CubesShape4	2.61
5.279	N	NO	9CubesShape5Right	9CubesShape5	0.52
7.279	N	NO	9CubesShape5Right	9CubesShape8	1.04
5.575	N	NO	9CubesShape6	9CubesShape3	2.61
4.847	N	YES	9CubesShape2Right	9CubesShape2Right	2.093
4.79	N	NO	9CubesShape7Right	9CubesShape5	0.52
1.872	N	NO	9CubesShape7Right	9CubesShape8	2.61
4.297	N	NO	9CubesShape1Right	9CubesShape8	2.093
4.797	N	NO	9CubesShape1Right	9CubesShape9	2.093
4.479	N	NO	9CubesShape7Right	9CubesShape6Right	3.14
2.815	N	NO	9CubesShape9Right	9CubesShape1	1.04
1.935	N	NO	9CubesShape7	9CubesShape4	0.52
2.199	N	NO	9CubesShape7Right	9CubesShape4	1.57
2.855	N	NO	9CubesShape5Right	9CubesShape4Right	1.57
2.992	N	NO	9CubesShape8	9CubesShape7	2.093
3.15	N	NO	9CubesShape2Right	9CubesShape3	0.52
10.207	N	NO	9CubesShape8Right	9CubesShape2	1.57
4.223	N	NO	9CubesShape5	9CubesShape2	1.57
4.87	N	NO	9CubesShape9	9CubesShape2	1.04
2.167	N	NO	9CubesShape6Right	9CubesShape2Right	0.52
2.752	N	NO	9CubesShape3	9CubesShape2	1.57
11.815	Y	YES	9CubesShape9Right	9CubesShape9Right	3.14
17.455	N	NO	9CubesShape4Right	9CubesShape9	1.04
1.847	N	NO	9CubesShape9Right	9CubesShape3	2.61
6.127	N	NO	9CubesShape9Right	9CubesShape8	2.61
4.127	N	NO	9CubesShape9	9CubesShape6	1.04
2.471	N	NO	9CubesShape2Right	9CubesShape6	1.57
3.551	N	NO	9CubesShape2Right	9CubesShape5	2.61
1.735	N	NO	9CubesShape1Right	9CubesShape3	0.52
2.647	N	NO	9CubesShape8Right	9CubesShape7Right	0.52
10.95	N	NO	9CubesShape2Right	9CubesShape4	1.57
3.223	N	NO	9CubesShape8Right	9CubesShape3	3.14
3.239	N	NO	9CubesShape8	9CubesShape3	0.52
5.887	Y	YES	9CubesShape8Right	9CubesShape8Right	3.14
2.39	N	NO	9CubesShape8	9CubesShape1	1.57
1.799	N	NO	9CubesShape7Right	9CubesShape2	0.52
2.207	N	NO	9CubesShape4Right	9CubesShape6	0.52
11.791	N	NO	9CubesShape3Right	9CubesShape3	1.57
10.535	N	NO	9CubesShape4Right	9CubesShape3	1.04

