Development of Mental Rotation Skills Using 3D Visualization Tool

Submitted in partial fulfilment of the requirements

For the degree of

Doctor of Philosophy

by

Kapil Kadam
(**Roll Number:** 10438002)

Supervisor:

Prof. Sridhar Iyer

Interdisciplinary Program in Educational Technology

INDIAN INSTITUTE OF TECHNOLOGY, BOMBAY

2017

Dedication Sheet

Dedicated

to

my Family Members

my Teachers

my Department: IITB-EdTech

and

my Friends

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

<div align="right">

_____

(Signature)
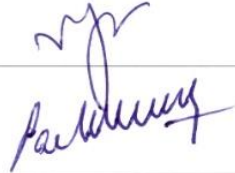
_____

(Name of the student)

_____

(Roll No.)

</div>

Date: _____

Approval Sheet

This thesis entitled **"Development of Mental Rotation Skills Using 3D Visualization Tool"** by Kapil Kadam is approved for the degree of Doctor of Philosophy.
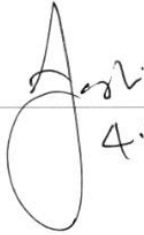
Examiners

_____

_____

_____

Supervisor (s)

_____

_____

_____

Chairman

Date: 4.7.2018

Place: Mumbai

_____

Abstract

First-year undergraduate students in engineering often face difficulties in learning and solving the engineering drawing (ED) problems that require visualization of three-dimensional objects. Conventional methods of teaching ED require students to learn the course for a semester-long duration, and it involves them to do the practice of sketching and drawing for longer durations. Certainly, these teaching methods assist the learning of a subject but do not guarantee the elimination of the learning difficulties entirely (Akasah & Alias, 2010; Kosse, 2005).

In modern teaching methods, instructors make use of software tools such as computer-aided design (CAD), multimedia tutors, and web-based instructions as a supplementary visual aid for learning of ED concepts (Branoff & Mapson, 2009; Cincou, 2013; Jerz, 2002). These methods found to be useful in the teaching of the engineering drawing course and involve various additional activities like content presentations with voice-over, demonstrations of software, and videos of sketching. Despite the fact that these methods are useful in improving the learning of ED concepts and skills; certain difficulties remain (Kuang & Thomas, 2004). One of the potential reasons is students' deficiency in visualizing spatial relationships, i.e., poor spatial skills.

This problem is significant in the context of engineering domain because ED is one of the fundamental courses for various engineering disciplines like Mechanical Engineering and Civil Engineering. Spatial skills, such as mental rotation (MR) play a major role in learning concepts that involve 3D visualization. Consequently, for the successful learning of such courses, students should be trained for the development of MR skill.

In order to address the issue, we have created a Blender-based training program '**TIMeR**' to improve mental rotation skills of the students and hence the learning of relevant concepts. **TIMeR** stands for '**T**raining to **I**mprove **Me**ntal **R**otation Skills'. TIMeR has three phases which are the preparatory phase, the training phase, and the transfer phase. Each phase has hands-on MR training task which is tightly coupled with the cognitive steps of mental rotation. Each task is executed using the instructional strategy of demo-drill-practice (DDP).

In this thesis, we present the work carried out in order to develop TIMeR and investigate its impact on the improvement of students' MR skill. We also extended the work to the domain of

engineering drawing and computer graphics. Total seven empirical research studies were carried out by applying mixed methods research design. The key results include (i) TIMeR found to be effective in the development of mental rotation skill, engineering drawing problem-solving performance and computer graphics problem-solving performance (ii) TIMeR helped students in resolving their engineering drawing learning difficulties (iii) TIMeR resulted as a workshop model and was successfully incorporated in engineering drawing course. The training structure would be useful for teachers to create their own mental rotation training program when the training objects are of three-dimensional nature.

Table Contents

List of Figures

List of Tables

Abbreviations and Acronyms

ACW	Anti Clock-Wise
CAD	Computer Aided Design
CBMT	Computer Based Multimedia Training
CBT	Computer Based Training
CG	Computer Graphics
CW	Clock Wise
DAT: SR	Differential Aptitude Test: Spatial Relations
DDP	Demo-Drill-Practice
DQ	Design Question
ED	Engineering Drawing
FGI	Focus Group Interview
LMB	Left Mouse Button
MCT	Mental Cutting Test
MI	Multiple Intelligence
MMB	Middle Mouse Button
MR	Mental Rotation
MRT	Mental Rotation Test
OPT	Orthographic Projection Test
PFT	Paper Folding Test
PP Plot	Probability-Probability Plot
PSVT	Purdue Spatial Visualization Test
QQ Plot	Quantile-Quantile Plot
RJ	Reflective Journal
RMB	Right Mouse Button
RQ	Research Question
SVATI	Spatial Visualization Ability Test Instrument
TIMeR	Training to Improve Mental Rotation Skills
UI	User Interface
VMRT	Vandenberg's Mental Rotation Test
2D/3D	Two/Three Dimensional

Chapter 1

Introduction

1.1 Background and Motivation

It is well known that freshman engineering students face various difficulties in learning engineering drawing (ED), (Garmendia, Guisasola, & Sierra, 2007; Nagy-Kondoor, 2007; Upadhye, Shaikh, & Yalsingikar, 2013). Some of these difficulties are the analysis of the shapes of surfaces of a three-dimensional object, interpretation and analysis of the various views of a three-dimensional object, and visualization of a three-dimensional object. One reason for this is that students have difficulties in learning the concepts of orthographic projections and isometric projections, where it is required to identify and visualize multiple views of a three-dimensional object. This leads to challenges in performing the transformations between two-dimensional (2D) and three-dimensional (3D) views of an object (Akasah & Alias, 2010; Jiannan, 1998; Kosse, 2005; Nagy-Kondoor 2007).

Visualization of a three-dimensional object is complex in nature, and hence it causes the difficulty in performing the transformations between 2D projections and 3D views of objects (Akasah & Alias, 2010; Jiannan, 1998; Kosse, 2005). Teachers also find it challenging to explain the three-dimensional concepts of orthographic and isometric views. (Khabia & Khabia, 2012; Sutton, Heathcote, & Bore, 2005; Upadhye, et al., 2013).

Conventional instruction methods of teaching engineering drawing require students to learn engineering drawing course for a semester-long duration, and it involves them to do the practice of sketching and drawing for longer durations. Such teaching techniques assist the learning of a subject but do not guarantee the elimination of the learning difficulties entirely (Akasah & Alias, 2010; Kosse, 2005). In modern instruction methods, instructors make use of software tools such as computer-aided design (CAD), multimedia tutors, animations, and web-based instructions as a supplementary visual aid in learning (Branoff & Mapson, 2009; Cincou, 2013; Froese, et al., 2013; Jerz, 2002; Wu & Chang, 2013). These methods found to be useful in the teaching of the engineering drawing course and involve various additional activities such as content presentations with voice-over, demonstrations of software, and videos of sketching. Despite the fact that these techniques are useful in improving the learning of engineering drawing concepts and skills, certain difficulties remain. These are the interpretation of engineering drawings and manipulation of objects required for performing 2D and 3D transformations (Kuang & Thomas, 2004).

The persistence of these learning difficulties in ED raises the question what are the fundamental reasons for the continued existence of such problems? One of the potential reasons is students' poor spatial skills (Medupin, et al 2015).

Spatial skills play an important role for learning concepts that involves 3D visualization of an object, and for acquiring knowledge in engineering drawing concepts. Consequently, for the successful learning of such courses, students should be trained to acquire these skills (Alias, 2000; Leopold, Gorska, & Sorby, 2001; Nagy-Kondor, 2007). This motivated us to identify the underlying spatial skills and the methods of training for the improvement of those spatial skills, and to develop our own training method. In the next part, we present an overview of spatial skills and spatial skills training methods.

1.2 Spatial Skills and their Improvement

Overview of Spatial Skills

Spatial skill is the skill of performing mental rotation of objects, visualizing how objects appear at different angles, and conceptualizing how objects relate to each other in 3-D space (Sutton & Williams, 2007). This skill is differentiable from other types of intelligence, such as verbal ability, reasoning ability, and memory skills. Spatial skill is required to construct efficient mental models of objects. The spatial task includes the formation of mental representations of objects configuration from a different perspective of objects.

Spatial skill has various components, which are interrelated with each other. These are spatial perception, mental rotation, and spatial visualization (Maier, 1998). We identified mental rotation (MR) skill, a major component of spatial skills. Maier defines mental rotation as "the ability to rapidly and accurately rotate a 2D or 3D figure" (Maier, 1998). Mental rotation is a significant aspect of learning and problem-solving that involves imagination and visualization of a 3D object.

Mental Rotation: Mental rotation plays an important role in the learning of engineering drawing concepts. (Kadam & Iyer, 2014, 2015; Khabia & Khabia, 2012; Maier, 1994; Norman, 1994; Olkun, 2003; Voyer, et al., 1995; Yue, 2009). For example, to perform the transformations between 2D and 3D, the cognitive process often requires doing the mental rotation as an essential sub-step for visualizing the object from different perspectives. Thus, we have identified mental rotation as one of the essential steps to learn and solve engineering drawing problems of 3D nature.

Improvement of Spatial Skills: Studies have shown that spatial skills can be improved by training (Olkun, 2003; Sorby, 2009; Yue, 2009; Ferguson, et al., 2008; Martin-Dorta, et al., 2008, 2011). To improve spatial skills, especially for engineering students a variety of approaches have been devised by engineering educators. These methods are comprised of increased sketching practices of 3D objects, use of 3D objects as a manipulative, computer-aided design (CAD) courses, and use of computer graphics animations of rotating 3D objects.

(Ault 2010, Ardebili, 2006; Crown, 2001; Ferguson et al., 2008; Holliday-Darr et al., 2003; Miller, 1992; Olkun, 2003; Onyancha et al., 2007, 2009; Sutton & Williams, 2007).

However, it is essential to focus on the improvement of skill that is an important aspect of three-dimensional visualization skills, which in this case is a mental rotation. Interventions to improve the mental rotation skill also range from physical activities (Flusberg, 2011; Olkun, 2003), to computer-based training (Samsudin & Ismail, 2004; Samsudin, et al., 2011, Vandenberg & Kuse, 1978; Wiedenbaur & Jansen-Osman, 2008; Yue, 2009).

Our interest lies in computer-based training for the improvement of mental rotation. The existing computer-based training methods are found to be useful in developing spatial skills, but most of them focused on developing multiple spatial skills during the study and did not focus on a specific spatial skill. Focusing on the development of multiple skills at the same time may affect the development of individual skill. Therefore, we focus on the development of a single spatial skill. The existing studies also found to have training duration spread over weeks, i.e., about five to sixteen weeks or semester-long duration. (Gillespie, 1995; Godfrey, 1999; Thomas, 1996; Turner, 1997; Yate, 1998; Zaiyouna, 1995). While this is valid, we wanted to explore the effect of shorter duration training by focussing on single spatial skill, i.e., mental rotation. In the next part, we present the research goal and the research questions that we are investigating in this thesis.

1.3 Research Questions (RQ)

Our broad research goal is to improve student's spatial skills using computer-based training. Our specific research goal is to investigate the effect of our training using a 3D visualization tool on the improvement of mental rotation skill. The nature of activities to improve spatial skills are also similar to the tasks used in teaching-learning of engineering drawing (Baartmans & Sorby, 1996; Ben-Chaim, Lappan, Houang, 1985; Smail, 1983). So, we extended our research goal to investigate the effect of our training on students' engineering drawing problem-solving performance, and further to the computer graphics domain.

We have developed a computer-based training to improve mental rotation skill and hence to enhance the learning of relevant engineering drawing and computer graphics concepts. We have used Blender, an open source 3D interactive visualization tool (Blender website, 2012, 2017) for content creation and hands-on training. The training is specifically targeted towards the enhancement of mental rotation skill. We call our intervention as *"TIMeR: Training to Improve Mental Rotation Skills using Blender"* Thus, we have the following specific research questions:

RQ1: How effective is TIMeR for improving students' MR skill?

RQ2: How effective is TIMeR for improving first-year engineering undergraduate students' engineering drawing problem-solving performance?

RQ3: In what way does TIMeR resolve the learning difficulties that students face while solving the engineering drawing problems?

RQ4: How effective is TIMeR for improving students' computer graphics problem-solving performance?

In the next part, we present an overview of TIMeR.

1.4 TIMeR: Training to Improve MR Skills using Blender

As mentioned earlier we name our training as *"TIMeR: Training to Improve Mental Rotation Skills using Blender."* The key aspects of TIMeR are as follows.

Blender: TIMeR is a computer-based training, using Blender an open source 3D visualization tool. Blender provides a 3D workspace for 3D visualization, it has an interactive user interface, it supports easy customization of the interface, and it also supports easy and rich 3D content development. Further, Blender can run on any platform and is easily trainable, (Blender website, 2012, 2017). We used Blender for content development, and for hands-on training. Blender allows interactivity with 3D models and 3D view, that could be achieved by making use of keyboard and mouse controllers.

Hands-on Training: Participants receive hands-on, i.e., practical training, wherein they essentially get to use the Blender tool and get to perform the training tasks. Hands-on tasks involve active manipulation of three-dimensional objects.

Three Phase Training: Training is divided into three different phases: the preparatory phase (phase 1), the training phase (phase 2) and transfer phase (phase 3). Each phase consists training tasks relevant to mental rotation.

Alignment to Cognitive Steps of MR: We have used the cognitive steps of mental rotation as the basis for designing TIMeR tasks. Essentially, these steps are operationalized as the training tasks so that each one is aligned with those respective steps. The cognitive steps of mental rotation as specified by Johnson (1990) involve: (a) formation of a mental representation of an object, (b) mental rotation of the object until its axial orientation allows the comparison, (c) the comparison, (d) making a judgment, and (e) reporting a decision.

Theoretical Basis: Common-coding theory is a theoretical basis that we have used to support the selection criteria of pedagogical elements (use of visualization tool, interactive tasks, and instructional strategy – Demo-Drill-Practice), and also to support our findings. As per common coding theory, the perception, execution, and imagination of movements (actions or events) are connected by a common neural representation (i.e. common code). This connection allows movements in any of the modality (say perception) to activate movements in the other two modalities (execution and/or imagination) (Chandrasekharan, et al., 2010). Mental rotation is treated as imagination or action in imagination, and as per the common-coding theory this action in imagination is triggered and hence improved by the actual actions and the perception of those actions that are performed on an object on the screen during the training.

Instructional Strategy: To execute all the mental rotation training tasks, we have used instructional strategy Demo-Drill-Practice (DDP) (Kadam, et al., 2012), which is based on an instructional strategy of demonstration and practice (Gould, 2012).

The detailed information about TIMeR and its aspects is presented in chapter 4. In the next part, we give an overview of the overall research design used for conducting various research studies in order to investigate the answers to the research questions of this thesis.

1.5 Research Design

To answer the research questions RQ1, RQ2, RQ3, and RQ4, we investigated the impact of TIMeR by conducting various research studies. To address RQ1, we administered two research studies (MR1 and MR2) and examined the effect of TIMeR on students' mental rotation (MR) skill. To address RQ2 and RQ3, we conducted four research studies (ED1, ED2, ED3, and ED4) and investigated the impact of TIMeR on students' engineering drawing (ED) problem-solving performance. The research study (CG1) was conducted to address RQ4 and to investigate the impact of TIMeR on students' computer graphics (CG) problem-solving performance.

To provide a comprehensive analysis of the research problem we needed to combine quantitative and qualitative data (Creswell, 2012), so we selected mixed methods research design. In this design, we collected both forms of data during the above mentioned studies and then integrated the information in the interpretation of the overall results. The designs of research studies comprise of series of single group pretest-posttest design, and two groups posttest-only design. The main sample is undergraduate students of the first year in engineering, who are learning the engineering drawing course. The other sample includes engineering students having prior knowledge of engineering drawing, and undergraduate students learning fundamental computer graphics course.

The data collection instruments used were: Performance scores in tests, i.e., pretests and posttests based on the standardized tests, students' reflective journals in the written form, audio/video recorded interviews. The assessment instruments used were: for mental rotation we used Vandenberg's standard mental rotation test (VMRT), (Vandenberg & Kuse, 1978), for engineering drawing, we used Spatial Visualization Ability Test Instrument (SVATI), (Alias, 2000), and problems from the standard ED exercise books (Earle, 1967, 1968, 1969; Sorby & Wysocki, 2003), for computer graphics, we used questions based on the CG textbook (Marschner & Shirley, 2015).

The data analysis procedure used was: quantitative analysis was performed in the form of descriptive analysis such as means, standard deviations, learning gains, and the statistical analysis such as Mann Whitney test, Wilcoxon test, and effect size. Qualitative analysis was performed in the form of content analysis of reflective journals, content analysis of interviews.

The detailed description of research design and its components is presented in Chapter 3. In the next part we brief about the findings and the contributions of the thesis.

1.6 Findings and Contributions of the Thesis

Here we provide an overview of the findings from the research studies concerning the relevant research questions mentioned in section 1.3. The details are presented in chapter 9.

Findings

Results of research studies MR1 and MR2 showed that TIMeR improves MR skill of first-year undergraduates in engineering. Results of research studies ED1, ED2, ED3 and showed that TIMeR improves ED performance of the students not having prior knowledge as well as of the students having prior knowledge of ED. TIMeR also found to be useful in resolving their learning difficulties in ED. Results of research study CG1 showed that TIMeR improves CG performance of the students undertaking the basic course in computer graphics.

Contributions

TIMeR and results are supporting the common-coding theory where the mental rotation is treated as 'imagination' or 'action in imagination'. So, the action in imagination is improved by the actual actions (training tasks) that are performed on the object (using controllers) on the screen.

TIMeR resulted in a workshop model, we also able to incorporate this model into an engineering drawing curriculum and students got benefited from it in learning of ED concepts of orthographic and isometric projections.

We successfully operationalized the cognitive steps of mental rotation into TIMeR tasks, so that the mental process can be viewed as well as carried out by utilizing 3D tool and controllers. It supports the user in visualizing the representations which are difficult to do so without any medium. This operationalization would be useful for the researchers and the teachers, which they can adapt to mental rotation skill training. It would be beneficial for students to understand

the underlying mechanism of visualization skills similar to the mental rotation. It would also be useful for the developers for design and development of learning environments similar to TIMeR.

We found that Blender is a useful tool for various purposes such as the content development of TIMeR and to design TIMeR activities due to its rich 3D environment, high-end 3D interactivity. Other researchers or teachers can reuse TIMeR content or create similar content by using Blender.

In addition to the VMRT objects and ED concepts, our training method would be useful for learning of all the other topics where 'mental rotation' is involved. For example, 3D transformation topics in Computer graphics, Computer-based 3D modelling, Mechanical engineering, and stereochemistry concepts.

Throughout the research we able to conduct a total of seven training workshops within the different engineering colleges from India, with training 360 students from engineering domain.

Thus, this thesis contributes to the field of spatial skills research and also to its application domains such as in engineering drawing and computer graphics.

1.7 Structure of the Thesis

This thesis has nine chapters and several appendices. Chapter 1 is the introduction. Chapter 2 is the literature survey, which provides an overview of multiple intelligence, the literature on the spatial skills and mental rotation research, synthesis of the literature, and literature on instructional strategy. Chapter 3 provides an overview of the research methodology used in this work. Chapter 4 details about TIMeR, a training to improve mental rotation skills. Chapter 5 provides the empirical results of the impact of TIMeR on the improvement of students' mental rotation skills. Chapter 6 and 7 describes the impact of TIMeR on students' engineering drawing problem-solving performance. Chapter 8 describes the impact of TIMeR on students' computer graphics problem-solving performance. Chapter 9 is the discussion, which includes findings, generalizability, limitations, future research scope, and conclusion followed by appendices and references.

Chapter 2

Survey of Literature

This chapter provides the literature on multiple intelligence; spatial skills and their categories, their importance in different domains, and methods of improvement. Further sections provide literature on mental rotation skill, its definitions, measurement, cognitive steps involved, and methods of improvement. Then it provides summary while identifying gaps in existing work, and the emerging research questions in the appropriate research context that includes mental rotation training transfer to an engineering drawing and computer graphics domains. Further it provides an overview of literature on instructional strategy of demonstration and practice-based training, and a brief overview on common coding theory in cognitive science. Figure 2.1 shows an overview of the literature survey.