6.231	Y	YES	9CubesShape1	9CubesShape1	2.093
13.72	N	NO	9CubesShape6Right	9CubesShape5Right	3.14
10.943	N	NO	9CubesShape9Right	9CubesShape5	0.52
6.655	N	NO	9CubesShape9Right	9CubesShape8Right	1.57
1.744	N	NO	9CubesShape1Right	9CubesShape4	3.14
1.543	N	NO	9CubesShape5	9CubesShape3	0.52
1.551	N	NO	9CubesShape9Right	9CubesShape2Right	2.093
2.311	N	NO	9CubesShape2Right	9CubesShape1	0.52
4.215	N	NO	9CubesShape9Right	9CubesShape7Right	2.61
1.431	N	NO	9CubesShape7	9CubesShape5	1.04
9.511	N	NO	9CubesShape4Right	9CubesShape5	2.61
7.496	Y	YES	9CubesShape5Right	9CubesShape5Right	2.61
1.407	N	NO	9CubesShape4Right	9CubesShape1Right	1.04
2.191	N	NO	9CubesShape8	9CubesShape6	1.04
16.647	N	NO	9CubesShape9Right	9CubesShape4	2.093
1.952	N	NO	9CubesShape3Right	9CubesShape4	0.52
1.719	N	NO	9CubesShape6Right	9CubesShape4Right	2.61
2	N	NO	9CubesShape1Right	9CubesShape6	2.093
2.719	N	NO	9CubesShape3Right	9CubesShape7	2.093
3.6	N	NO	9CubesShape8Right	9CubesShape5Right	3.14
8.376	N	NO	9CubesShape8Right	9CubesShape5	2.093
1.391	N	NO	9CubesShape7Right	9CubesShape3Right	1.57
3.88	N	NO	9CubesShape6Right	9CubesShape8	3.14
8.279	N	NO	9CubesShape5Right	9CubesShape4	3.14
4.207	N	NO	9CubesShape9	9CubesShape8	1.04
1.615	N	NO	9CubesShape3Right	9CubesShape5	1.57
2.591	N	NO	9CubesShape2Right	9CubesShape2	2.093
4.39	N	NO	9CubesShape9	9CubesShape3	1.04
5.383	Y	YES	9CubesShape7Right	9CubesShape7Right	0.52
2.72	N	NO	9CubesShape3Right	9CubesShape2Right	1.04
1.511	N	NO	9CubesShape3Right	9CubesShape1Right	1.57
1.559	N	NO	9CubesShape6Right	9CubesShape1	2.61
2.711	N	NO	9CubesShape1Right	9CubesShape5	1.57
3.287	N	NO	9CubesShape6	9CubesShape5	3.14
2.192	N	NO	9CubesShape2Right	9CubesShape7	1.57
4.583	Y	YES	9CubesShape5	9CubesShape5	3.14
1.415	N	NO	9CubesShape9	9CubesShape7	0.52
4.431	N	NO	9CubesShape6Right	9CubesShape9	1.04
7.912	Y	NO	9CubesShape8Right	9CubesShape8	2.093
1.647	N	NO	9CubesShape1Right	9CubesShape2	1.57
3.31	N	NO	9CubesShape9Right	9CubesShape6Right	0.52
1.415	N	NO	9CubesShape8Right	9CubesShape7	2.093
6.199	N	NO	9CubesShape9Right	9CubesShape9	1.04
1.695	Y	YES	9CubesShape1Right	9CubesShape1Right	0.52
3.48	N	NO	9CubesShape8Right	9CubesShape1Right	2.093
1.319	N	NO	9CubesShape7Right	9CubesShape1Right	1.57
2.167	N	NO	9CubesShape4	9CubesShape1	3.14
1.519	N	NO	9CubesShape8Right	9CubesShape1	1.04
2.463	N	NO	9CubesShape8Right	9CubesShape3Right	0.52
2.512	N	NO	9CubesShape8Right	9CubesShape2Right	2.093
1.327	N	NO	9CubesShape2	9CubesShape1	0.52
3.631	N	NO	9CubesShape6Right	9CubesShape6	0.52
2.447	N	NO	9CubesShape7	9CubesShape3	1.04
8.999	N	NO	9CubesShape8Right	9CubesShape6Right	3.14
4.55	N	NO	9CubesShape5Right	9CubesShape9	3.14
2.191	N	NO	9CubesShape5Right	9CubesShape1Right	3.14