Figure 2-1: Overview of the Literature Survey
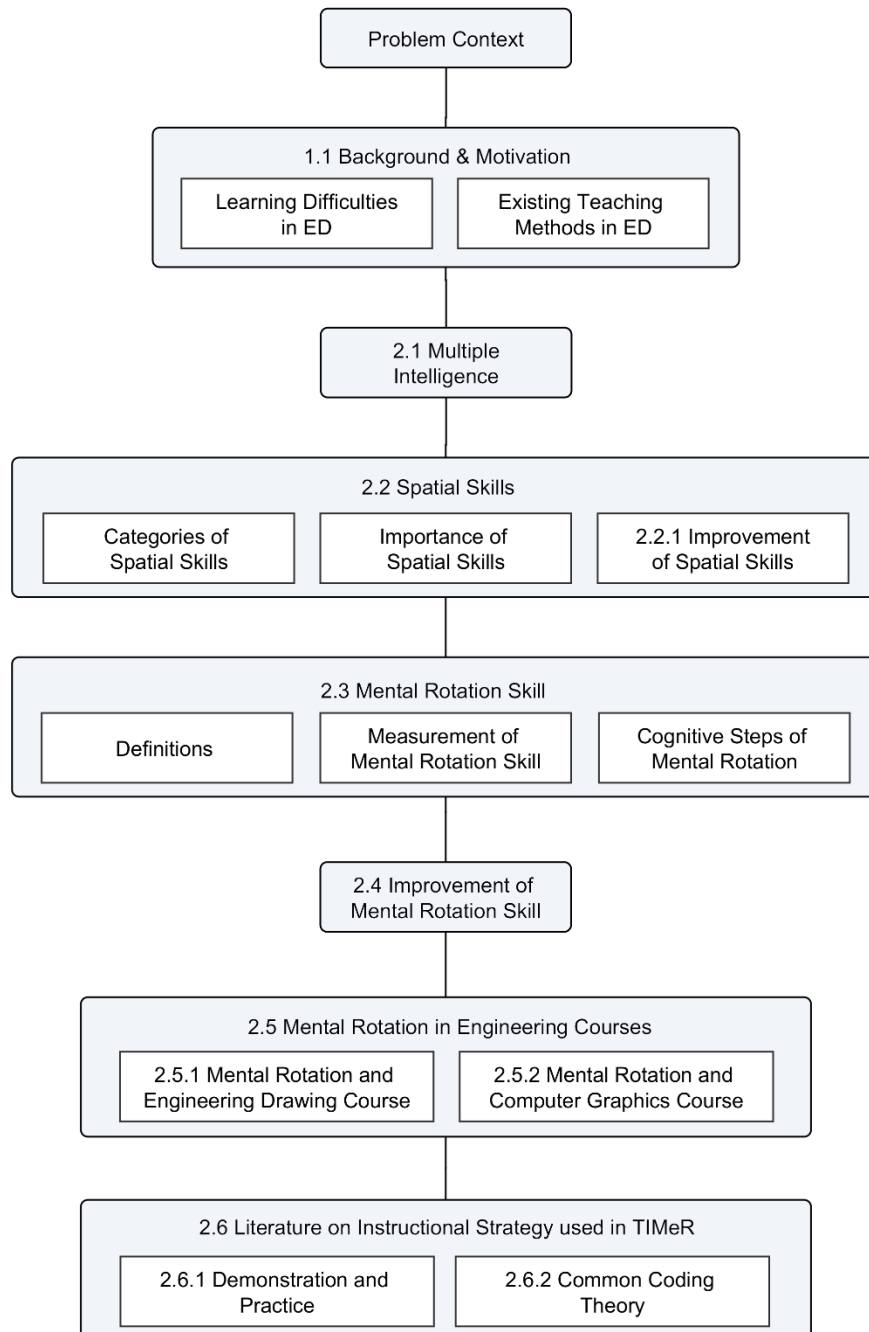
2.1 Multiple Intelligence

Spatial skill is one of the seven main components proposed by Gardner's model of intelligence in his theory of multiple intelligence. The seven intelligences defined by Gardner (1983, 2011), are: (1) Logical-Mathematical Intelligence: It is the ability of detecting patterns, reasoning

deductively and thinking logically. It has most common association with the scientific and mathematical thinking. (2) Linguistic Intelligence: It comprises the ability of effectively manipulating the language for expressing oneself rhetorically or poetically. With this one can use language as a means for remembering the information. (3) Spatial Intelligence: It can give one the ability of manipulation and creation of mental images that are required for solving the problems. (4) Musical Intelligence: It is the capability of recognizing and composing musical pitches, tones, and rhythms. (5) Bodily-Kinaesthetic Intelligence: It is the ability of using one's mental abilities for coordinating the bodily movements. (6) Interpersonal Intelligence: The ability of apprehending the feelings and intentions of others is known as interpersonal intelligence. (7) Intrapersonal Intelligence: The ability of understanding one's feelings and motivations is known as intrapersonal intelligence. For our research purpose, we have selected spatial intelligence i.e. spatial skills, more specifically mental rotation. Figure 2-2 illustrates mental rotation as a subset of spatial skills, and spatial skill as a subset of multiple intelligences.

Figure 2-2: Mental Rotation as a Subset of Spatial Skills
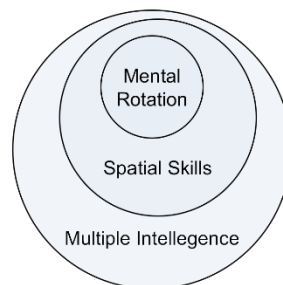
2.2 Spatial Skills

Spatial skills deal with performing the mental rotation of the objects, visualization of the appearance of an object at different angles, and conceptualizing the relation of objects in three-dimensional space (Sutton, 2007). There are many definitions of spatial skills, (Linn & Petersen, 1985; Maier, 1998; Mohler, 2006; Sutton, 2007). Linn and Peterson (1985), identified three categories of spatial skill as Spatial Perception, Mental Rotation, and Spatial Visualization. Maier (1998), extended Linn and Peterson's work to include two more categories: Spatial Relations and Spatial Orientation.

Spatial Perception: In spatial perception tests, it is required to determine the spatial relationships for the orientation of the bodies of subjects, regardless of the distracting information. For example, the water level task, in a tilted bottle it requires to identify a horizontal line (Linn & Peterson, 1985).

Mental Rotation: "Mental rotation is the ability of rotating a two-dimensional (2D) or three-dimensional (3D) figure with speed and accuracy", (Maier, 1998). Mental rotation details are provided in section 2.3.

Spatial Visualization: Spatial visualization has association with spatial skill tasks that include complex, multistep manipulations of spatially presented information. These tasks may include the processes necessary for spatial perception and mental rotations but are separated by the possibility of multiple solution strategies. The example is a Paper Folding task, Surface Development (Linn & Peterson, 1985).

Spatial Relations: The ability to comprehend the spatial configuration of the object or its part and their relation to each other is known as spatial relations. For example - recognising the identity of an object shown in different positions, Maier (1998).

Spatial Orientation: The ability to orient oneself physically or mentally in space is known as Spatial orientation, Maier (1998).

The Importance of Spatial Skills

Spatial skills are essential for various domains ranging from art and education to science and engineering (Mohler, 2006). Though not a complete list, these domains include, art (Humphreys, et al., 1993), architecture (Sutton & Williams, 2011), biology (Lennon, 2000), chemistry (Harle & Town, 2011; Sorby, et al., 2006), engineering (Alias, et al., 2002; Leopold, et al., 2001; Sorby, 2009; Wu & Chang, 2013), geology (Kali and Orion, 1996), mathematics (Hegarty and Kozhevnikov, 1999), medicine (Hegarty, et al., 2007), music (Hassler, et al.' 1985), and physics (Pallrand & Seeber, 1984).

2.2.1 Improvement of Spatial Skills

This section provides the literature on various studies that have applied different training methods for developing spatial skills.

The notion that "the Spatial skills can be improved through training," has been supported by a large number of empirical demonstrations in literature. There have been a number research works that inform various technology tools, pedagogies, and domain contexts as vehicles to improve the spatial skills. These pedagogies or training methods range from physical training to the computer-based training. They are comprised of various technology tools and learning activities, such as sketching practices, engineering drawing activities, use of 3D objects as manipulatives, computer-aided design courses, video games, computer graphics animations, etc. The objectives of these training methods range from improving students' spatial skills (Contero, et al., 2005; Ferguson, et al., 2008; Leopold, et al., 2001; Martin-Dorta, et al., 2008; Sorby, 2009; Yate, 1988,), in general to improving students' spatial visualization (Ault & John, 2010; Contero, et al., 2005; Samsudin, et al., 2011; Yue, 2008), and students' mental rotation skills (Samsudin, et al., 2011; Samsudin & Ismail, 2004) in specific.

As far as the tools used for improving spatial skills are concerned, they range from physical manipulatives to computer-based stand-alone and web-based applications. Ardebili (2006) has demonstrated the effects of the Interactive multimedia tool and a solid modeling software. Contero, et al. (2005) also demonstrated the use effects sketch-based modeling tools. Ferguson, et al. (2008) and Kinsey, et al. (2008) have explored the role of physical manipulatives and physical models for improving learner's spatial skills. Many others have used web-based games (Crown, 2001), web-based graphics tool (Crown, 2001), web-based handheld touch-screen devices (Martin-Dorta, et Al., 2011), and web-based training with interaction-enabled and animation (Samsudin, et Al. 2011). Froese, et al. (2013) has explored the use of 2D illustrative diagrams. Onyancha, et al. (2009) also explored that a four-week targeted training on a 3D CAD course improved students' spatial skills performance. The training consisted activities of creating engineering drawings, rotations, and verification of the results.

In addition to employing technology tools or environments, many researchers have argued that certain regular courses, if pursued by learners can develop spatial skills. Leopold, et al. (2001),

Yue (2008), and Ault & John (2010) has shown the use of engineering drawing courses. Martin-Dorta, et al. (2008), Olkun (2003), Yue (2008) has used CAD courses for the improvement of spatial or visualization skills. Leopold, et al. (2001) has also explored the similar utility of the descriptive geometry course, while Sorby (2009) have presented separate course specifically on spatial skills.

As far as the different learning activities are concerned, researchers have presented a range of activities including solving the engineering drawing problems such as activities on orthographic projection, rotations, reflection and symmetry (Ardebili, 2006; Ault & John, 2010; Olkun, 2003). Other popularly used activities are related to CAD-based interaction and manipulation of 3D objects (Kinsey, et al., 2008; Leopold, et al., 2001). Additionally, Ardebili (2006) has shown activities with physical manipulatives such as the creation of solid models and their projection at different angles. Crown (2001) has shown puzzle-based activities that contains multi-view drawings and isometric, construction of auxiliary views, and other activities. Implementation of different activities was done in different modes, such as single lectures with exercises (Ault & John, 2010; Ferguson, et al., 2008) or four-week long training implementations (Kinsey, et al., 2008).

2.3 Mental Rotation (MR) Skill

Mental rotation is an important aspect of spatial skills, and it has been defined by various authors as: *"The ability to mentally rotate a two or three-dimensional figure rapidly and accurately"*, (Ferguson, 2008; Linn & Peterson, 1985);

"Mental rotation is the ability to mentally rotate an object in one's mind and compare it with a given. This can be done in both the two or three-dimensional domain", (Gillespie, 1995);

"It is the ability to mentally rotate an object in space", (Gurney, 2003);

"The cognitive process of imagining an object turning around is called mental rotation", (Jansen-Osmann, 2007; Shepard and Metzler, 1971);

"Mental rotation is a spatial task that involves the ability to mentally retain an object and rotate it in space", (Moe, 2009);

"Mental rotation: rotation of three-dimensional solids mentally", (Nagy-kondor, 2007);

"Mental rotation is the ability to quickly and accurately rotate two-dimensional (2D) or three-dimensional (3D) objects in one's mind", (Samsudin 2004);

"The ability to rapidly and accurately rotate a 2D or 3D figure", (Maier, 1998).

While all these definitions of mental rotation are valid and rather similar, we adopt Maier's (1998) definition of mental rotation as it encapsulates the essence of all the definitions.

Measurement of Mental Rotation Skill

Mental rotation skill is measured by using valid and reliable test instruments. Vandenberg's Mental Rotations Test (VMRT) appears to have high construct validity in the area of spatial visualization skill (Guay, 1980). Due to its high validity and reliability, as a valid measure of spatial skills; and its use by prior researchers; we used VMRT test as a method for determining the mental rotation skill of students. It is a paper-pencil test developed by Vandenberg & Kuse (1978). VMRT contains 20 questions, a sample item is shown in Figure 2-3. Each item consists of a standard figure, two correct options that are identical to the standard figure in structure but are shown in rotated position, and two incorrect ones.

Figure 2-3: VMRT Sample Item (reproduced from Vandenberg & Kuse, 1978)
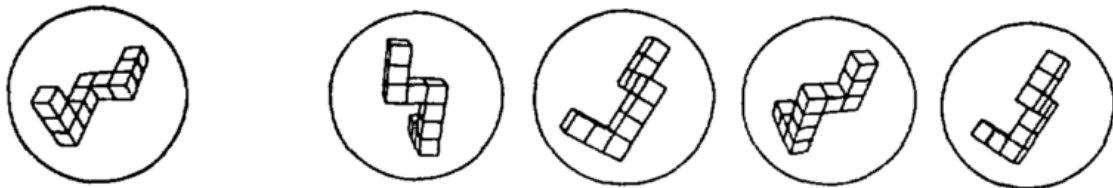
The first and the fourth alternatives are correct.

The person taking the test supposed to identify two correct options for which he/she gets one mark. The minimum and maximum achievable score for the test is zero and ten respectively. The achievement levels based on the test score can be decided by forming three clusters by dividing maximums score (ten) with desired levels (say three). It results into three ranges of scores that are between 0 to 3.33, between 3.34 to 6.66, and between 6.67 to 10. These values are used for defining different achievement levels. So, the three achievement levels are low (0, 1, 2, and 3), medium (4, 5, and 6), and high (7, 8, 9, and 10). We call the students from each level as, low-performers, medium-performers, and high-performers.

Cognitive Steps of Mental Rotation

The nature of mental rotation questions requires thinking in three dimensions. In order to solve mental rotation problems similar to the VMRT item, it requires to perform the rotations mentally, and that involves performing certain cognitive steps. These cognitive steps in performing mental rotation as specified by Johnson (1990) are: (a) "Form a mental representation of an object," (b) "Rotate the object mentally until its axial orientation allows the comparison to the standard," (c) "Make the comparison," (d) "Make a judgment," and (e) "Report a decision." The first step would require a careful observation of an object in order to form the mental representation. Once the mental image of an object is formed, it would require imagining different axes so as to do the mental rotation. After that in a second step, it would be likely to have multiple mental rotations resulting in multiple mental representations of that object. The comparison and judgement steps would allow to have the comparison of the current rotated mental representation of an object with the standard figure. In order to design mental rotation training activities, it is desirable to address these cognitive steps of mental rotation. In this work, these steps form as one of the basis for designing the training intervention, where we have operationalised them in the form of training. The details are provided in section 4.2.

2.4 Improvement of Mental Rotation Skill

The mental rotation training methods involve physical training, computer-based training, computer-aided design training, video games, animations, engineering drawing activities and

many. This section provides the literature on studies that have applied different training methods for developing mental rotation skills.

Contero et al. (2005), in their study showed that interactive rotation of 3D models in a web-based rotation tutor improve students' mental rotation performance. The rotation tutor was a part of a six-hour remedial course for spatial skill training that included a web-based graphic tool and sketch-based modelling tools. The study also focuses on providing students with the applications with the combination and development of three skills namely spatial visualization, freehand sketching, and standardized view generation. Flusberg & Boroditsky (2011), in their study used wooden Shepard and Metzler objects for physical rotation training, and used images of wooden objects for mental rotation task. Their findings suggest that mental rotation is connected to the real-world motor experiences. Froese, et al. (2013), showed that the dynamic training method (animation of 2D to 3D) improved students' performance in mental rotation test. In addition to rotation the training involved 3D task which was creating an orthographic projections of a 3D object. Gillespie (1995), showed that training on CAD and solid modelling improves students' visualization skills, where in addition to the rotation students were tested for paper folding task. Godfrey (1999), found a training in CAD modelling to be beneficial for developing students' spatial skills, where students were tested with mental rotation test. Kinsey, et al. (2008), in their study showed that training for rotation of physical model in synchronization with CAD model of the object, and viewing alternate views of shaded CAD model with its linear views, improve students' spatial skills. Leopold, et al. (2001), showed that courses on descriptive geometry and introductory engineering drawing improve students' spatial abilities when tested on mental rotation test. To measure spatial skills, in addition to mental rotation students were also tested on mental cutting test and differential aptitude test of space relations. Lohman (1990), showed that practice on spatial tasks and tests (mental rotation) produces significant improvements in performance.

Martin-Dorta, et al. (2008), showed that a CAD based course improved students' performance on mental rotation test. Onyancha, et al. (2009), showed that a targeted training on a CAD course improved students' performance on mental rotation test. In addition to the rotation, the training consisted activities of creating engineering drawings, and verification of the results. Samsudin & Ismail (2004), showed that an interactive computer-based multimedia tutor (with animation) improves students' mental rotation performance on the posttest, which was same as the pretest. Samsudin, et al (2011), showed that web-based training improved students' mental

rotation and spatial visualization skills. The training instructions include conditions such as interaction-enabled, animations, and printed material, where an interaction enabled condition was found to be more useful than other two. Sorby (2009), showed that spatial skills can be developed through a dedicated course, where in addition to the rotation activity, course topics include sketching isometric and multi-view drawings, 2D-3D transformations, paper folding, 3D coordinate systems, cross section of solids, and combining objects. Thomas (1996), showed that three-dimensional CAD instructions improves students' spatial skills when tested on author developed cube rotation test. Turner (1997), showed that CAD based training improves students' performance in mental rotation test. Wiedenbauer et al. (2007), in their study showed that manual training (with the use of joystick) of mental rotation in a virtual environment is effective but limited to trained objects. Yue (2008), showed that students' performance on spatial visualization test (rotation) with realistic 3D views was improved as compared to isometric drawings. Students completed the engineering drawing and CAD courses before being tested on spatial skill test. Zaiyouna (1995), investigated the effect of computer-based training on mental rotation and found no significant difference in the performance of male versus female candidates. These studies are summarized in Table 2-1, with providing additional information of duration of the treatment, type of assessment to measure outcome, training description, sample, and brief information on outcomes.

Table 2-1: Literature on Mental Rotation Trainings

Study	Treatment duration	Outcome measure	Training Description	Sample (Size & background)	Brief Outcomes
Contero, et al. (2005)	3 sessions of 2 hours	Paper Pencil, Web based	6-hour course, web-based	78 low scorers from 461, engg. students	Improvement in MR and spatial skills
Flusberg (2011)	8 min tasks	MRT	Physical rotation of Shepard & Metzler objects	64 participants	MR is connected to the real-world motor experiences
Froese (2013)	1.5-hour session	MRT, PFT, OPT	CAD, static vs. dynamic visualization	117 participants	Improvement in the performance
Gillespie (1995)	10 weeks	PFT, MRT, Rotated Blocks	CAD, solid modeling tutorials	41 Engg. Graphics students	Improvement of visualization skills
Godfrey (1999)	16 weeks	PSVT	CAD	76 Engg Graphics students	Training is beneficial
Kinsey, et al. (2008)	4 weeks	PSVT	Physical model, CAD	11 Mechanical Engg. students	Improvement in the performance
Leopold (2001)	15 weeks	MRT, MCT, DAT:SR	Descriptive geometry, Graphics course	Engg. Students 220, 190, 55	Positive impact on spatial skills. Improvement in MR

Lohman (1990)	3 sessions	Rotation and visualization test	Rotation problems	83, 50, 385	Improvement in performance
Martin-Dorta, et al. (2008)	3 weeks	MRT, DAT:SR	CAD	40 Freshman Engg. students	Improvement in performance score.
Onyancha, et al. (2009)	4 weeks	PSVT (web-based)	CAD course	81, 59, 23, 27	Improvement in performance score.
Samsudin & Ismail (2004)	5 weeks, 1.5 hours per week	CB	CAD	58 Undergraduates, Info. Tech. & Communication.	Treatment was effective in terms of accuracy
Samsudin, et al. (2011)	8 weeks, 2 hours per week	CB and Online	CBMT (free)	98 secondary school students	Statistically significant
Sorby (2009)	14 weeks in a semester	PSVT:R	Multimedia software course	157, 186 Engg. students	Development in spatial skills
Thomas (1996)	13 weeks	Cube Rotation	3D CAD vs 2D CAD	50 Technology Students	3D CAD is more effective than 2D CAD
Turner (1997)	12 weeks	MRT	CAD	556 Engg. Students	CAD shows more improvement than non-CAD
Wiedenbauer, et al. (2008)	Study 1: 37 minutes, Study 2: 60 minutes	CB	Game Studio	Study 1: 107 Study 2: 67	Effective for limited trained objects
Yue (2008)	Semester	Computer-based (CB)	CAD	157 Engg., 34 High School Students,	Improvement in the performance
Zaiyouna (1995)	4-5 weeks	MRT	CBT	19	Gender study, no difference

CAD – Computer-Aided Design
CB – Computer-based
CBT – Computer-based Training
CBMT – Computer-based Multimedia Tutor
DAT:SR - Differential Aptitude Test: Space Relations

MCT – Mental Cutting Test
MRT – Mental Rotations Test
OPT – Orthographic Projection Test
PFT – Paper Folding Task
PSVT:R – Purdue Spatial Visualization Test: Rotation

The reviewed literature shows that the existing methods found to be useful in spatial skill development. However, these methods focus on the development and assessment of multiple spatial skills (such as visualization, mental rotation, paper folding) at a time, rather than on an individual skill. The focus of training and assessment on multiple skills at a time may affect the development of an individual skill. Such training sessions had longer durations (spread over weeks), with only few exceptions. It was also observed that, most of the studies have used computer-based training methods based on three-dimensional (3D) visualization tools (such as CAD) and utilized interactivity as an important instructional element. Additionally, most of the work was carried out in an engineering drawing domain; this emphasises the importance of spatial skills, especially mental rotation. However, these studies demonstrated the effect of

training only for spatial skills and did not examine the effect of mental rotation training on the relevant topics such as engineering drawing.

This synthesis helped direct the broad goal of our work "to improve students' spatial skill with computer-based training" to a more specific research goal "to improve students' mental rotation skill using 3D visualization tool." Further, we extend this work to test the training transfer to engineering drawing and computer graphics domains, which is described in the section 2.5.1 and 2.5.2.

2.5 Mental Rotation in Engineering Courses

Mental rotation is required in learning of engineering courses such as engineering drawing, civil engineering, mechanical engineering, machine design, computer graphics, etc. In this thesis, we focus on the importance of mental rotation skills in engineering drawing course and basic computer graphics course.

2.5.1 Mental Rotation and Engineering Drawing Course

We observed from the literature that mental rotation is important for the learning of engineering drawing concepts (Alias, 2000; Kadam & Iyer., 2015; Khabia & Khabia, 2012; Maier, 1994; Norman, 1994; Olkun, 2003; Pillay, 1994; Sorby, et al., 2006; Sorby, 2009; Voyer, et al., 1995). For example, while solving engineering drawing problems of performing the transformations between orthographic projections and isometric projections, the cognitive process often requires visualization of an object from different perspectives; eventually it requires doing mental rotation as an essential sub step. Thus, we have identified mental rotation as one of the essential steps to learn and solve engineering drawing problems, mainly of three-dimensional nature. (See section 4.9 for the details on the connection of mental rotation with engineering drawing concepts). We also observed that the combined effect of mental rotation and other spatial skills training on learning of engineering drawing had been studied. However, an individual impact of mental rotation training on learning of engineering drawing has not been

studied yet. This indicates the necessity to investigate the effect of the mental rotation training on the learning of the engineering drawing concepts.

2.5.2 Mental Rotation and Computer Graphics Course

Computer graphics (CG) is one of the essential components of computer science curriculum. The prerequisites for learning CG course include knowledge of basic programming (or minimum a year of programming course) and knowledge of basic Linear Algebra. Besides, it requires knowledge of basic math for representing objects in two and three dimensions using geometry and matrix manipulations, basic data structures and algorithms, and visualization in three dimensions, (Wolfe, 2000).