14.135	N	NO	9CubesShape8Right	9CubesShape9	3.14
3.4	N	NO	9CubesShape5Right	9CubesShape3	1.57
5.295	Y	YES	9CubesShape3Right	9CubesShape3Right	1.04
1.896	N	NO	9CubesShape7Right	9CubesShape4Right	1.04
3.543	N	NO	9CubesShape8Right	9CubesShape6	1.57
1.512	N	NO	9CubesShape3Right	9CubesShape6	1.57
3.63	Y	YES	9CubesShape6	9CubesShape6	0.52
1.983	N	NO	9CubesShape9Right	9CubesShape1Right	1.57
9.896	N	NO	9CubesShape9Right	9CubesShape4Right	3.14
3.575	N	NO	9CubesShape2Right	9CubesShape8	2.093
5.967	Y	YES	9CubesShape7	9CubesShape7	2.61
2.55	N	NO	9CubesShape6Right	9CubesShape5	1.57
5.464	N	NO	9CubesShape5	9CubesShape4	3.14
3.631	Y	YES	9CubesShape4Right	9CubesShape4Right	0.52
3.256	Y	YES	9CubesShape3	9CubesShape3	0.52
2.607	N	NO	9CubesShape6Right	9CubesShape2	1.04
3.607	N	NO	9CubesShape9Right	9CubesShape5Right	2.093
1.879	N	NO	9CubesShape9	9CubesShape4	1.04
2.655	N	NO	9CubesShape7Right	9CubesShape5Right	0.52
1.551	N	NO	9CubesShape6Right	9CubesShape3Right	0.52
1.519	N	NO	9CubesShape5Right	9CubesShape7	1.04
1.335	N	NO	9CubesShape5Right	9CubesShape6	1.04
13.727	N	NO	9CubesShape7Right	9CubesShape9	2.61
5.152	N	NO	9CubesShape5Right	9CubesShape2Right	1.04
2.223	N	NO	9CubesShape6	9CubesShape4	1.57
4.455	N	NO	9CubesShape8Right	9CubesShape4Right	3.14
6.623	N	NO	9CubesShape9Right	9CubesShape2	2.61
3.775	N	NO	9CubesShape8	9CubesShape5	1.04
2.175	N	NO	9CubesShape3	9CubesShape1	2.093
2.32	Y	YES	9CubesShape2	9CubesShape2	0.52
8.431	N	NO	9CubesShape8	9CubesShape2	3.14
6.288	Y	YES	9CubesShape6Right	9CubesShape6Right	1.04
2.951	N	NO	9CubesShape4Right	9CubesShape2Right	0.52
5.743	N	NO	9CubesShape4Right	9CubesShape4	2.61
6.08	Y	NO	9CubesShape7Right	9CubesShape7	2.61
2.281	N	NO	9CubesShape7	9CubesShape6	1.57
3.926	N	NO	9CubesShape9	9CubesShape5	2.093
3.111	N	NO	9CubesShape9Right	9CubesShape3Right	1.57
13.391	N	NO	9CubesShape2Right	9CubesShape9	2.61
1.687	N	NO	9CubesShape6	9CubesShape2	1.57
2.471	N	NO	9CubesShape6Right	9CubesShape7	3.14
2.112	N	NO	9CubesShape6	9CubesShape1	3.14
4.95	N	NO	9CubesShape9Right	9CubesShape7	2.61
12.319	Y	YES	9CubesShape9	9CubesShape9	3.14
3.783	N	NO	9CubesShape7Right	9CubesShape3	3.14
4.423	N	NO	9CubesShape6Right	9CubesShape4	1.57
1.535	N	NO	9CubesShape4Right	9CubesShape1	3.14
1.407	N	NO	9CubesShape9	9CubesShape1	2.61
3.296	N	NO	9CubesShape6Right	9CubesShape1Right	2.61
2.31	N	NO	9CubesShape9Right	9CubesShape6	2.61
1.448	N	NO	9CubesShape7Right	9CubesShape2Right	1.57
6.551	N	NO	9CubesShape4Right	9CubesShape2	1.04
6.295	N	NO	9CubesShape7Right	9CubesShape6	1.04
3.96	N	NO	9CubesShape6Right	9CubesShape3	0.52
2.222	N	NO	9CubesShape5Right	9CubesShape1	3.14
1.111	N	NO	9CubesShape2Right	9CubesShape1Right	1.04

6.255	N	NO	9CubesShape8Right	9CubesShape4	3.14
1.688	N	NO	9CubesShape4Right	9CubesShape3Right	0.52
1.159	N	NO	9CubesShape7Right	9CubesShape1	0.52
9.79	Y	NO	9CubesShape1Right	9CubesShape1	2.093
2.711	N	NO	9CubesShape1Right	9CubesShape7	2.61
1.751	N	NO	9CubesShape3Right	9CubesShape1	2.093
2.519	N	NO	9CubesShape7	9CubesShape2	2.61
3.423	N	NO	9CubesShape4Right	9CubesShape8	0.52
1.743	N	NO	9CubesShape3Right	9CubesShape2	1.04

# Curriculum Vitae

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