Teaching methods for CG concepts vary from traditional strategies like drawings, verbal explanations, and supportive hand gestures to the computer-based training (Divjak, 2004; Luiz, 2002; Yuan, 2010). However, students who study CG for the first time often face difficulties such as, understanding the basic and abstract concepts, (Dehui, 2005; He & Zhao, 2012), understanding and visualizing of graphics algorithms (Vila & Hartman, 2001), and visualizing concepts (Seren et al., year) such as three-dimensional transformations (translation, rotation, and scaling). The teaching of CG concepts is also found to be challenging and non-intuitive to explain, additionally spatial concepts or multi-dimensional geometric operations are also considered to be complicated to illustrate (Peternier 2006).

However, programming the three-dimensional concepts requires one to visualize first, formulate mathematical equations and matrices later, and finally translate the formulations into solid code. In this particular process, it is desirable for students to have the spatial skills mainly mental rotation, as it plays an important role for learning concepts that involve three-dimensional visualization. Consequently, for the successful learning of such courses, students should be trained to acquire these skills. We did not find studies relevant to mental rotation training and its effect on computer graphics course. Hence, in this work, in addition to the engineering drawing concepts, the effect of mental rotation training on learning of CG concepts has been investigated, the details are provided in Chapter 8.

2.6 Literature on Instructional Strategy used in TIMeR

An instructional strategy used in this work is demo-drill-practice (DDP), which is based on demonstration and practice-based methods of teaching. This section has two parts, in the first part we provide an overview of the literature on demonstration and practice as these teaching methods are often used in the process of skill acquisition. In the second part we brief about the common coding, which is a theoretical basis used for supporting the selection criteria of pedagogical elements (use of visualization tool and interactive tasks), and additionally to support the findings of this work.

2.6.1 Demonstration and Practice

Studies have shown that demonstration, when included in spatial skills training found to be beneficial in improving spatial skills (Blatnick, 1996; Kozhevnikov & Thornton, 2006; Mowrer-popiel, 1991; Pulos 1997; Robert and Chaperon 1989; Samsudin & Ismail 2004). Similarly, practice in spatial skills training also found to be helpful in their development (Duesbury & O'Neil 1996; Lohman & Nicholas 1990; Martin-Dorta, et al., 2008; Sorby, 2009; Wiedenbauer et al., 2007).

The purpose of this work was to train students for acquiring mental rotation skill. The method of training in a skill is dependent on the nature of that skill, which can be achieved by first identifying the definition of skill. As defined by Gould (2012), skill is "an organised pattern of mental and/or physical activity". This definition of skill suggests that a skill contains a 'knowledge' component and a 'doing' component. To perform the skill, it is desired for the learner to possess the knowledge of what has to be done, and also the sequence in which it has to be done. For different skills, the balance of these components would differ (Gould, 2012). For example, swimming will have a greater 'doing' component, whereas using a computer will have a greater 'knowledge' component. However, irrespective of the relative proportions, all skills will possess elements of each component.

Demonstration and practice-based instructions play a significant role in skill acquisition. Where, in order to impart the 'knowledge' component of a skill the demonstration is used which

is followed up with the practice in order to acquire the 'doing' component of the skill. A standard skill acquisition session will include both the activities, where the relative amount of each will be dependent on the nature of the skill. Consequently, a skills analysis needs to be conducted before demonstration.

The primary purpose of the skills analysis is to know all the specific actions involved in the skill, the particular sequence of these actions, the sensory information required at each stage, the decisions that need to be made during the execution of the skill, and any other specific problems related to that skill (Gauld, 2012). This can be accomplished by breaking down the overall skill (main skill) into sub-skills, which can be further broken down to the level of detail appropriate for the learning. Consider, for example, mental rotation as the main skill, so the sub-skills would be the cognitive steps involved in performing mental rotation. Additionally, skills analysis helps learners during the practice as the total skill has been simplified into smaller sub-skills. This allows the learner to learn the skill in a systematic and in more convenient manner.

Demonstration

Knowledge required to perform the skill is provided by the demonstration. Normally, the demonstration starts with an example of the whole process in order to help in establishing the cognitive phase of skill acquisition (through modelling, video, animation or any visualization approach). During the demonstration process, the learner observes the task being performed by another person, which is associated with the skills that are targeted for training. Then in the final demonstration of the skill, the different sub-skills are linked together.

Practice

Post demonstration learners will be ready to proceed further to the phase of skill acquisition, and this is accomplished through practice. The practice should happen immediately after the demonstration. The practice involves mastering the sub-skills. Each of these sub-skills getting builds upon the previous one until the complete skill is learned. During practice sessions, the teacher provides reinforcement, feedback, and guidance that helps to improve the performance. External feedback and guidance are important elements of the practice phase.

In this work, in order to train students in mental rotation skill, we used Demo-Drill-Practice (DDP) as the instructional strategy. DDP is based on the demonstration and practice, where the training task will be demonstrated and assisted by an instructor, followed by the students performing the practice. The demo part ensures students acquiring the knowledge required to perform the task. The drill part ensures students performing the task sequentially by repeating it instantly as they saw the demo which also ensures the retention of the mental representation acquired during the demo part. Finally, the practice part ensures that students have performed the sufficient amount of rehearsal of the task. The details of DDP are provided in section 4.4.

2.6.2 Common Coding Theory

This section provides a brief overview about the linking of common coding in perception, execution, and imagination. Research studies in the field of cognitive science and neuroscience have provided a model of cognition where a common coding in the brain is shared by perception, execution, and imagination of movements, (Decety, 2002; Hommel, Mu¨sseler, Aschersleben, & Prinz, 2001; Prinz, 1992, 2005). This common coding allows any one of these movements to generate the other two movements automatically, (Chandrasekharan, et al., 2010; Chandrasekharan, 2009; Decety, 2002; Hommel et al., 2001; Prinz, 2005; Sebanz, et al., 2005; Wohlschlager, 2001; Wong, et al., 2013). This suggests an adequate evidence in favour of the common code linkage to the perception, execution, and imagination of movement. We further use common coding to explain the effect of TIMeR, our intervention, that involves perception and execution of the movements of the activities related to mental rotation.

The details of common coding and the discussion of results from the perspective of common coding is provided in section 9.2.

Chapter 3

Research Methodology

This chapter includes, the research questions, research design, sampling, data collection, assessment instruments, data analysis procedures and overview of the research studies.

3.1 Research Questions

The main research objective of this work is to investigate the effect of 3D visualization tool-based mental rotation training on students' mental rotation skill, leading to the broad research question *"How to improve students' mental rotation skills using 3D visualization tool?"* Since mental rotation has significant importance in engineering drawing course and basic computer graphics course, we extended the research objective to investigate the effect of 3D visualization tool-based mental rotation training on student's engineering drawing (ED) problem-solving skills and computer graphics (CG) problem-solving skills, respectively.

We have developed a *"TIMeR: **T**raining to **I**mprove **Me**ntal **R**otation Skills using Blender"* and hence to enhance the learning of relevant concepts. Subsequently, we have examined the effectiveness of TIMeR, and also to examine its impact on the learning of ED concepts and CG concepts. Details of TIMeR are presented in chapter 4.

Research Questions

In the course of the research two categories of questions were answered, which are design questions and research questions. Design Question (DQ) relate to finding specific operationalization of theories or practices to design or develop interventions or pedagogies. Whereas, in Research Questions (RQ), the answers to these set of questions help to evaluate the output of the research studies and reflect on it. We present the specific DQs and RQs in this work below.

DQ1: How to design a 3D visualization tool-based mental rotation training program?

RQ1: How effective is TIMeR for improving students' MR skill?

RQ2: How effective is TIMeR for improving first-year engineering undergraduate students' engineering drawing problem-solving performance?

RQ3: In what way does TIMeR resolve the learning difficulties that students face while solving the engineering drawing problems?

    RQ3.1: What are the learning difficulties that students face while solving the engineering drawing problems?

    RQ3.2: What are the benefits of TIMeR as perceived by the students?

DQ2: How to incorporate TIMeR in a conventional ED course?

RQ4: How effective is TIMeR for improving students' computer graphics problem-solving performance?

3.2 Research Design

We employ mixed method as the overall research design and for the research studies reported in this thesis. A mixed methods research design is a procedure for collecting, analysing, and synthesizing data and results from both quantitative and qualitative methods in one or more studies to address a research problem (Creswell, 2012). Combination of quantitative and qualitative methods provide deeper understanding of the research problem. We collected both forms of data during all the research studies carried out and then integrated the information in the interpretation of the overall results. The designs of research studies are comprising of series of (a) single group pretest-posttest design, and (b) two groups posttest only design. The single group pre-post design enabled us to identify and observe the change in the performance of the same set of students i.e. within the group, here they serve as their control. However, two group designs enabled us to compare the performance of students between two groups to determine the differences. The individual study designs are summarised in Table 3-2 in the later part of this chapter.

3.3 Sample

The most appropriate sample for testing our intervention were the students who were learning a subject that requires visualization and imagination. So, we included students who were learning subjects: engineering drawing and computer graphics. We used convenient sampling technique for all the studies. We ensured the equal distribution by random assignment as applicable to individual research studies. Below we provide the details of sample used for research studies carried out in this work.

Sample Type1 (Students without prior knowledge of ED)

A major sample was undergraduate students of the first year in engineering, who were learning the fundamental engineering drawing course. These students were used to investigate the effectiveness of TIMeR and to test the impact of the training on their mental rotation skills and engineering drawing problem-solving skills. The total number of Type1 sample was 245, and the study-wise distribution is given in Table 3-2.

Sample Type2 (Students with prior knowledge of ED)

We also investigate the effectiveness of TIMeR on students with having prior knowledge of ED. These students are from their first term of the second year of mechanical engineering and who have already learned the ED course in their previous academic year. The total number of Type2 sample was 97, and the study-wise distribution is given in Table 3-2.

Sample Type3 (Students learning CG course)

To test the applicability of TIMeR in a domain other than engineering drawing, we identified basic computer graphics course which involves concepts requiring mental rotation skills. So, the third sample is students from masters in computer application (MCA) who are learning a basic computer graphics course. The total number of Type3 sample was 17.

3.4 Instruments and Data Collection

The data was collected in both the quantitative and qualitative forms. The quantitative data involves students' performance scores on tests, and the qualitative data involves reflective journals, focus group interviews and individual interviews.

3.4.1 Quantitative Data Collection Instruments

Performance scores

Participants take tests that measure their achievement, their intelligence, or their aptitude (Creswell, 2012). In this thesis, students' performance scores on pre-tests and post-tests in three types of tests i.e. mental rotation test, engineering drawing (ED) problem-solving test, and computer graphics (CG) problem-solving were collected and measured for the quantitative analysis of the research studies. This analysis enabled us to respond the major research questions (RQ1, RQ2, and RQ4) of identifying students' improvement on performance scores

and skills of mental rotation skill, engineering drawing performance, and computer graphics performance for the respective research studies.

As we are evaluating students' MR skill, ED performance, and CG performance; the respective assessment instruments used are VMRT (Vandenberg & Kuse, 1978), SVATI (Alias, 2000), and questions from the textbook (Bhatt, 2010; Earle, 1967, 1968, 1969), as described below.

Mental Rotation Assessment (VMRT)

For the assessment of mental rotation skill, we used Vandenberg's Mental Rotation Test (VMRT), a standardized instrument. It is highly reliable, and a valid measure of MR skills and prior researchers have widely used it. It is a paper-pencil test developed by Vandenberg & Kuse (1978) and contains twenty questions. Figure 3-1 shows a sample MR question. Each VMRT item has a standard figure (shown on the left) and four choices (shown on the right). From the four options, two are the correct alternatives and shown in rotated position, and the other two are incorrect. The two correct options are always same in structure to the standard figure and shown in a different orientation. We used ten items each for pretest and posttest assessment.

Figure 3-1: VMRT Sample Item (reproduced from Vandenberg & Kuse, 1978)

The first and the fourth alternatives are correct.
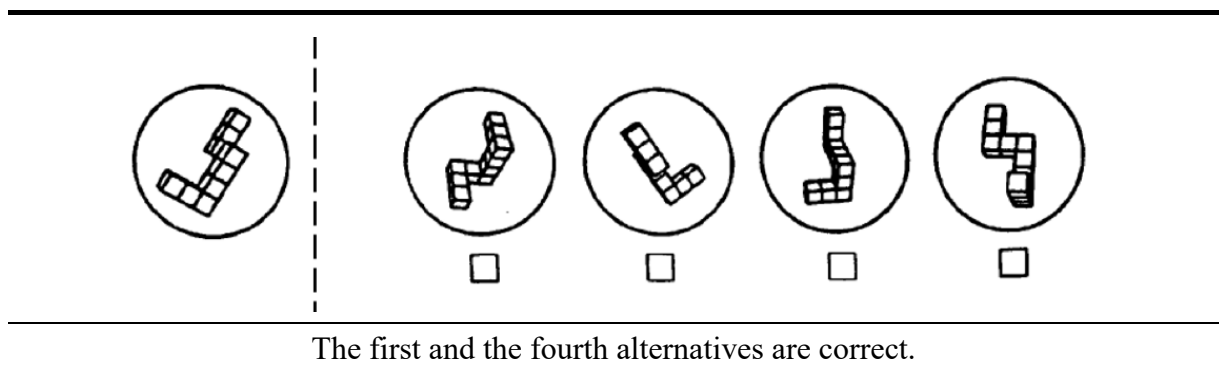
ED Assessment (SVATI)

For the assessment of ED skills, we used Spatial Visualization Ability Test Instrument (SVATI) (Alias, 2000). This is a set of multiple choice questions. We considered only engineering drawing tasks from the set of test items. The reason for using multiple choice question is that students haven't learned the drawing task. The problems involved in the tests are: Conversion

of isometric view to orthographic views, in which for a given isometric view student have to identify the correct set of orthographic views, Figure 3-2.

Figure 3-2: Isometric to Orthographic Conversion (reproduced from SVATI, Alias, 2000)
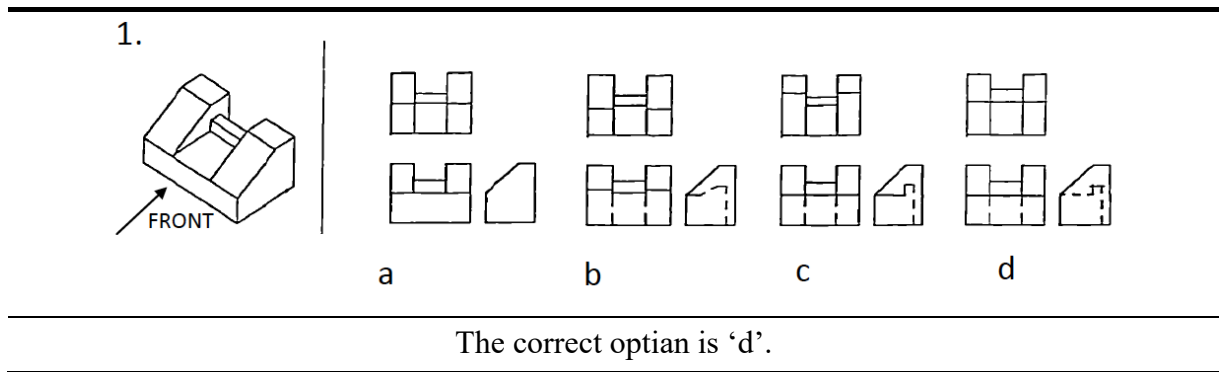
The correct optian is 'd'.

Conversion of orthographic views to an isometric view, in which for a given set orthographic views students have to identify the correct isometric view, as shown in Figure 3-3.

Figure 3-3: Orthographic to Isometric Conversion (reproduced from SVATI, Alias, 2000)

The correct optian is 'd'.
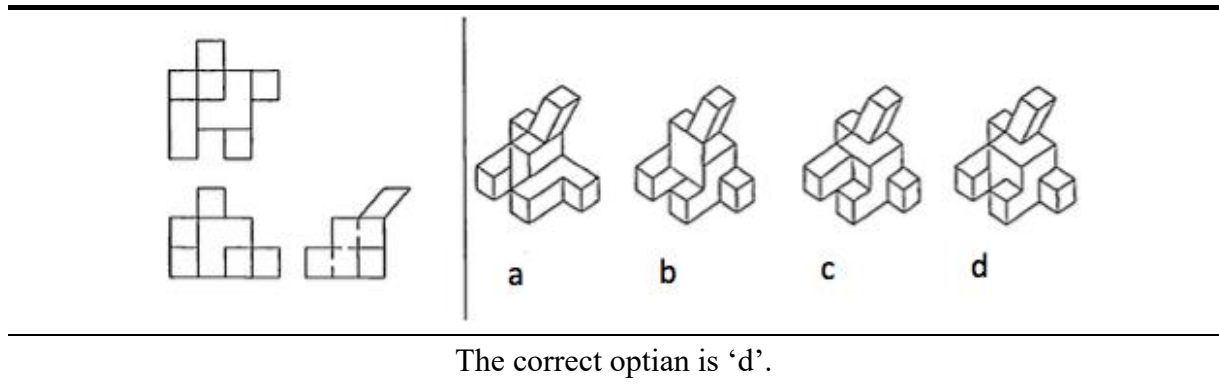
ED Assessment (Textbook Questions)

For research study ED3 we used ED problems where students have to make drawings. This particular assessment instrument was used for the sample having prior knowledge of ED. These questionnaires were selected from the standard textbook and exercise books of engineering drawing (Bhatt, 2010; Earle, 1967, 1968, 1969). Sample question is shown in Figure 3-4.

CG Assessment

For research study CG1, we used questions based on the computer graphics textbook (Marschner & Shirley, 2013). Figure 3-5 illustrates the sample test item, where figure A shows the initial orientation of an object and figure B is the transformed orientation of the same object. Students are required to identify the transformations from A to B.

Figure 3-4: ED Test Item (reproduced from Earle, 1969)

Exercise 1A: Orthographic. SIX View Sketching
Instructions : Sketch SIX orthographic views of the object shown below.
Six views are: TOP, BOTTOM, FRONT, BACK, LEFT, RIGHT.

Front
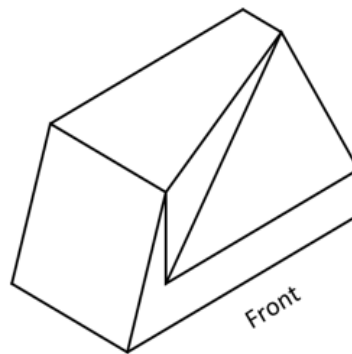
Figure 3-5: CG Test Item

Q. 3D Transformations
Figure-A shows initial orientation of an object, which is then transformed to an orientation shown in
Figure-B. Identify transformations required, with correct order.

Figure-A   Figure-B

o   o
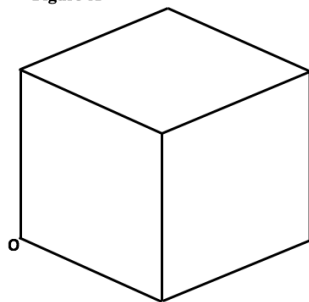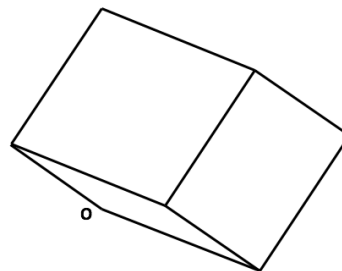
3.4.2 Qualitative Data Collection Instruments

Reflective Journals

A reflective journal is one of the qualitative data collection method of written or verbal description of an event, or group of events, over time (Ortlipp, 2008). A reflective journal allows students to reflect and write about their learning experiences. They can identify and reflect on learnings and challenges. Teacher or researcher can obtain information on what student thinks and feels about the learning process or a particular learning event.

In this thesis, to triangulate the quantitative results, we collected the qualitative data in the form of students' reflective journals in the written form; this was used particularly for engineering drawing studies for answering the research questions RQ3.1 and RQ3.2. Students responses were collected twice. Firstly, the responses were collected just after the pretest (pre-responses), where they had to think about pretest problems and their solutions to reflect about learning difficulties faced while solving the pretest. Secondly, the responses were collected just after the posttest (post-responses), where they were supposed to reflect about the posttest problems and solutions, other learning difficulties faced if any, and feedback about mental rotation training they received. The content analysis of this data helped us in answering the research questions on the students' learning difficulties of ED concepts, and the way in which TIMeR resolved those problems.

Focus-Group Interview

A focus group interview technique involves the use of in-depth group interviews. The selection of participants has to be purposive, and they should be sampled from a specific population (Rabiee, 2004). Focus groups could be useful to gather information about a range of ideas and feelings focus on certain issue that individuals may have, as well as revealing the differences in perspective between groups of individuals. In this thesis, in addition to reflective journals, we also conducted focus group interviews and recorded responses using audio-video recordings. The interview questions were centred around getting the answers for RQ2.1, RQ2.2 for the respective research studies. Students were allowed to respond in any order with or without discussing with other individuals.

Semi-structured Interview

Due to logistics issues where students had other academic engagements after our sessions, especially after study ED4, it was not feasible to conduct focus-group interviews. Therefore, as an alternate arrangement, we conducted semi-structured one to one interviews. We maintained the equivalence of interviews as the interview questions were centred around getting the answers for RQ3, RQ3.1, and RQ3.2 for the ED4. Students were allowed to respond to the questions in any order. It allowed us to receive additional responses from the students who either wrote nothing or little in the reflective journals.

3.5 Data Analysis Procedure

We performed the both quantitative and qualitative data analysis. The qualitative data analysis was done to triangulate the results from the quantitative results.

Quantitative Data Analysis

For deciding which statistical test to be used for comparing the means, we tested the data for normality using Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011). Based on the results of normality test, to investigate the statistical significance, we performed t-test analysis for normal data, and Mann-Whitney test or Wilcoxon test as per the suitability of the research design and sample size of the individual research study. For our analysis, we use the significance level 0.05 (5%). In addition to means and standard deviations, we also computed the effect size (Cohen, 1988) and learning gain (Marx & Cummings, 2007).

Qualitative Data Analysis

We performed following steps for analysis of the qualitative data

1. Transcription - we transcribed the collected data in text form, where the original data was in the form of written text or audio or video.
2. Categorizing - we analysed the transcriptions and coded the common trends of the words, phrases, and statements to classify and reflect the purpose of the research

questions. The main categories of our focus are students' learning difficulties while attempting pretests, and training benefits for addressing whether training helped in resolving those learning difficulties.

3. Interpreting - we interpreted the data for making meaning of the categories related to the research questions or additional if any.

4. Reporting - we reported inferences by summarizing which resulted in the form of a list of learning difficulties, and a list of training benefits with respect to the cognitive and affective learning component.

Table 3-1 summarizes the qualitative data collection instruments, the type or format of data collected, transcription type, the associated research question, and the categories of the inference.

Table 3-1: Data Collection Instruments for Qualitative Data

Data Collection Instrument	Data Type	Transcription Format	RQ	Categories of Inferences
Reflective Journals (Pretest)	Hand-Written Text	Text	3, 3.1	Learning Difficulties
Reflective Journals (Posttest)	Hand-Written Text	Text	3, 3.2	Training Benefits
Focus Group Interview	Audio-Video	Text	3, 3.1, 3.2	Learning Difficulties & Training Benefits
Semi-Structured Interview	Audio-Video	Text	3, 3.1, 3.2, 4	Learning Difficulties & Training Benefits

3.6 Answering Research Questions

In this section, we present how we answered the design questions (DQ) and research questions (RQ).

DQ1: How to design a 3D visualization tool-based mental rotation training program?
We answered this design question by operationalizing the cognitive steps of mental rotation (Johnson, 1990) from literature in the form of a training program. The details of the operationalization are mentioned in the section 4.2. We call the training program, *"TIMeR: Training to Improve Mental Rotation Skills using Blender."*

RQ1: How effective is TIMeR for improving students' MR skill?

We answered RQ1 using single group pretest-posttest design study MR1 and compared pretest and posttest scores, and further conducted a confirmatory study MR2 with same research design. The details of the MR1 and MR2 are provided in chapter 5.

RQ2: How effective is TIMeR for improving first-year engineering undergraduate students' engineering drawing problem-solving performance?

We answered RQ2 by comparing pretest and posttest scores of ED1 and further conducted a confirmatory study ED4. The results of study ED1 also lead to follow-up studies ED2 and ED3 to give a more detailed answer to the RQ3. The ED1, ED2, and ED3 are detailed in chapter 6.

RQ3: In what way does TIMeR resolve the learning difficulties that students face while solving the engineering drawing problems?

We answered RQ2 by mapping the learning difficulties (answered in RQ2.1) to the TIMeR features. We confirmed this by the list of benefits reported by the students (answered in RQ2.2). The mapping is detailed in the section 6.1.2.1.

RQ3.1: What are the learning difficulties that students face while solving the engineering drawing problems?

We answered RQ3.1 by extracting the list of difficulties from the reflective journals obtained in the study ED1 and confirmed it from the similar data obtained in ED2, ED3, and ED4. The difficulties are listed in section 6.1.2.1, Table 6-9.

RQ3.2: What are the benefits of TIMeR as perceived by the students?

To answer RQ3.2, by extracting the list of benefits from the reflective journals obtained in the study ED1 and confirmed it from the similar data obtained in ED2, ED3, and ED4. The benefits are listed in section 6.1.2.1, Table 6-9.

DQ2: How to incorporate TIMeR in ED course?

We answered the design question DQ2 by aligning TIMeR structure to the conventional ED class structure (regular lab-based class structure) for the two topics from ED. The details are provided in chapter 7, section 7.1.

RQ4: How effective is TIMeR for problems involving MR in other domain such as CG?

We answered RQ4 using two group pretest-posttest design study CG1 and compared the posttest scores between groups. We also compared the pretest scores with the posttest scores within the groups. The details of the study are provided in chapter 8.

We conducted a pilot run of the experiment, using ten volunteers outside the sample, which helped us to fine-tune the sequence of the treatment and the time allotted for each part. It also confirmed that our data collection instruments were unambiguous and timed appropriately. Table 3-2 provides the summary of research design for studies in this thesis. The details of MR studies are provided in chapter 5.

Table 3-2: Research Methodology and Research Studies

RQ	RQ1		RQ2, RQ3				RQ4
Study Type	MR		ED				CG
Study	MR1	MR2	ED1	ED2	ED3	ED4	CG1
Method	Quantitative	Quantitative	Quantitative Qualitative	Quantitative Qualitative	Quantitative Qualitative	Quantitative Qualitative	Quantitative Qualitative
Study Design	Single Group Pre-Post	Single Group Pre-Post	Single Group Pre-Post	Single Group Pre-Post	Single Group Pre-Post	Two Group Posttest	Two Group Pre-Post
Sample	$N=42$, Type^1	$N=55$, Type^1	$N=114$, Type^1	$N=59$ Type^2	$N=38$, Type^2	$N_1=16$, $N_2=18$ Type^1	$N_1=8$, $N_2=9$, Type^3
Intervention	TIMeR	TIMeR	TIMeR for ED	TIMeR for ED	TIMeR for ED	TIMeR for ED	TIMeR For CG
Data Collection	Scores	Scores	Scores, RJ, FGI	Scores, FGI	Scores, FGI	Scores, RJ, Interview	Scores, Interview
Assessment Instrument	VMRT	VMRT	SVATI	SVATI	ED Drawing Problems	SVATI	CG Problems
Data Analysis	Descriptive, Statistical	Descriptive, Statistical	Descriptive, Statistical, Content	Descriptive, Statistical, Content	Descriptive, Statistical, Content	Descriptive, Statistical, Content	Descriptive, Statistical, Content

RQ – Research Question
MR – Mental Rotation
ED – Engineering Drawing
CG – Computer Graphics
TIMeR – Training to Improve Mental Rotation Skills
RJ – Reflective Journal
FGI – Focus Group Interview

VMRT – Vandenberg's Mental Rotation Test Instrument
SVATI – Spatial Visualization Ability Test Instrument
Sample Type:
1 – First year engg. students with no prior ED knowledge
2 – Second year engg. students with prior ED knowledge
3 – Second year Master of Computer Applications (MCA) students

Chapter 4

TIMeR: Training to Improve MR Skills using Blender

In this work, we have developed 3D visualization tool (Blender) based training program to improve mental rotation skill and we call it *"**TIMeR**: **T**raining to **I**mprove **M**ental **R**otation Skills using Blender."* This chapter provides the details of TIMeR. It includes sections on TIMeR overview, Blender, alignment of mental rotation (MR) steps, instructional strategy demo-drill-practice (DDP), TIMeR procedure, TIMeR phases, and TIMeR for ED and CG.

4.1 Overview of TIMeR

TIMeR is a hands-on training and has three phases, Preparatory Phase (Phase 1), Training Phase (Phase 2), and Transfer Phase (Phase 3). Each phase consists of different training tasks that involve active manipulation of a three-dimensional (3D) object being displayed on a computer screen. An active manipulation of a 3D object is achieved by performing various functions of

the keyboard and mouse controllers within the 3D environment of a Blender tool. The main objective of TIMeR is the improvement of mental rotation (MR) skill. Therefore, the cognitive steps of MR have been used as the basis for the pedagogical design of tasks in TIMeR. (see section 4.2 for details). The execution of a task is achieved using an instructional strategy Demo-Drill-Practice (DDP).

An overview of TIMeR is illustrated in Figure 4-1 with providing the structure of each phase which has several elements as Pre-requisite, Instructional Goal, Task, Rationale, Expected Outcome, Tools and Material, Common, and Different. These elements are explained below.

Figure 4-1: TIMeR Overview

Phase 1	Phase 2	Phase 3
Preparatory Phase	**Training Phase**	**Transfer Phase**
Pre-requisite Completion of Pretest.	**Pre-requisite** Completion of Phase 1.	**Pre-requisite** Completion of Phase 2.
Instructional Goal Students should be able to use Blender user interface for getting acquainted with the 3D workspace.	**Instructional Goal** Students should develop the cognitive understanding of a 3D object and its rotation.	**Instructional Goal** Students should apply Phase 2 learnings to verify their pretest solutions.
Task (30 min approximate) Getting Acquainted with the Blender User Interface.	**Task** (120 min approximate) A. Observation Task B. Rotation Task	**Task** (30 min approximate) Applying Learnings of the Training Phase to Pretest Objects
Rationale This phase is desirable for performing tasks from subsequent phases.	**Rationale** This phase will help in forming the mental representations of a 3D object required for MR.	**Rationale** This phase will allow to concretize MR strategies.
Expected Outcome Students will operate basic Blender user interface and 3D workspace.	**Expected Outcome** Students will be able to form various mental representations of a 3D object and recognise the cognitive process of MR.	**Expected Outcome** Students will apply the cognitive process of MR to different objects.
Tools and Material Computer, Blender tool, blender files of 3D objects, instruction handout.	**Tools and Material** Computer, Blender tool, blender files of 3D objects, instruction handout.	**Tools and Material** Computer, Blender tool, blender files of pretest objects, instruction handout.
Instructional Strategy Demo-Drill-Practice.	**Instructional Strategy** Demo-Drill-Practice.	**Instructional Strategy** Demo-Drill-Practice.
Common Instructional Strategy.	**Common** Instructional Strategy.	**Common** Instructional Strategy.
Different Training objects, Training Tasks.	**Different** Training objects, Training Tasks.	**Different** Training objects, Training Tasks.

The **Prerequisite** is the prior condition mandatory for participating in the TIMeR phases. For participating in the preparatory phase, it is mandatory for the student to complete the pretest on mental rotation problems. For participating in the Training Phase, it is mandatory to complete the training of preparatory phase. Similarly, to participate in the transfer phase, it is mandatory to complete the training of training phase. An **Instructional Goal** in TIMeR phases describes what students should be able to do after undergoing a distinct unit of instruction in that phase. A **Task** is the training activity to be accomplished for achieving an instructional goal within the scope of a particular training phase of TIMeR. The approximate time required to execute the task is shown in the bracket. The training phase has single or multiple tasks, where the main task was broken down into subtasks for achieving the goal. The individual task details of each TIMeR phase are provided in their respective sections (see sections 4.6.1, 4.7.1, and 4.8.1). Each TIMeR task has specific **Rationale** which is the logical basis for a course of actions involved in that task. Figure 4-1 provides the rationale of the different TIMeR phases. An

Expected Outcome indicates what the TIMeR phase is intended to achieve in terms of students' learning and behaviour after the completion of phase. The **Tool and Material** are the training tools and training materials provided to the students in order to accomplish the training task. Here students are provided with a computer having Blender tool installed, blender files of 3D objects created in Blender ('blender file' is a Blender executable file), and the instruction hand-outs. **Instructional Strategy** indicates the instruction method used to execute the TIMeR tasks in order to meet the various instructional goals. We have used Demo-Drill-Practice (DDP) as the instructional strategy for executing all tasks in TIMeR. The details of DDP are provided in section 4.4. A **Common** indicates the things that are common in all three phases, whereas **Different** indicates the things that are not common in all three phases. In TIMeR a common element in all three phases is the DDP instructional strategy, whereas each phase has different training task and different training objects.

4.2 Alignment of Cognitive Steps of MR and TIMeR Tasks

This section provides the alignment between the cognitive steps of mental rotation and tasks in TIMeR, as these steps form the basis for the pedagogical design of those tasks. As mentioned in Section 2.3, these steps involve the formation of a mental image of an object, mental rotation,

comparison, judgement, and decision. In a typical mental rotation problem, the three-dimensional (3D) object is represented in a two-dimensional (2D) drawing, and while performing the cognitive steps of mental rotation, it requires doing the imagination of that object in a three-dimensional space. Table 4-1 shows the alignment between cognitive steps of MR and tasks in TIMeR.

Table 4-1: Alignment of TIMeR Tasks and Cognitive Steps in MR

TIMeR Phases	Training Tasks and Subtasks	Cognitive Steps in MR relevant to the Task (Johnson, 1990)
Phase1: Preparatory Phase	**Getting Acquainted with the Blender User Interface**	Not applicable.
Phase 2: Training Phase A: Observation Task	**Observation Task** 1. **Observation of the object using 3D View** To view and observe the object in a default 3D workspace.	(a) to form a mental representation of an object
	2. **Observation of the object using multiple views** To observe the object from different views such as the top view, front view, side view, and 3D view, separately. To observe the object from different views together using the quad-view feature of Blender.	(a) to form mental representations of an object
B: Rotation Task	**Rotation Task** 1. **Rotation of the object in default orientation** To rotate the object in default orientation using Blender key shortcuts.	(a) to form mental representations of an object (b) to rotate the object mentally
	2. **Rotation of the object using 3D View** To rotate the object along different axes such as an axis perpendicular to the screen, x-axis, y-axis, and z-axis using Blender features.	(a) to form a mental representation of an object (b) to rotate the object mentally
	3. **Rotation of the object using multiple views** To rotate the object as mentioned in 1(a) above in different views, separately and together.	(a) to form a mental representation of an object (b) to rotate the object mentally until its axial orientation allows the comparison
	4. **Rotation of Views** To rotate views by keeping the object stationary.	(a) to form a mental representation of an object (b) to rotate the object mentally
Phase 3: Transfer Phase	**Applying Learnings of the Training Phase to Pretest Objects** To verify pretest solutions by applying transfer phase learnings.	(a) to form a mental representation of an object (b) to rotate the object mentally until its axial orientation allows the comparison to the standard. (c) to make the comparison (d) to make judgement

The initial step of forming the mental representation requires a careful observation of an object and imagining all the aspects of a 3D form of that object. The different aspects include geometrical forms, views (top, front, side, back, and 3D), faces, shapes, edges, vertices,

dimensions, and orientations. To achieve this, the **Observations Task** (Training Phase) are designed. The description of the execution of observation task is given Section 4.7.1.1.

After forming the mental representation, it would also require imagining the various axis of rotations, like the standard axes (x, y, and z) or an arbitrary axis. Further, it would require doing mental rotations about those axes resulting in multiple mental representations of that object. Then, the current instance of the rotated object would need to be stored mentally for comparing with the standard one. To achieve this, the **Rotation Tasks** (Training Phase) are designed. The description of the execution of the rotation task is given Section 4.7.1.2.

The **Transfer Phase** tasks are designed to achieve the later steps of comparison, judgment and decision making. In this it required to apply Phase 2 learnings to pretest objects in order to verify the pretest solutions. The detailed description of task execution is given Section 4.8.1.

4.3 Blender: a 3D Visualisation Tool

This section provides information related to Blender tool and its features used for TIMeR. Blender is the free and open source 3D Visualization tool and 3D content creation suite. It supports the entire features of the 3D production pipeline. Blender has been used in different entertainment domains like animated movies, short films, television commercials, gaming (Blender website, 2017), and in Education and eLearning domain (Andrei, 2012; Gumster 2003; Sahasrabudhe, 2009). The rich set of Blender features include Photorealistic Rendering, Fast Modeling, Realistic Materials, Fast Rigging, Animation toolset, Sculpting, Fast UV Unwrapping, Full Compositor, Simulations, Game Creation, Camera and Object tracking, Library of Extensions, Video Editing, File Formats, and Flexible Interface (Blender website, 2017).

For TIMeR, the criteria for tool selection was such that, the tool should possess following characteristics.

1. 3D workspace for 3D visualization.
2. Interactive user interface.
3. Support for easy customization of the interface.

4. Support for easy and rich 3D content development.

5. To run on any platform.

6. Easy to train.

Though many tools satisfy 1-6, we picked Blender as it is 'Open Source' and this is important in Indian context since many colleges cannot afford proprietary software.

Blender User Interface (UI)

The Blender UI has the flexibility to customize as per the user requirements. It allows novice or advanced users to customize their layout completely. This also includes splitting the viewport and full customization with python scripting. In addition, Blender's interface provides consistency across all platforms, no disruptive pop-up windows, and support for the crisp text. On start-up, Blender displays the default interface or screen. The screen is divided into five parts that contain the Editors listed below and shown in Figure 4-2.

1. **The Info Editor:** It provides access to the Blender's main menu options, such as to open a new file or quit Blender. The Info Editor was used to open and close the blend-files while developing contents, and during the training as well. The other options of Info Editor were not relevant for TIMeR.

2. **A 3D View:** The purpose of a 3D View is to interact with the 3D scene. The other usage includes modelling, animation, and texture painting. In TIMeR 3D view was used for designing tasks, creating 3D models, and for the training.

3. **An Outliner:** An Outliner is a list that organizes data in the blender file, i.e. the scene data and also the User Preferences. It is used to view the data in the scene, to select and deselect objects in the scene, to hide or show an object in the scene, to enable or disable the selection (to make an object "unselectable" in the 3D View), to enable or disable the rendering of an object, to delete objects from the scene, to unlink data, to easily select which render layer to render, and to easily select which render pass to render. In TIMeR, an Outliner was used for selecting and naming the training objects during the modelling process.

4. **The Properties Editor:** The Properties Editor is used to edit data and properties for the Active Scene and the Active Object. It has several tabs, which can be selected through the

icon row in the header. These tabs are used to add features, and to change properties for the Active Object. In TIMeR, the object properties were used to change the properties of training object such as the colour and display form.

5. **The Timeline:** The timeline at the bottom is mainly used for animation development. This feature was not relevant for TIMeR.

Figure 4-2: Blender User Interface
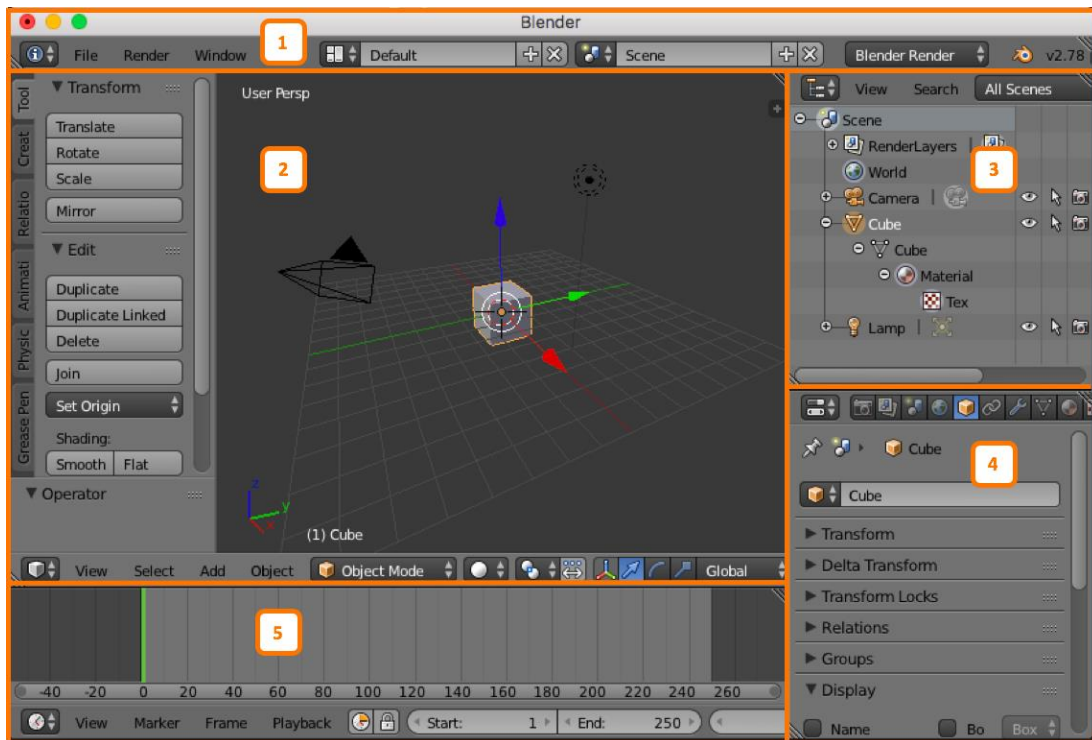
4.3.1 Blender Features used in TIMeR

Table 4-2 provides the list of Blender features used in TIMeR, and their association with the training tasks. These features were used for content development and hands-on training. Other features utilized for the content development include Info Editor, Outliner, Properties Editor, User View, Orientation, 3D Object, Active Object, and Modelling.

Table 4-2: Blender Features and TIMeR Tasks

TIMeR Phases	Training Tasks		Corresponding Blender Features
Preparatory Phase	Getting Acquainted with the Blender User Interface		• Blender User Interface • 3D view • Relevant Mouse & Keyboard Functions
Training Phase A: Observation Task	**1.**	Observation of the object using 3D View	• 3D View • Relevant Mouse & Keyboard Functions
	2.	Observation of the object using multiple views	• Views • Quad-view
B: Rotation Tasks	**1.**	Rotation of the object in default orientation	• Mouse and Keyboard Functions of Rotation
	2.	Rotation of the object using 3D View	• Mouse and Keyboard Functions of Rotation • Axes: X, Y, and Z • 3D Rotation Manipulator • Transform Properties
	3.	Rotation of the object using multiple views	• Views • Quad-view
	4.	Rotation of views	• Relevant Mouse & Keyboard Functions
Transfer Phase	Applying the learnings of the training phase to pretest objects.		• Features from Phase 2

Customized Blender UI for TIMeR

Figure 4-3 shows a sample of customized Blender UI used in TIMeR, mainly a 3D View with major elements. 3D view provides the 3D environment required for the visualization and interaction with 3D training objects.

1. **User View:** It shows the current user view, either orthographic or perspective and can be switched by pressing Numpad5 key. In the Figure 4-3, the view is perspective denoted by 'User Persp.'

2. **Orientation:** It shows the current orientation of the 3D View with the axes. X, Y, and Z axes are labelled and denoted by colours red, green, and blue respectively.

3. **3D Object:** 3D object is any 3D model in 3D View. The object shown in the Figure 4-3 is a 3D model of VMRT test problem, created with same orientation of the original.

4. **Active Object:** It is the name of the active object i.e. object currently being selected.

5. **Transform Manipulator:** It allows the user to do the transformation on an object such as rotate, scale or move objects. This is achieved by grabbing (clicking with the mouse) their

controls (the curved axes) and moving the mouse in the direction of an axis. The active manipulator (number 6) shown in the Figure 4-3 is Rotation Manipulator.

Figure 4-3: Customized Blender User Interface
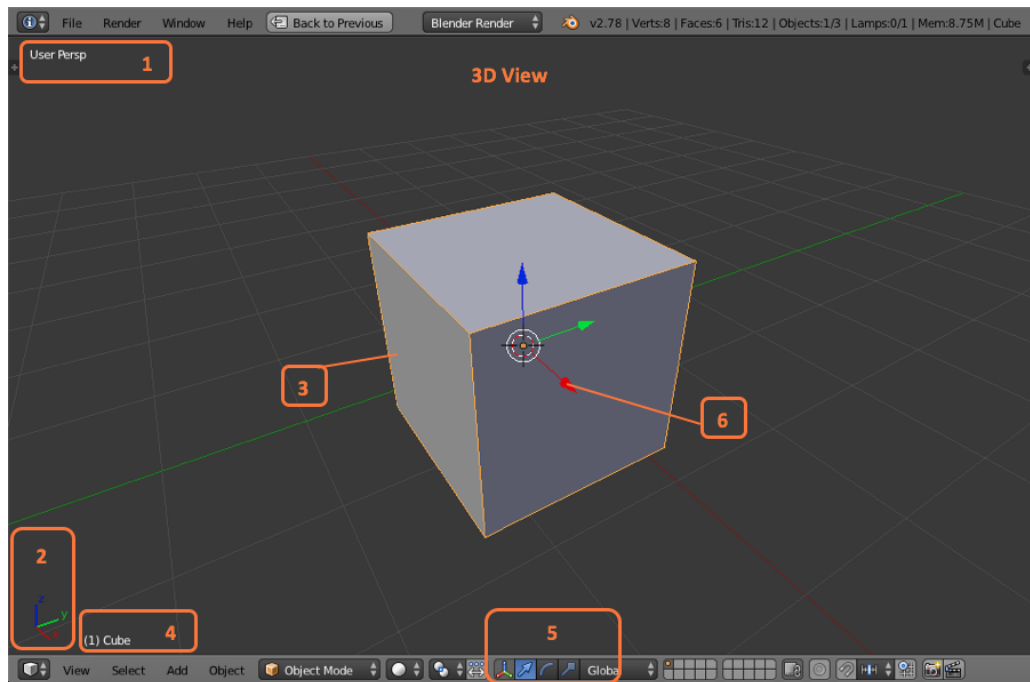
3D Modelling in Blender

Blender's complete set of modelling tools allow the user to create, transform and edit 3D models efficiently. Blender's modelling tools include Keyboard shortcuts for a fast workflow, Edge slide, collapse and dissolve, Grid and Bridge fill, Python scripting for custom tools and add-ons. In this work, the training content was developed using Blender's modelling technique. The training content includes the 3D models of practice objects, mental rotation objects, engineering drawing objects, and computer graphics object.

Views

Different views of an object can be observed by switching viewing directions of a 3D View. Figure 4-4 show these views (3D, user perspective, top, bottom, front, back, right side, left side) of the same object. This can be achieved by pressing the Numpad keys 1,3,7, and 0. The opposite directions can be selected by holding Ctrl while using the same Numpad Shortcuts. User perspective view can be viewed by pressing Numpad5.

Figure 4-4: Views in Blender

3D or User View

User Ortho

(1) Cube

User Perspective View

User Persp

(1) Cube

Front View

Front Ortho

(1) Cube

Back View

Back Ortho

(1) Cube

Top View

Top Ortho

(1) Cube

Bottom View

Bottom Ortho

(1) Cube

Right Side View

Right Ortho

(1) Cube

Left Side VIew

Left Ortho

(1) Cube
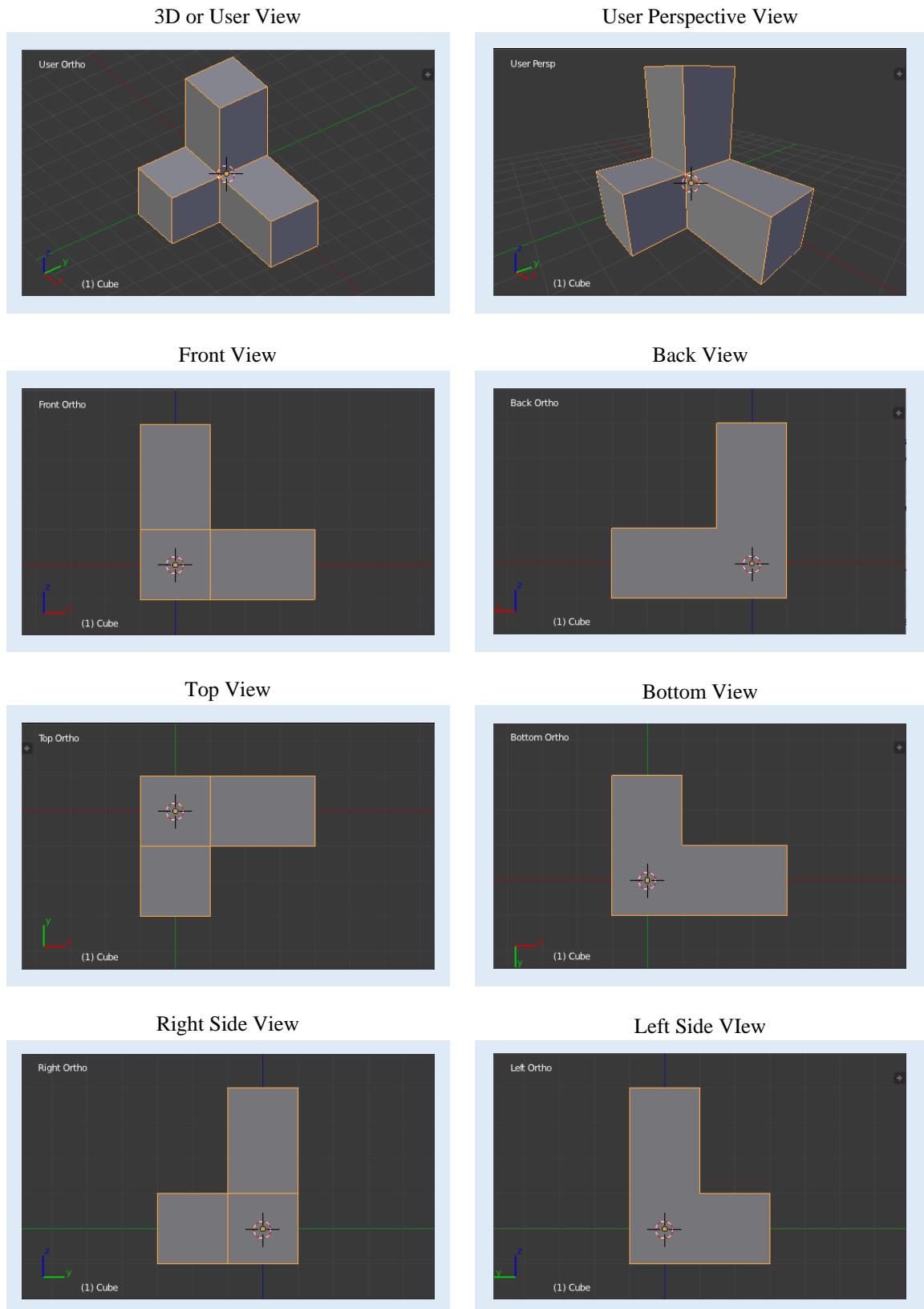
Quad-View

Changing to Quad-View splits the 3D View into four views: Three Orthographic "side views" and one Camera or User View. This view allows the user to instantly see the model from many viewpoints. For instance, in Figure 4-5 the cylinder object and its different views are shown using quad-view feature. In this arrangement, the user can zoom and pan each view independently. In Quad View, the four views are still part of a single 3D object.

Figure 4-5: Blender Quad-view
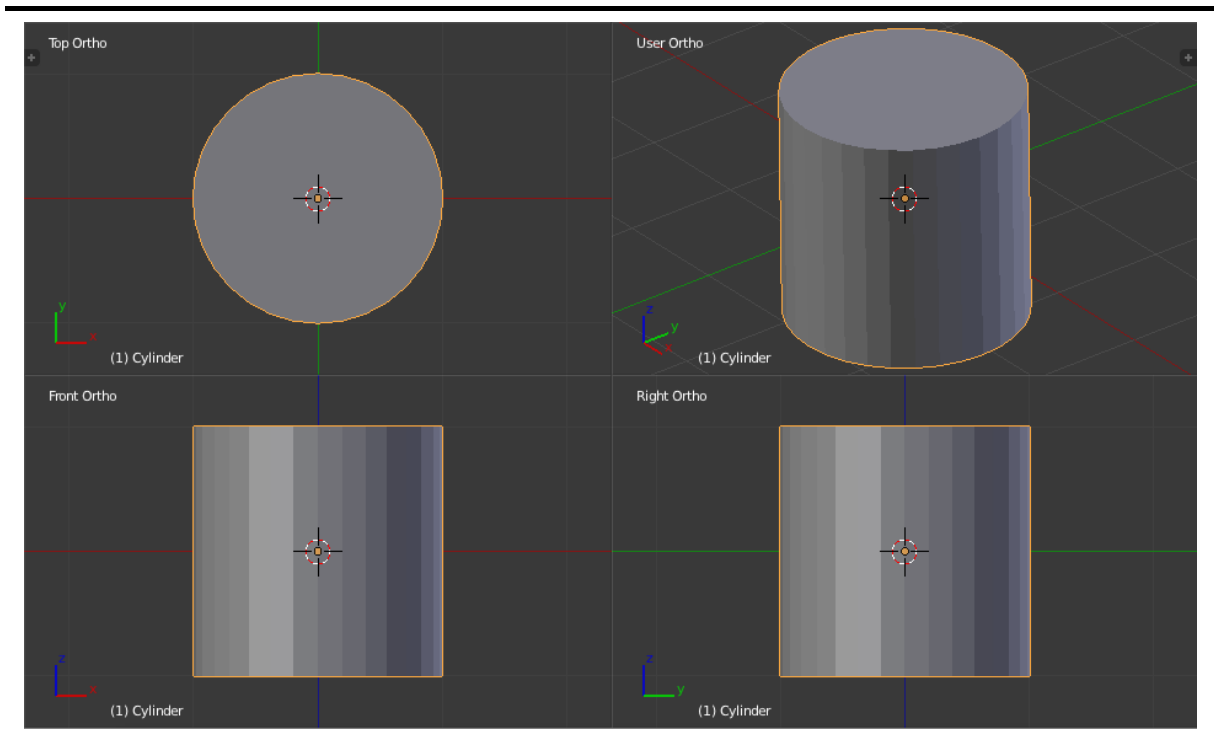
Rotation

Rotation involves changing the orientation of the object around one or more axes or the Pivot Point. The angle of rotation gets displayed in the footer of the 3D View editor. Free rotation mode is performed by pressing R and moving the mouse. Figure 4-6 shows different instances of cube rotation in Blender, such as (a) initial orientation, (b) free rotation, (c) rotation about x-axis, (d) rotation about y-axis, and (e) rotation about the z-axis.

3D Rotation Manipulator

The 3D Rotation manipulator widgets allow mouse controlled rotation in the 3D View. It allows the rotation of object by grabbing its control and moving the mouse in the direction of an axis. In TIMeR rotation manipulator was used for Rotation Task. Figure 4-6 (f) shows rotation manipulator.

Figure 4-6: Rotations in Blender

(a) Initial orientation	(b) Free rotation
(c) Rotation about X axis	(d) Rotation about Y axis
(e) Rotation about Z axis	(f) Rotation using rotation manipulator
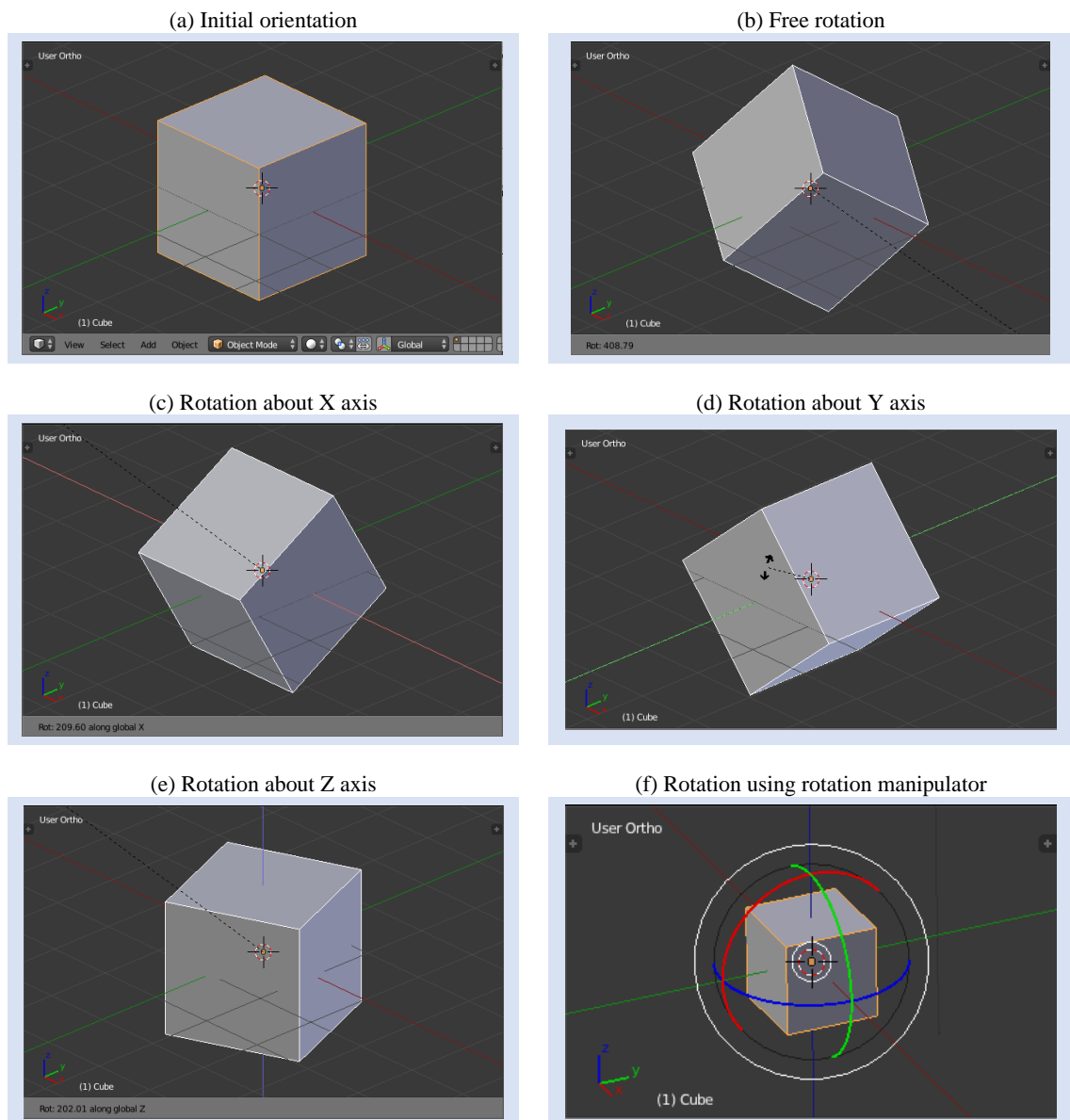
4.4 Instructional Strategy: Demo-Drill-Practice (DDP)

The Demo-Drill-Practice (DDP) instructional strategy is based the teaching method of demonstration and practice, (See Section 2.6.1 for details on demonstration and practice). In this work, DDP is used to execute all the tasks in TIMeR. The actions involved in DDP are described below.

Demo: In a Demo part instructor demonstrates the training task, and students watch a demonstration and observe attentively.

Drill: In the Drill part instructor makes students repeat the steps of the task in a step-by-step manner in-tandem with an instructor. Drill activity ensures that students have performed the task sequentially by repeating it as soon as they saw the demonstration. Having done this part, it supports students' retention of the mental representation acquired during the Demo part.

Practice: In the Practice part, students perform an independent practice with the three-dimensional training objects. During this, they are provided with hand-outs of training instructions. They also receive teaching assistance from the instructor. This part of the instruction is required for rehearsing and improving the task. DDP is illustrated in Figure 4.7.

Figure 4-7: Instructional Strategy: Demo-Drill-Practice (DDP)
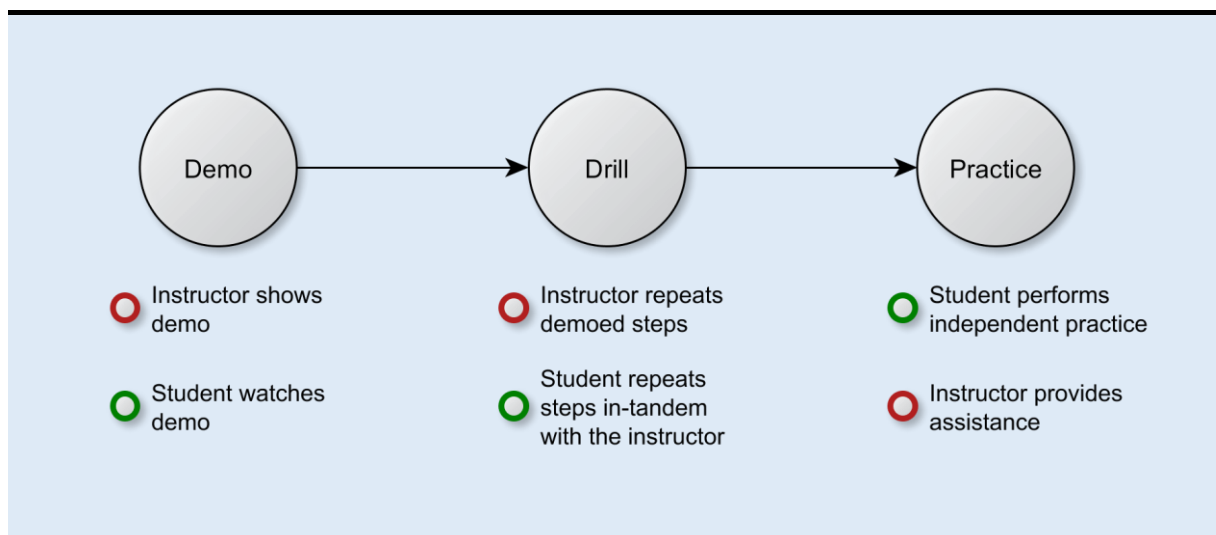
4.5 TIMeR Procedure

The TIMeR procedure begins with an ice-breaker activity that focuses on highlighting the importance of visualization skills. Then students solve pretest based on the mental rotation problems, followed by receiving the mental rotation training through TIMeR. In the end, students solve posttest equivalent to the pretest. The sequence of TIMeR procedure is illustrated in Figure 4-8.

Figure 4-8: TIMeR Procedure
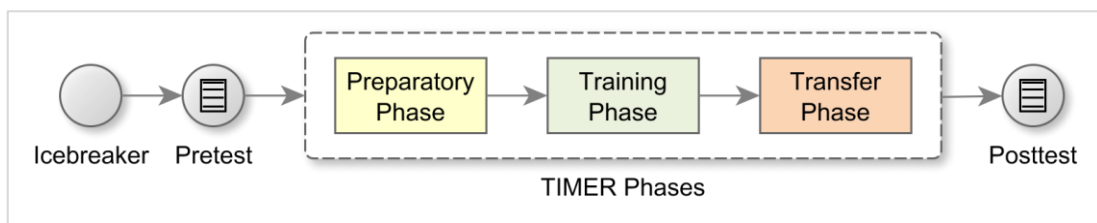
Ice-breaker Activity: We use the example shown in Figure 4-9 (Olkun, 2003). We display only the top view and the side view (See Figure 4-10 a) and then ask students to think, visualize, and draw the possible solutions for the missing views, which are the front view and 3D view. No hints are provided initially. While doing this activity, students are expected to use their prior visualization skills and to think about the process of solving such problems. Figure 4-10 (b), (c), and (d) show some of the possible solutions. This activity helps not only to engage the students but also to underline the importance of spatial skills.

Figure 4-9: Icebreaker Activity Object (reproduced from Olkun, 2003)
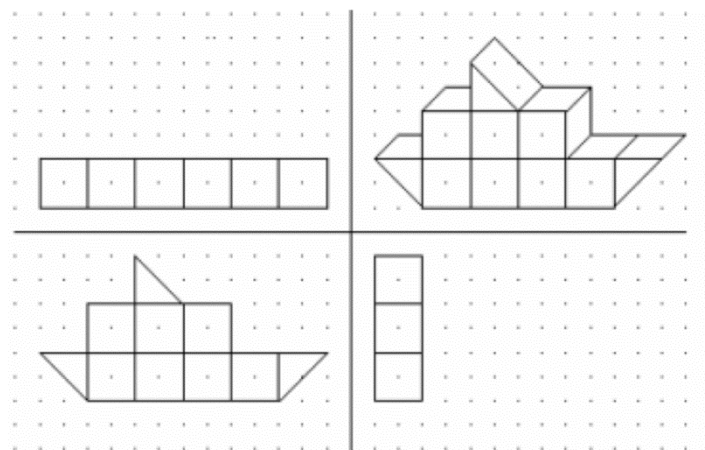
Figure 4-10: Icebreaker Activity Problem (adapted from Olkun, 2003)
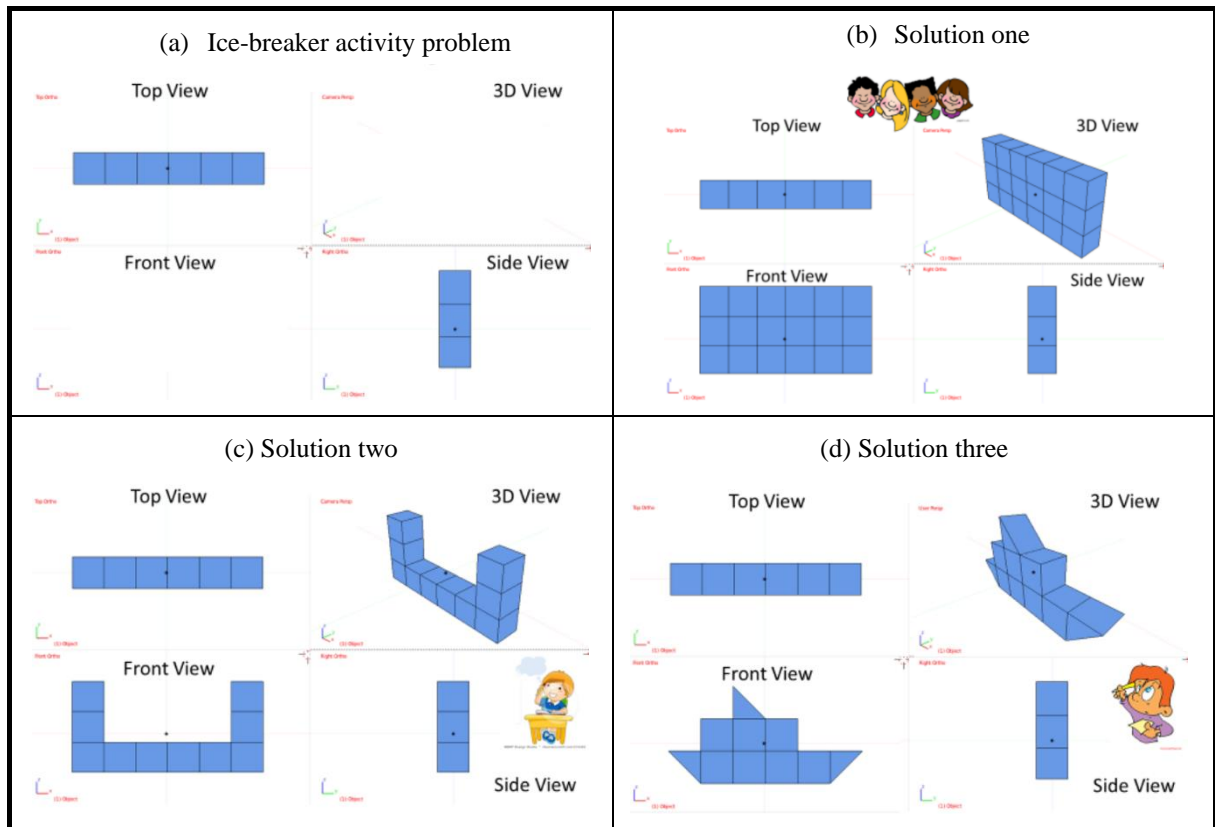
Pretest: Pretest has ten mental rotation problems from VMRT (Vandenberg & Kuse, 1978), (see section 3.4.1 for more information VMRT). The pretest was conducted to make students identify their solution strategies, and the possible challenges they face while solving the pretest, i.e. before receiving the training. It is a prerequisite for participating in TIMeR.

TIMeR Phases: After the pretest students receive TIMeR, details of TIMeR phases are given in section 4.6, 4.7, 4.8.

Posttest: Posttest was conducted after the successful completion of TIMeR. It has ten mental rotation problems equivalent to the pretest. Posttest measure the students' performance and the effectiveness of TIMeR.

The TIMeR procedure is common to all the research studies in this work, the only difference is the pretest, posttests, and training objects. The next section provides the details of the execution of Training Phase of TIMeR.

4.6 TIMeR Phase 1: Preparatory Phase

This section provides details of the preparatory phase of TIMeR, which includes describing different training tasks involved. Here, students experience the Blender user interface and the features essential for performing the activities in other phases of TIMeR. The association between cognitive steps in mental rotation and the training activities is not applicable here. The section ends with summarizing Blender commands and actions used in this phase.

Pre-requisite: For participating in the preparatory phase, it is mandatory for the students to complete the pretest on mental rotation problems.

Instructional Goal: Students should be able to use Blender user interface for getting acquainted with the 3D workspace.

Task: Getting Acquainted with the Blender User Interface (UI). This task is broken down into subtasks, (1) Running Blender, (2) Working with blender files, (3) Working with mouse functions, (4) Working with keyboard shortcuts, (5) Understanding the elements of 3D view. These tasks are executed by applying Demo-Drill-Practice (DDP) instructional strategy.

Rationale: For performing the tasks from the training phase of TIMeR, it is desirable to get familiar with Blender UI, as the training phase activities would require students to interact and manipulate various objects within the 3D workspace of Blender.

Expected Outcome: By the end of the preparatory phase, students are expected to understand how to use Blender for getting familiar with the 3D workspace.

Training Material: In this phase, students are provided with a computer having Blender application installed, with the blender files of practice objects created in Blender, and with the instruction hand-outs. Practice objects consist of 3D primitive objects such as a cube, cone, cylinder, and other objects. The instruction hand-outs have step by step instructions along with keyboard and mouse commands required for completing the task.

4.6.1 Execution of the Tasks

Students perform training subtasks (also illustrated in Figure 4-11) by following the training instructions given by the instructor.

Figure 4-11: Preparatory Phase Task Diagram
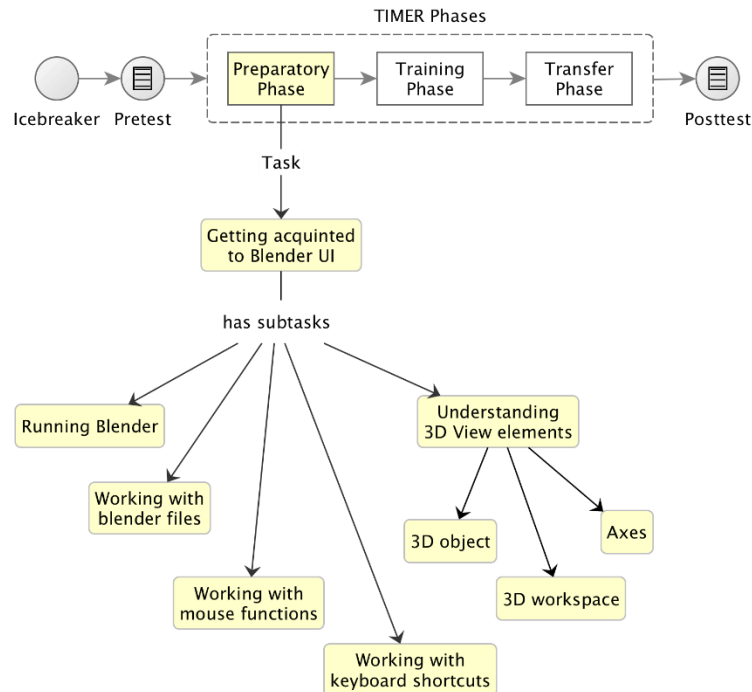
1. **Running Blender:** Students require running the Blender application that is pre-installed on their computers. They have to quit and re-run Blender. Then they repeat these actions for a couple of times. To quit Blender, the shortcut keys are Ctrl + Q or quit from the file menu.

2. **Working with blender files:** New blender file can be created using Ctrl + N or by using new file option from the file menu. To open an existing file, open option from file menu can be used. Here, students are not require creating new files but have to open and work with existing blender files.

3. **Working with mouse functions:** In Blender, the Right Mouse Button (RMB) is used for selection, and the Left Mouse Button (LMB) initiates or confirms actions. Students require selecting the object by using these functions. They have to repeat these steps for a couple

of times for getting their hands on it. By clicking the middle mouse button (MMB), holding and dragging it, the view can be rotated around the point of interest. Starting in the middle of the area and moving up and down or left and right, the view will get rotated around the middle of the area. This activity is essential here to get accustomed to using MMB.

4. **Working with keyboard shortcuts:** Blender has a rich set of keyboard shortcuts to perform various actions. For instance, the active object can be deselected by pressing A key. Also, to zoom in and zoom out, the hotkeys are NumpadPlus and NumpadMinus. It moves the camera forwards and backward. With the help of wheel mouse, it is also possible to zoom by rotating the Wheel. Each task has different keyboard shortcuts.

5. **Understanding 3D View elements:** Students are required to get familiar with a 3D view of Blender as it provides the 3D environment in which all TIMeR tasks are to be performed. They get familiar with a 3D view by observing and understanding the different elements of 3D view such as User View, Orientation, and mini axis, 3D Object, and Transform Manipulator shown in Figure 4-12. (For more details on elements of 3D view see section 4.3.1).

Figure 4-12: Customized Blender User Interface
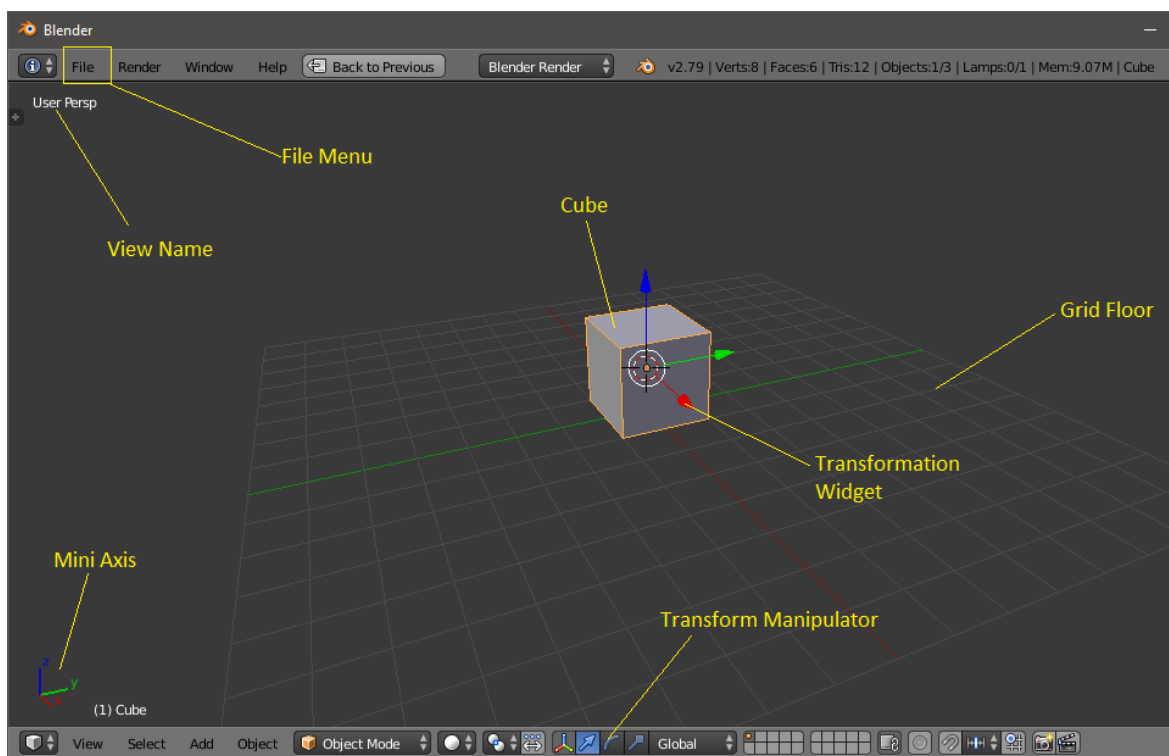
In table 4-3 we summarise Blender actions from this section, doing these actions help in getting familiar with the basic Blender UI and the UI customized for TIMeR. To see the set of preparatory phase training instructions, see Appendix I.

Table 4-3: Blender Commands for TIMeR Phase 1

Actions	Blender Commands (for Windows)
Quitting Blender	Ctrl + Q
New blender file	Ctrl + N
Open existing blender file	Ctrl + O
Save blender file	Ctrl + S
Deselect	Keyboard 'A'
Select all	Keyboard 'A'
Selection of single object	Right Mouse Button (RMB) press
Initiation or confirmation of actions	Left Mouse Button (LMB)
To rotate view (with mouse)	Press Middle Mouse Button + Hold + Drag
Zooming with keyboard	NumpadPlus and NumpadMinus
Zooming with mouse	Rotate mouse wheel
Discard any action	Keyboard 'Esc'

4.7 TIMeR Phase 2: Training Phase

This section provides details of the training phase of TIMeR, where students get trained for observation task and rotation task.

Pre-requisite: For participating in the training phase, it is mandatory for the students to complete the preparatory phase.

Instructional Goal: The overall instructional goal of this phase is, students should develop the cognitive understanding of a 3D object and its rotation. However, each task has a specific instructional goal and is given in Table 4-4, column two.

Task: Training phase has two main tasks, (A) Observation Task, and (B) Rotation Task. The observation task is broken down into subtasks, (1) Observation of the object using 3D View

and (2) Observation of the object using multiple views. The rotation task is broken down into subtasks, (1) Rotation of the object in default orientation, (2) Rotation of the object using 3D View, (3) Rotation of the object using multiple views, and (4) Rotation of views.

Rationale: This phase helps in forming the mental representations of a 3D object required for mental rotation and hence helps in doing the mental rotation.

Expected Outcome: Students will be able to form various mental representations of a 3D object and recognise the cognitive process of mental rotation.

Training Material: In addition to the phase 1, in the training phase, students are provided with the blender files of practice objects related to observation and rotation task, and the hand-outs.

4.7.1 Execution of the Tasks

Students perform training phase tasks (also illustrated in Figure 4-13) by following the training instructions given by the instructor using DDP. Here first we explain the information specific to each task such as instructional goal, rationale, the relevant cognitive step of mental rotation, and the expected outcome in a tabular form, followed by the execution part of the task.

Figure 4-13: Training Phase Task Diagram
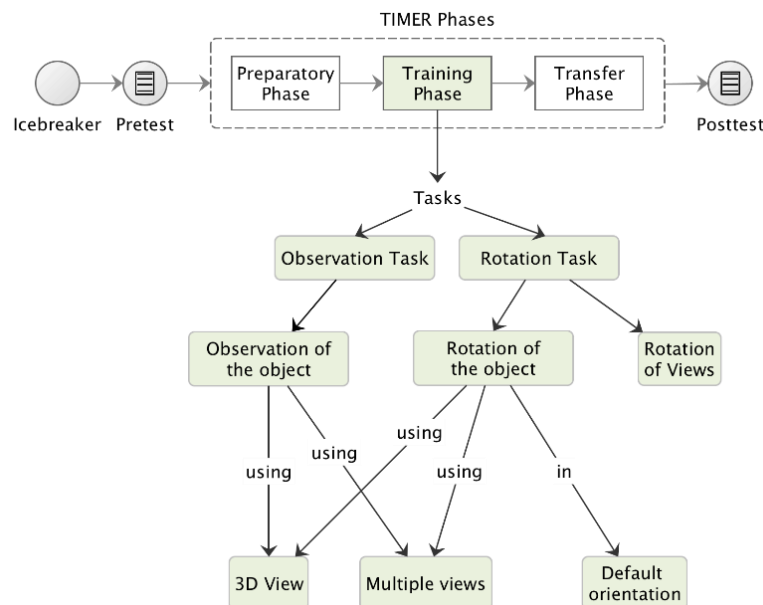
4.7.1.1 Observation Task

Here the students observe the object by analyzing its geometry, shapes, and various views so that they can form its mental image. Table 4-4 provides information specific to the observation tasks, such as instructional goal, rationale, relevant cognitive steps of mental rotation, and the expected outcome.

Table 4-4: Training Phase: Observation Task

Training Task	Instructional Goal	Rationale	Cognitive Steps in MR (Johnson, 1990)	Expected outcome
Observation of the object using 3D View	Students should be able to observe the object using Blender 3D View. They should be able to identify & distinguish between views.	Observing the object from different directions in 3D environment may help in forming the mental representations of it.	(a) to form a mental representation of an object	Students develop the cognitive understanding of the object.
Observation of the object using multiple views	Students should be able to observe the object from different views (top, side, and front) individually as well all together using Blender features.	Observing the object in different views at the same time may strengthen the process of the formation of the various mental representations (at different orientations) of it.	(a) to form a mental representation of an object	Students develop the cognitive understanding of the object.

(1) Observation of the object using 3D View

In a 3D view, students observe the given object by navigating the 3D space with the use of both keyboard shortcuts and mouse movements. They require rotating the view around the point of interest, by clicking and dragging MMB on the viewport's area. Starting in the middle of the area and moving up and down or left and right, the view will get rotated around the middle of the area. To change the viewing angle in discrete steps, students have to use Numpad8 and Numpad2 in vertical direction, or have to use Numpad4 and Numpad6 to rotate in horizontal direction. To have closer focus onto the object, students zoom onto it at any instance. They can use either NumpadPlus, NumpadMinus, or mouse wheel. When navigating the scene, if they accidentally navigate away from the scene, this can be fixed by pressing NumpadPeriod. Figure 4-14 shows the instances of view rotation when pressed Numpad2 for three to four times.

Figure 4-14: Observation Task in 3D View
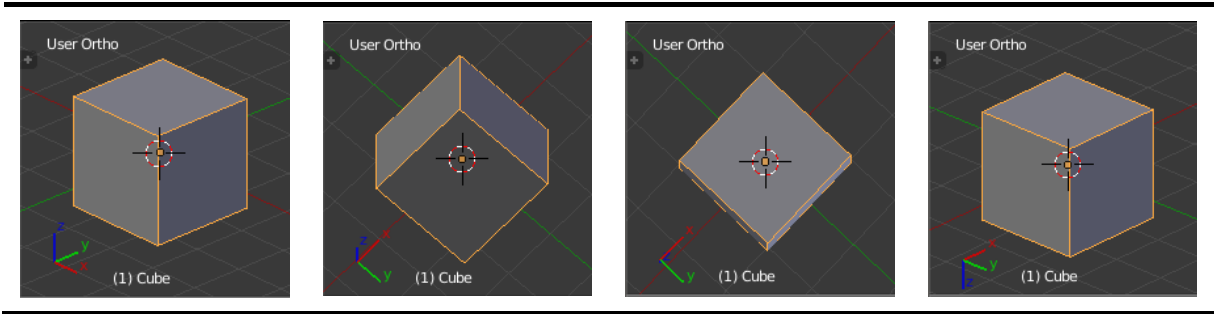
(2) Observation of the object using multiple views.

Students observe the object from different views by switching viewing directions of a 3D View such as a top view, bottom, front, back, right side, left side, and user perspective. To change the viewing direction to a front view, side view, top view and camera view students have to use Numpad1, Numpad3, Numpad7, and Numpad0, see Figure 4-15 (a). To view the opposite directions, they use the same Numpad keys by holding Ctrl. User perspective view can be viewed by pressing Numpad5. To see the object from many viewpoints at the same instance student change the 3D View to Quad-View by using keyboard shortcut Ctrl+Alt+Q. Changing to Quad-View splits the 3D View into four views: Three Orthographic "side views" and one Camera or User View, see Figure 4-15 (b).

Figure 4-15: Observation Task in Multiple Views

(a) Views (individual)   (b) Quad view
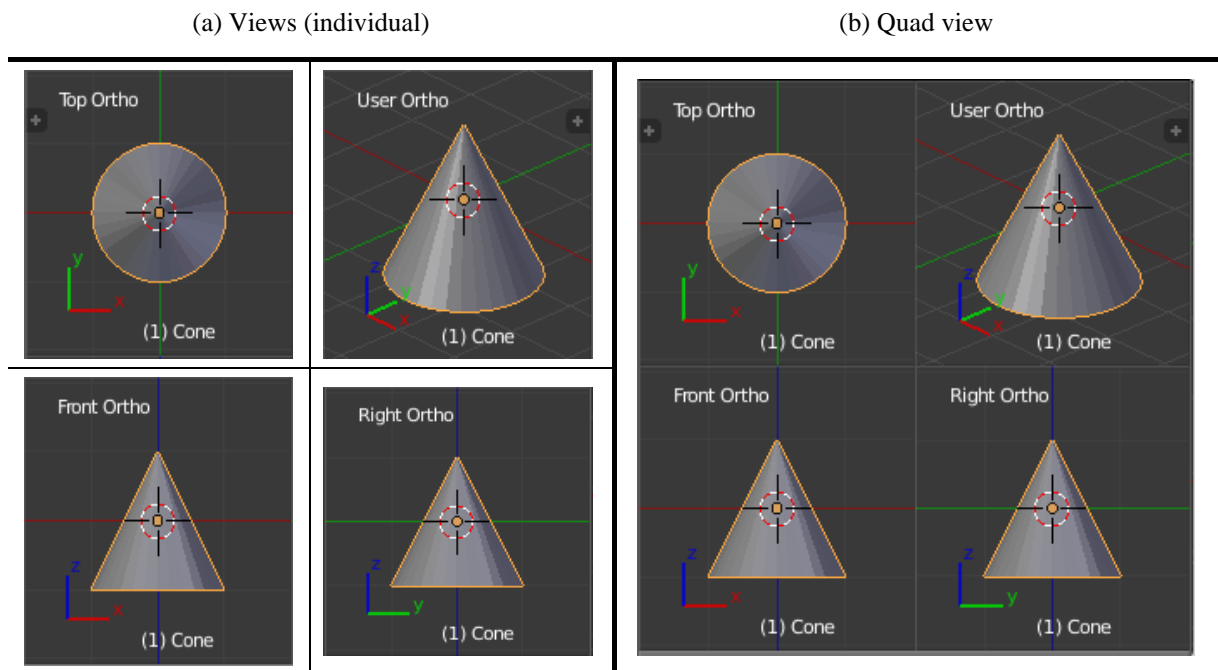
4.7.1.2 Rotation Task.

Rotation involves changing the orientation of the object around one or more axes or the Pivot Point. Table 4-5 provides information specific to the rotation tasks, such as instructional goal, rationale, relevant cognitive steps of mental rotation, and the expected outcome.

Table 4-5: Training Phase: Rotation Task

Training Task	Instructional Goal	Rationale	Cognitive Steps in MR (Johnson, 1990)	Expected outcome
1. Rotation of the object in default orientation	Students should be able to perform the rotation of the object and identify the axis of rotation.	After learning to form the various mental representations of the object, rotation task may trigger the mental rotation.	(a) to form a mental representation of an object (b) to rotate the object mentally	Students develop the cognitive understanding of a 3D object and its rotation.
2. Rotation of the object using 3D View	Student should be able to perform the rotation of the object using Blender features: individual axes, 3D rotation manipulator, and transform properties	Rotation about various axes may enable the formation of the multiple mental representations of an object at different angles with respect to the individual axes.	(a) to form a mental representation of an object (b) to rotate the object mentally	Students develop the cognitive understanding of rotation of the object.
3. Rotation of the object using multiple views	Students should be able to perform the rotation task by utilizing the quad-view feature. They should be able to distinguish between the different orientations of the same object when rotated in quad-view.	Rotation in different views at the same time may strengthen the process of the formation of various mental representations (at different angles with respect to the individual axes) of an object. It also may enable the comparison between those multiple orientations.	(a) to form a mental representation of an object (b) to rotate the object mentally until its axial orientation allows the comparison	Students develop the cognitive understanding of rotation of the object.
4. Rotation of Views	Students should be able to perform the rotation of views by keeping the object stationary.	Observing object in 3D space by rotating various views may help in forming the multiple mental representations of an object.	(a) to form a mental representation of an object (b) to rotate the object mentally	Students develop the cognitive understanding of a 3D object and its rotation.

(1) Rotation of the object in default orientation: Students rotate the object in default orientation by pressing R and moving the mouse. (See Figure 4-16 (a)).

(2) Rotation of the object using 3D View

Students rotate the object about x-axis by pressing keys R+X and moving the mouse in the desired direction. Similarly, they perform the rotation about y-axis and z-axis by pressing the keys R+Y, R+Z respectively, and moving the mouse in desired directions. The axis of rotation gets displayed after pressing the keys and disappears on the completion of the action. The Figure 4-16 shows the one instance of each rotation as (a) free rotation, (b) rotation about x-axis, (c) rotation about y-axis, and (d) rotation about the z-axis.

Figure 4-16: Rotation Task in 3D View
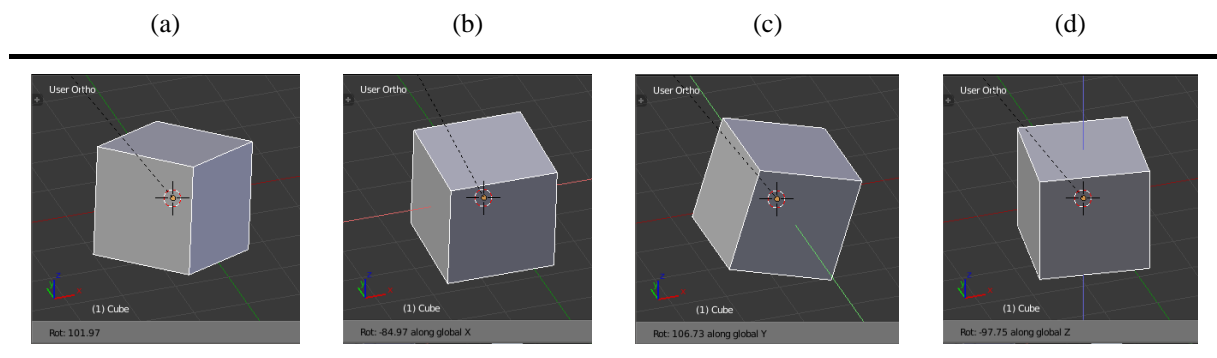
3D Rotation Manipulator: Here, students use the 3D rotation manipulator widgets to perform the mouse controlled rotation in the 3D View. They rotate the object by grabbing its control and moving the mouse in the direction of an axis. Below Figure 4-17 shows the four instances of rotation of the cube using manipulator. The red, blue, green coloured curves denote rotation path about the x-axis, y-axis, z-axis respectively. The white circle indicates the rotation path about the user view.

Figure 4-17: Rotation using 3D Rotation Manipulator
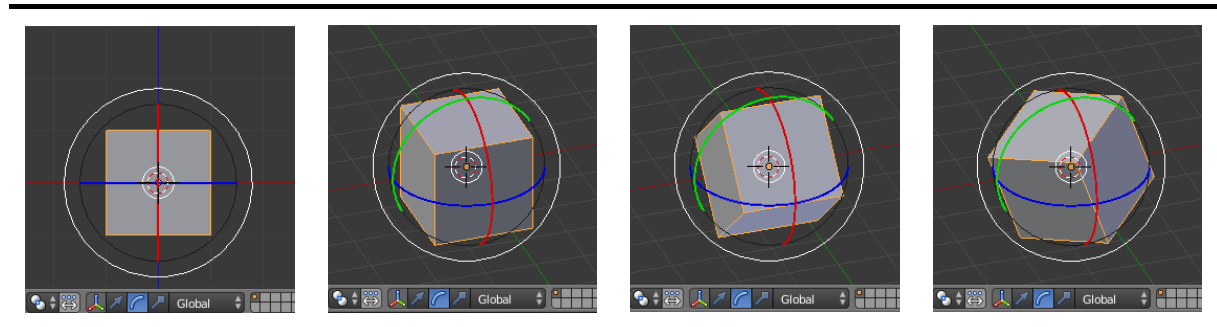
Transform Properties Panel: Students use the Transform panel in the Properties region to view and manually or numerically control the rotation properties of an object. As shown in the Figure 4-18, the object is rotated by entering numerical values as 55 degrees about x-axis and by 120 degrees about z-axis.

Figure 4-18: Rotation using Transform Properties Panel
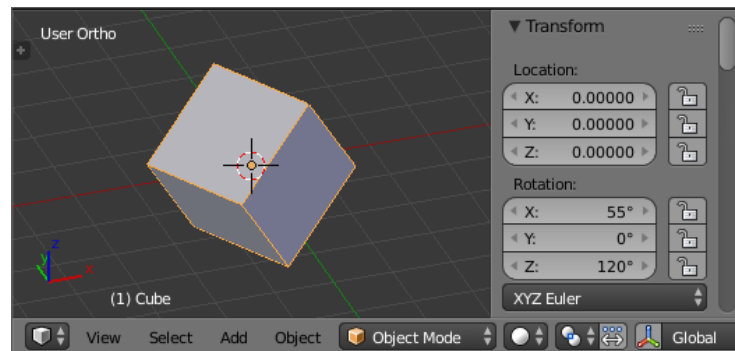
(3) Rotation of the object using multiple views

To see the rotation of the object from many viewpoints at the same instance students change the 3D View to Quad-View by pressing Ctrl+Alt+Q and then perform the various rotation operations. In the Figure 4-19, while rotating the object about x-axis, the same instance can be observed in different views.

Figure 4-19: Rotation Task in Multiple Views
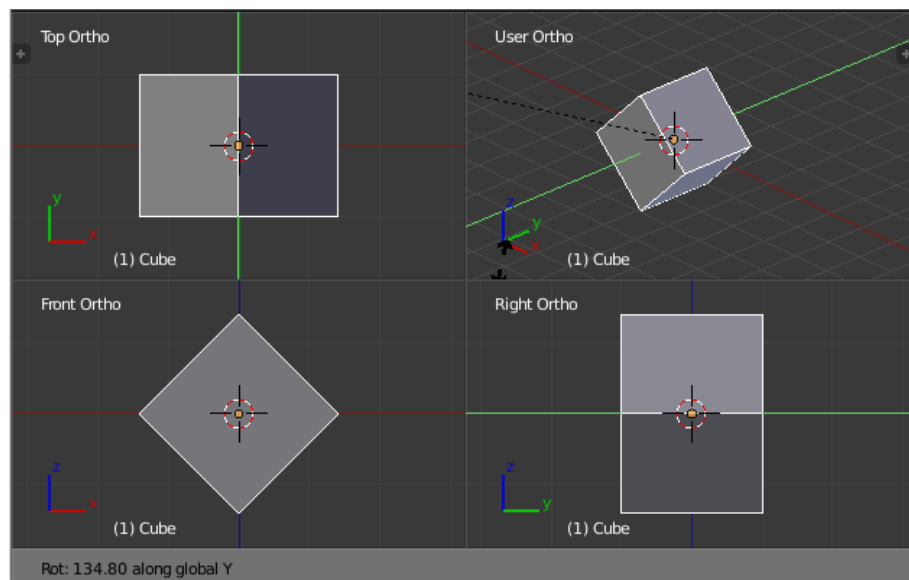
(4) Rotation of views.

Here students repeat the tasks of rotating the view around the point of interest, by changing the viewing angle in discrete steps (same as in observation task). They use Numpad8 and Numpad2 or Numpad4 and Numpad6 to rotate the view around the global Z axis from the current point of view. They also use MMB and drag the mouse to achieve the same effect.

In table 4-6 we summarise Blender actions from this section, doing these actions help in performing the observation and rotation tasks in TIMeR. To see the set of training phase instructions, see Appendix I.

Table 4-6: Blender Commands for TIMeR Phase 2

Actions	Blender Commands (for Windows)
To rotate view (with mouse)	Press Middle Mouse Button + Hold + Drag
Zooming with keyboard	NumpadPlus and NumpadMinus
Zooming with mouse	Rotate mouse wheel
Orbit left	Numpad4
Orbit right	Numpad6
Orbit up	Numpad8
Orbit down	Numpad2
Focus back on an object	NumpadPeriod
To rotate view (with mouse)	Press Middle Mouse Button + Hold + Drag
Zooming with keyboard	NumpadPlus and NumpadMinus
Zooming with mouse	Rotate mouse wheel
Top view	Numpad7
Front view	Numpad1
Side view	Numpad3
Camera view	Numpad0
Perspective view	Numpad5
Bottom view	Ctrl + Numpad7
Back view	Ctrl + Numpad1
Left side view	Ctrl + Numpad3
Quad-view	Ctrl + Alt + Q
Free rotation	R + move mouse
Rotate about x-axis	R + X + move mouse
Rotate about y-axis	R + Z + move mouse
Rotate about z-axis	R + Z + move mouse
Rotation using manipulator	Grab and drag on respective axis curve

4.8 TIMeR Phase 3: Transfer Phase

This section provides details of the transfer phase of TIMeR, where students apply learnings from previous phases and verify their pretest solutions. Figure 4-20 illustrates the transfer phase task diagram within the TIMeR procedure.

Figure 4-20: Transfer Phase Task Diagram
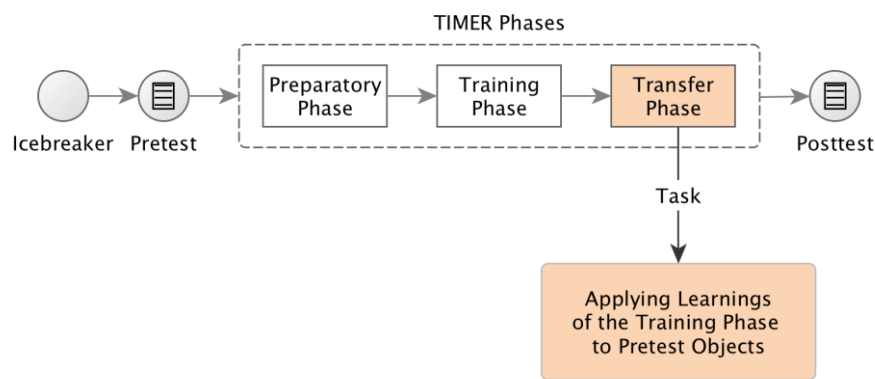
Pre-requisite: For participating in the transfer phase, it is mandatory for the students to complete the training phase.

Instructional Goal: Students should apply learnings from the transfer phase to verify their pretest solutions. They should also be able to identify the association between TIMeR activities and the strategies required for solving the pretest items.

Task: Applying Learnings of the Training Phase to Pretest Objects. In addition to the formation of mental representation and mental rotation of the object, transfer phase task involves later cognitive steps of mental rotation, which are comparison, judgment and decision making. Here students manipulate the pretest object, they rotate it until they get the exact match with the pretest solutions and then confirm their decision.

Rationale: This phase allows to concretize mental rotation strategies. Working with the pretest objects in Blender help students to concretize their mental rotation strategies in terms of TIMeR activities. Practicing with the pretest objects may also enable them to later apply these learnings to the different objects not included in the training.

Expected Outcome: Students apply the cognitive process of mental rotation to different objects. Their mental rotation performance in posttest will improve.

Training Material: Students are provided with the blender files of pretest objects and the instruction hand-outs. It is modelled in Blender and constructed as per the default orientation of the original test figure.

4.8.1 Execution of the Tasks
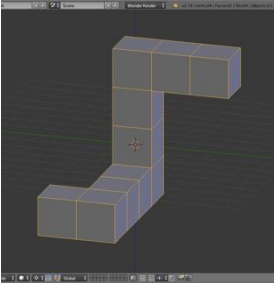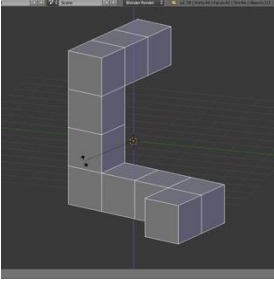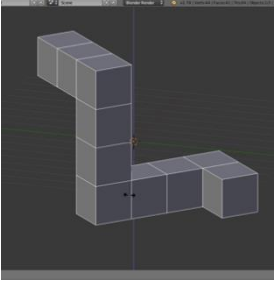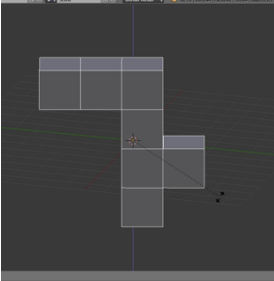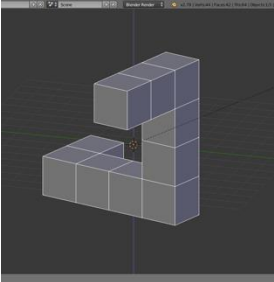
Instructor demonstrates the solution verification process for one pretest problem. Then students repeat the process. After this, students verify the remaining pretest problems by applying training activities from the training phase. Here we explain one example of how to verify pretest solution by applying the TIMeR rotation techniques. Figure 4-21 shows mental rotation test problem.

Figure 4-21: MR Problem (reproduced from Vandenberg & Kuse, 1978)
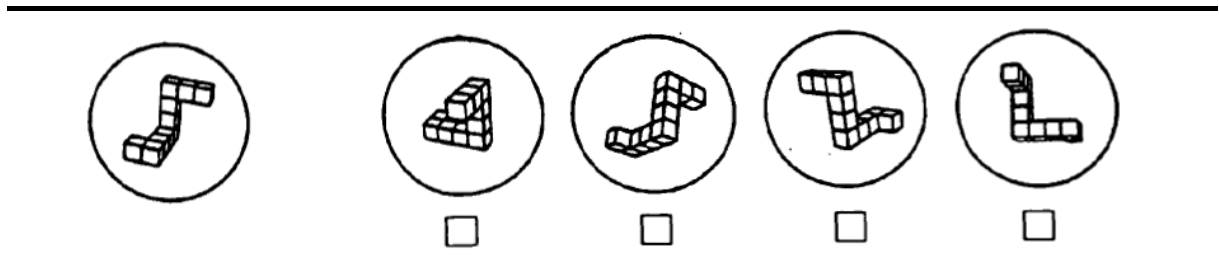
Test problem from Figure 4-21 is modelled in Blender. In Figure 4-22 we can see, (a) is the object with an original orientation of the test item. When the object is rotated around Z Axis we can see different instances of the same object as shown in b, c, d, e. It can be observed that instance (c) matches with the option three of the test problem, and instance (e) matches with the option one. Therefore, option one and three are the correct answers. In a similar way by performing combinations of rotation the results are achieved. The specific Blender commands are given with the Figure 4-22. This allows students to observe and rotate the 3D object in order to form the mental representation of that object.

Figure 4-22: Transfer Phase Task Execution

	(a)	The image is the 3D model of a VMRT test problem from Figure 4-21. It shows the initial orientation similar to the test problem.
	(b)	This shows one of the instances of object rotation about the Z axis (it is shown in blue colour). It is achieved by pressing the key combination 'first R + then Z' and using mouse movements. The action gets completed after pressing the enter key.
	(c)	This is another instance of the same test problem. It matches with the option three from Figure 4-21. The exact orientation can be achieved by performing additional rotations.
	(d)	From the orientation of this instance, it is not clear from this whether it resembles to any of the option from Figure 4-21. Hence it requires more rotations.
	(e)	This instance matches with the option one from Figure 4-21. The exact orientation can be achieved by performing additional rotations.

4.9 TIMeR for Engineering Drawing (ED)

In this section, we provide the details of the connection of mental rotation with the ED concepts: orthographic projection and isometric projection. Then we present the TIMeR structure for ED.

4.9.1 Orthographic Projection

In engineering and related professions, the way of representing three-dimensional (3D) objects as two-dimensional (2D) drawings is uniform. The procedure of drawing three orthogonal views directly from the top, front, and the left by allowing details of the physical structure for communicating to others, is known as orthographic projection (See Figure 4-23). This procedure requires the process of rotating the object for presenting a view perpendicular to each of the three faces to be drawn. When an object is available, the rotation may be physical but, the mental rotation must occur frequently. The projected representation is commonly known as an orthographic view or orthographic drawing or 2D view interchangeably, (Pillay 1994).

Figure 4-23: Orthographic Projection (reproduced from Pillay, 1994)
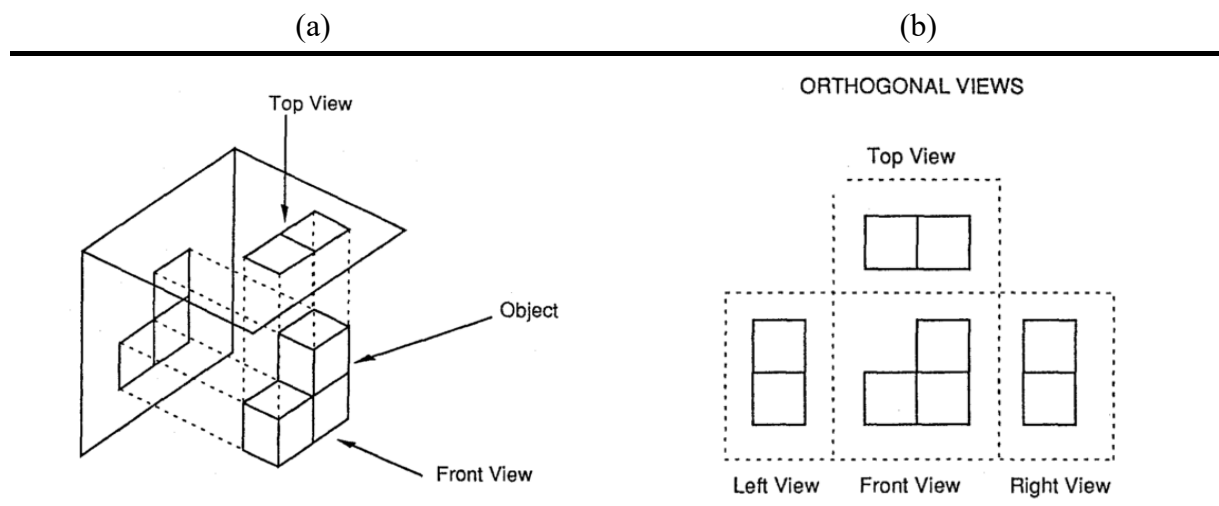
Sample Problem: Conversion from Isometric to Orthographic - In Figure 4-24 identify the correct orthographic views for the isometric view given on the left (Alias, 2000).

Figure 4-24: Isometric to Orthographic Conversion (reproduced from Alias, 2000)
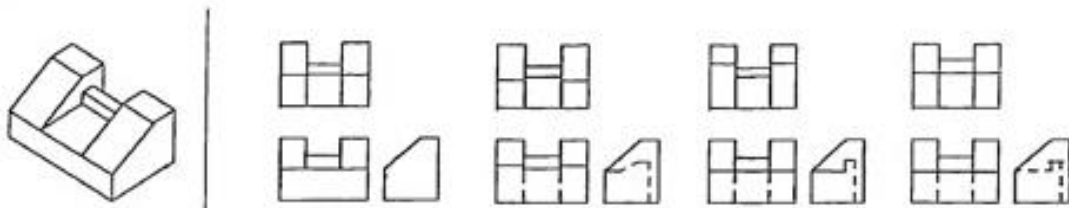
Solution Strategies

Table 4-7 shows the connection of mental rotation with the ED problem of converting isometric projection to its orthographic views. The second column denotes standard solution strategies as given by Alias, et al., (2000). Next, we identified that MR is required during every step. Column three denotes exactly when and why MR is required. In column four we identified possible ways rotation can be performed. The last column shows the relevant TIMeR activity.

Table 4-7: Solution Strategies: Isometric to Orthographic Conversion

Sr.	Solution Strategies	Does it require MR?	If yes, then exactly when and why?	Possible rotations (CW: Clockwise, ACW: Anti-Clockwise)	TIMeR intervention
1	Identification of the surfaces, front (F), top (T) and right (R) surfaces from the given isometric view.	Yes	For steps 1,3 In an isometric view, the object is oriented at an angle of 30 degrees to the base. Thereby all its surfaces are also inclined respectively.	By observing an object. By rotating the view or object. For the front view: 1. ACW rotation of an object about z-axis, 2. Then CW rotation about the horizontal axis.	The activities in column-4 are achieved through TIMeR tasks: Observation tasks, Rotation tasks
2	Note the shape of these surfaces by visualizing them if viewed at right angle	Yes	It is also possible that some surfaces are hidden. For steps 1, 2 Therefore, to identify the surface and viewing it at a right angle requires rotation of an object or observing the object from all sides. For step 2	For the right-side view: 1. CW rotation of an object about z-axis, 2. Then CW rotation about the horizontal axis. For the top view: 1. ACW rotation of an object about x-axis,	Useful Blender Features are - Rotations about axes, Rotation Manipulator, Using multiple views, Hidden lines, and Wireframe
3	Allocation of broken lines for hidden surfaces.	Yes			
4	Arrangement of the resultant shapes in the standard form	Yes			

			This rotation could be about an imaginary axis (horizontal or vertical) and in clockwise (CW) or anticlockwise (ACW) directions.	2. ACW rotation about z-axis, 3. Then CW rotation about the horizontal axis. Or 1. ACW rotation of an object about y-axis,	
5	Identification of the correct alternative from the set of alternatives		In the same way as above, while comparing with the alternatives and verifying the answer.	2. CW rotation about z-axis, 3. Then CW rotation about the horizontal axis.	

4.9.2 Isometric Projection

In a technical and engineering drawings, a method for visually representing three-dimensional objects in two dimensions is known as isometric projection. The projected representation is usually referred as an isometric view or isometric drawing a 3D view or pictorial view or interchangeably, see Figure 4-23 (a).

Sample Problem: Conversion from Orthographic to Isometric - In Figure 4-25, identify the correct isometric view for the orthographic views given on the left (Alias, 2000).

Figure 4-25: Orthographic to Isometric Conversion (reproduced from Alias, 2000)
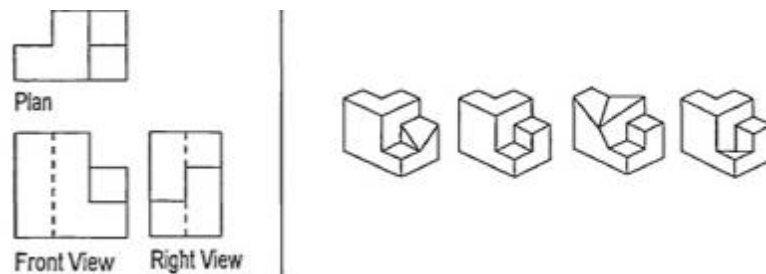
Solution Strategies

Table 4-8 shows the connection of mental rotation with the ED problem of constructing isometric projection from the given orthographic views. The second column denotes standard solution strategies as given by Alias, et al., (2000). Next column indicates whether MR is

required or not. The next column denotes precisely when and why MR is needed. Then we identified possible ways rotation can be performed. The last column shows the relevant TIMeR activity.

Table 4-8: Solution Strategies: Orthographic to Isometric Conversion

Sr	Solution Strategies (Alias, 2000)	Does it require MR,	If yes, then exactly when and why?	Possible rotations	TIMeR intervention
1	Attachment of the views to form flat pattern as shown	Yes	Views are shown on a 2D plane, and to form a 3D shape, and it needs to be visualized mentally. For the proper construction of 3D shape, the views need to be rotated at various angles and also about the different imaginary axis. But once the object is constructed, the mental rotation is required to verify the formed shape. The comparison could be with the orthographic views or given isometric views.	For the comparison of constructed shape, the object can be rotated about various axes. The possible rotations are similar to the steps from Table 4-11.	This is achieved by using Blender as a scaffold, where demos can be shown to students followed by similar activities from Table 4-11 last column.
2	To fold the pattern for joining T to R in order to form a 3D shape or rotate the unattached square faces to attach them to each other				
3	To retain the shape in mind and comparison with the constructed 3D to the alternatives	Yes			
4	Identification of the correct alternative from the set of alternatives				

4.9.3 TIMeR for ED Concepts

Hence, in order to investigate the effectiveness of TIMeR on the improvement of students' ED problem-solving performance, in TIMeR we replaced mental rotation training objects with an engineering drawing objects for the topics of orthographic projection and isometric projection. We followed the same TIMeR procedure as section 4.5. The Figure 4-26 shows a sample 3D model of an ED object with rotations in the quad-view.

Figure 4-26: Rotation of the ED Object in Quad-view.
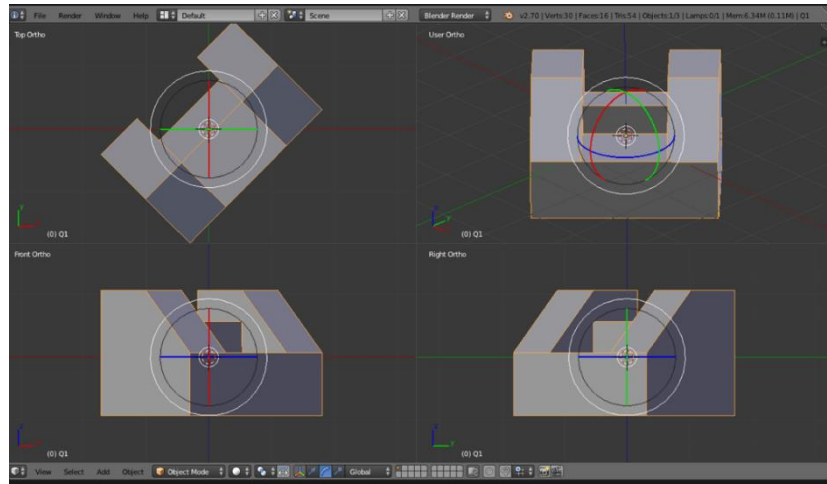
4.10 TIMeR for Computer Graphics (CG)

In order to test the applicability of TIMeR to other domain, in the TIMeR, we replaced mental rotation objects with computer graphics objects for the topics of 2D transformations and 3D transformations. We followed the same TIMeR procedure to investigate the impact of TIMeR on the improvement of students' CG problem-solving performance, and the conducted a research study. The study details and results are provided in chapter 8. The Figure 4-27 shows a sample screenshot of transformations in Blender.

Figure 4-27: CG Transformations in Blender
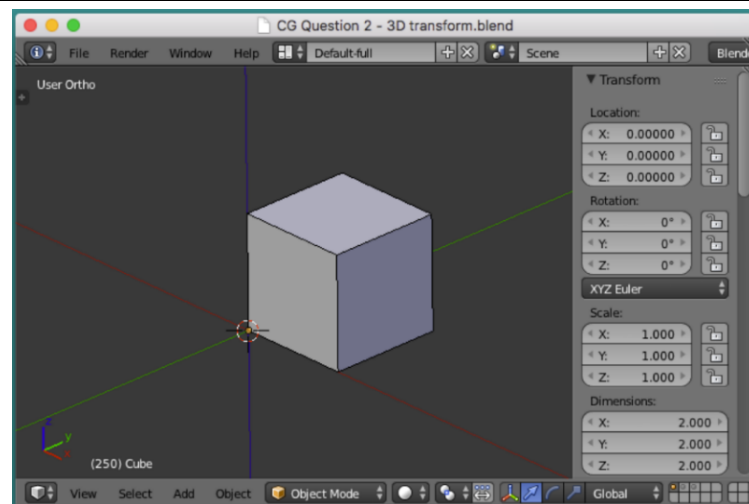
4.11 Summary of TIMeR for MR, ED, and CG

Table 4-9 shows the summary of TIMeR structures for MR, ED, and CG with the duration of three hours.

Table 4-9: Summary of Three-hour TIMeR for MR, ED, and CG

	Three-hour TIMeR for MR	Three-hour TIMeR for ED	Three-hour TIMeR for CG
Timespan (Total)	One day	One day	One day
Timespan (in days)	One day	One day	One day
Duration (hours per day)	~3	~3	~3
Total hours	~3	~3	~3
No of phases (total tasks)	3 (11)	3 (11)	3 (11)
Instructional strategy	DDP	DDP	DDP
Study design	Single group pre-post	Single group pre-post	Two groups pre-post
Total practice items	12	8	8
Pretest (total items)	1 (10)	1 (6)	1 (2)
Posttest (total items)	1 (10)	1 (6)	1 (2)
Assessment Instrument	VMRT	SVATI	Textbook Problems

The *Timespan (in days)* is the actual days of effective training, and the *Timespan (Total)* is the period of training. *Duration* is the effective training hours per day. The *number of phases* is the different training phases comprising of various training tasks. *Instructional strategy* is the method for delivering training instructions by the trainer, and to be used by the participants used to meet the different learning objectives of the training. The *study design* is the type of research design used for that specific study. *Practice items* are the total number of 3D models used for the training purpose. The *Pretest* is the number of pretests of the study, with the total test items of the pretest. *Posttest* is the number of posttests involved in the study, with the total test items of the posttest. *Assessment instrument* is the tool used for the assessment or measurement of the learner's ability. The nature and the difficulty level of test items are different for MR, ED, and CG; due to which the total number of practice items and test items differs.

Chapter 5

Effect of TIMeR on MR

This chapter provides the details of the research studies: **MR1** and **MR2**, the focus of which was specific to answer **RQ1** by investigating the effect of TIMeR intervention on improvement of MR skills of first-year engineering undergraduate students. The **RQ1** is *"How effective is TIMeR for improving students' MR skill?"* In the first two parts of this chapter, we put forward the details of MR1 and MR2 respectively. Then we present the discussions coming out of these studies.

5.1 Research Study 1 (MR1)

This study aimed at testing if the proposed intervention (TIMeR) was effective and to see in what way was it effective. A three-hour TIMeR session was given to first-year undergraduate engineering students.

Sample: The participants in this study were 42 undergraduate students (17 males and 25 females) from first-year engineering course from an engineering institute in Mumbai, India. Convenience sampling was used as the recruitment was done on a voluntarily basis.

Study Design and Implementation

The research study design applied for MR1 was single-group pretest-posttest. We followed the same training procedure as described in section 4.5, also illustrated in Figure 5.1 and briefed below.

Figure 5-1: TIMeR Procedure for MR1
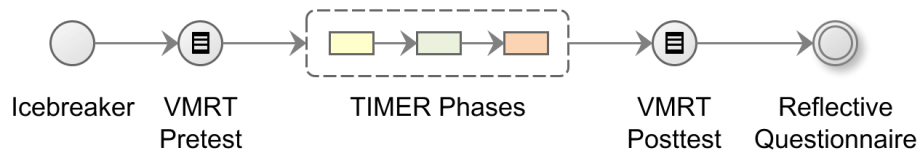
1. **Ice-breaker:** It was a fifteen-minute activity to highlight the importance of MR skill.
2. **Pretest:** It was a fifteen-minute pretest with ten items from VMRT. Complete set of test items is given in Appendix II.
3. **Treatment:** The pretest was followed by a three-hour TIMeR session. Students performed all the activities of TIMeR phases. In preparatory phase students learnt about Blender interface, in the training phase they performed observation and rotation tasks, and, in Transfer phase they applied learnings from these phases and verified their pretest solutions.
4. **Posttest:** It was a fifteen-minute test with ten items from VMRT.
5. **Students' reflection:** Further to the posttest, students were given fifteen-minute to respond to a reflective question on TIMeR tasks that helped them in solving posttest problems.

Training objects: For first two phases of TIMeR, the three-dimensional primitive objects were used. For the Transfer Phase, 3D objects based on pretest items were used. For details see Chapter 4.

Instrument and Data Collection

The data was gathered in the form of performance score of tests of MR problems of VMRT (Vandenberg & Kuse, 1978). We used ten items each for the pretest and posttest assessment.

The maximum obtainable score was ten, as each question carries one mark. We also collected data related to the students' reflections about which TIMeR tasks that helped them while solving posttest. It was collected in the form of seven 3-point Likert scale items as listed in table 5-1. From the table 5-1, the mapping of TIMeR tasks column was not shown to the students, only the other part of the table was shown.

Table 5-1: Students' Reflection about TIMeR Tasks Benefits

TIMeR Tasks	Reflection items	Mostly	Sometimes	Never
A: Rotation Task	Keeping the object still and moving around the object, observing it from various positions			
B: Observation task	Choosing a side of the object and using it as reference to compare with the given image			
C: Observation task with single and multiple views in transfer phase	Performing various extrusions of the object and using the angle between them to compare with the given image			
D: Rotation about individual axes in transfer phase	Identifying the center point of the object and rotating it along a particular axis (x-axis or y-axis or z-axis) and compare with the given image			
E: Rotation about different axes	Identifying an axis (x-axis or y-axis or z-axis) and rotating along the axis and compare with given image			
F: Rotation using transform properties feature	Rotating the object in the given angle incrementally and compare with given image			
G: Transfer phase all strategies	Mapping the x, y, and z-axis to the object and comparing its correspondence in the given image, followed by rotating the object to get the angle for the given image			

Data Analysis Procedure

To determine the effect of the TIMeR session on students' MR skill, we performed quantitative analysis of the pretest and posttest for all 42 students. In order to decide, which statistical test to be used for comparing the means, we tested the data for normality using Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011). Based on results of normality test, we used the Wilcoxon Signed-Rank Test to see how significant the improvement in students' scores are, and determined the effect size of the improvement. For our analysis, we use the significance level 0.05 (5%). We also computed average gain (Marx and Cummings, 2007) for all 42 students. To look into the effects at more granular level, we also did the same analysis separately for the students at different (pretest) achievement levels (low, medium, and high).

To determine which TIMeR tasks helped students in solving posttest we looked into the frequencies of responses to each reflective questionnaire items.

5.1.1 Results (MR1)

In this section, we present results of MR1 at two granularities. First, we provide the results of the effect of TIMeR on the whole class (n=42), and then separately for the different pretest achievement levels.

5.1.1.1 Effect of TIMeR on All Students

Test of Normality: The table 5-2 provides the statistical results of Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011), and the Figures 5-2 and 5-3 provide their histograms and normal Q-Q plots. The statistical results and the visual examination of the histograms, normal Q-Q plots (n=42) showed that the pretest data were not normally distributed with p=0.015 being less than 0.05, and the posttest data were approximately normally distributed with p=0.185 being higher than 0.05.

Table 5-2: Test of Normality (MR1)

Shapiro-Wilk			
	Statistic	**df**	**Sig. (p)**
Pretest	0.932	42	0.015
Posttest	0.963	42	0.185

Figure 5-2: Histogram & Q-Q Plots for Pretest data (MR1)

Figure 5-3: Histogram & Q-Q Plots for Posttest data (MR1)
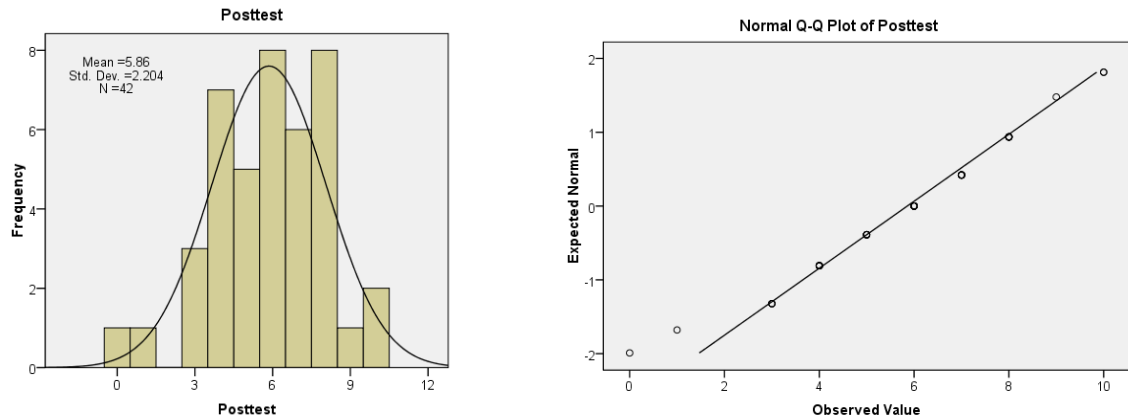
Wilcoxon Signed Rank Test

Since the pretest data showed no normal distribution, we chose to perform Wilcoxon Signed-rank test to analyse the significance of the difference between the pretest and posttest performances. Table 5-3 shows the descriptive statistics for n=42, with posttest mean (5.86) being higher than the pretest mean (4.48).

Table 5-3: Descriptive Statistics for All Students (MR1)

Descriptive Statistics					
	N	Mean	Std. Deviation	Minimum	Maximum
Pretest	42	4.48	2.725	0	10
Posttest	42	5.86	2.204	0	10

Test Statistics Table: It can be observed from the Table 5-4 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest score (with p=0.001).

Table 5-4: Test Statistics Table for All Students (MR1)

Test Statistics[b]	
	Posttest, Pretest
Z	-3.328[a]
Asymp. Sig. (2-tailed)	**0.001**

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Effect Size: We computed effect size by Cohen's (1988) formula *(r = z / square root of N)*, where N = the number of observations over two-time points, which is two-times the sample size, (Pallant, 2005). However, in this condition, Z = 3.328, and N = 42 x 2 = 84; therefore, r = 0.3631 indicating a medium effect size using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect.

Learning gain: To show the students average improvement, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(posttest\ score\ -\ pretest\ score)}{(maxscore\ -\ pretest\ score)} = \frac{(5.86\ -\ 4.48)}{(10\ -\ 4.48)} = \frac{1.38}{5.52} = 0.239$$

Students demonstrated an average gain of 13.8 percentage score out of a potential 55.2 percentage score that they could have gained. Thus, they gained 0.239 (or 23.9 %) of the possible percentage scores they could have gained from pretest to posttest assessment.

The overall results show that posttest performance of students is higher than pretest and the difference is statistically significant (p=0.001) with medium effect size (r=0.36) (Cohen, 1988) and a positive gain (23.9 %). We infer that TIMeR was effective for the improvement of mental rotation skills for the whole group of students. To go deeper, we did the same analysis separately for the students at different (pretest) achievement levels as low, medium, and high.

Ranks Table: From Table 5-5 we can see that 11 participants had a higher Pretest Score than Posttest Score. However, 27 participants had a higher posttest score compared to pretest score; and 4 participants saw no change in their pretest and posttest score. At this point, we postulate that the students with negative ranks are likely to fall into the high-performers groups. We examine this in the next section.

Table 5-5: Ranks Table for All Students (MR1)

Ranks				
		N	Mean Rank	Sum of Ranks
Posttest and Pretest	Negative Ranks	11[a]	13.05	143.50
	Positive Ranks	27[b]	22.13	597.50
	Ties	4[c]		
	Total	42		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

5.1.1.2 Effect of TIMeR on Students with Different Achievement Levels

The minimum and maximum achievable score for the pretest is zero and ten respectively. In order to decide the three achievement levels based on the pretest score, we formed three clusters by dividing maximums score (ten) with desired levels (three). It resulted into three ranges of scores that are between 0 to 3.33, between 3.34 to 6.66, and between 6.67 to 10. These values were used to define different achievement levels. So, we get three achievement levels as low (0, 1, 2, and 3), medium (4, 5, and 6), and high (7, 8, 9, and 10). We call students from each level as, low-performers, medium-performers, and high-performers.

Wilcoxon Signed Rank Test: As the sample sizes within the three levels were very smaller, we performed Wilcoxon signed-rank test. Table5-6 shows the descriptive statistics for the group of students with different achievement levels.

Table 5-6: Descriptive Statistics: Students with Different Achievement Levels (MR1)

Descriptive Statistics						
Pretest Achievement Level		N	Mean	Std. Deviation	Minimum	Maximum
Low Performers	**Pretest**	20	2.20	1.00	0.00	3.00
	Posttest	20	5.10	1.88	0.00	8.00
Medium Performers	**Pretest**	10	4.7	0.94	4.00	6.00
	Posttest	10	5.5	2.27	1.00	8.00
High Performers	**Pretest**	12	8.08	1.24	7.00	10.00
	Posttest	12	7.41	1.97	3.00	10.00

Ranks Table: From Table 5.7 we can see that, in a **low-performers**' group, zero participants had a higher Pretest Score than Posttest Score. However, 19 participants had a higher Posttest Score compared to Pretest Score; and one participant saw no change in their Pretest and Posttest Score. In a **medium-performers'** group, 3 participants had a higher Pretest Score than Posttest Score. However, 6 participants had a higher Posttest Score compared to Pretest Score; and one participant saw no change in their Pretest and Posttest Score. In a **high-performers'** group, 8 participants had a higher Pretest Score than Posttest Score. However, 2 participants had a higher Posttest Score compared to Pretest Score; and 2 participants saw no change in their Pretest and Posttest Score. Based on these results we can see that our earlier postulation of negative rank students falling into the high-performers group was correct.

Table 5-7: Ranks Table for the Students with Different Achievement Levels (MR1)

Pretest and Posttest	Pretest Achievement Level	Ranks			
			N	Mean Rank	Sum of Ranks
	Low Performers	Negative Ranks	0[a]	0.00	0.00
		Positive Ranks	19[b]	10.00	190.00
		Ties	1[c]		
		Total	20		
	Medium Performers	Negative Ranks	3[a]	4.33	13.00
		Positive Ranks	6[b]	5.33	32.00
		Ties	1[c]		
		Total	10		
	High Performers	Negative Ranks	8[a]	5.25	42.00
		Positive Ranks	2[b]	6.50	13.00
		Ties	2[c]		
		Total	12		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

Test Statistics Table: It can be observed from the Table 5-8 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance of the low-performers (with p=0.001); and showed no significant change for the medium and high-performers (with p=0.251 and p=0.125 respectively).

Table 5-8: Test Statistics for the Students with Different Achievement Levels (MR1)

Test Statistics[b]			
	Pretest, Posttest		
Pretest Achievement Level	Low Performers	Medium Performers	High Performers
Z	-3.444[a]	-1.147[a]	-1.535[a]
Asymp. Sig. (2-tailed)	0.000	0.251	0.125

a. Based on negative ranks.
b. Wilcoxon Signed Ranks Test

Effect size: We computed effect size by Cohen's (1988) formula ($r = z$ / square root of N), where N = the number of observations over two-time points, and to determine the effect size we used Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect. However, in the first condition, for low-performers Z = 3.444, and N = 20 x 2 = 40; therefore,

r = 0.5445 indicating a large effect size. In the second condition, for medium-performers Z = 1.147, and N = 10 x 2 = 20; therefore, r = 0.2564 indicating a small effect size. In the third condition, for high-performers Z = 1.535, and N = 12 x 2 = 24; therefore, r = 0.3133 indicating a medium effect size.

Learning gain: To show the students average improvement for each achievement level, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(posttest\ score - pretest\ score)}{(maxscore - pretest\ score)}$$

For low-performers g = (5.10 - 2.20) / (10 - 2.20) = (2.90 / 7.80) = 0.37

For medium-performers g = (5.5 - 4.7) / (10 – 4.7) = (0.80 / 5.30) = 0.15

For high-performers g = (7.41 – 8.08) / (10 – 8.08) = (-0.67 / 1.92) = -0.34

Low-performers demonstrated an average gain of 29.00 percentage score out of a potential 78.00 percentage score that they could have gained. Thus, they gained 0.37 (or 37.00 %) of the possible percentage scores they could have gained from pretest to posttest assessment. Similarly, medium-performers gained 0.15 (or 15.00 %) of the possible percentage scores they could have gained. However, high-performers showed no positive gain.

The deeper results show that for low-performers, posttest is higher than pretest and the difference is statistically significant (p=0.000) with large effect size (r=0.5445) and a positive gain (g=0.37). For medium-performers even though posttest is higher than pretest the difference is not statistically significant (p=0.251) with small effect size (r=0.2564) and a positive gain (g=0.15). For high-performers even though posttest is lower than pretest the difference is not statistically significant (p=0.125). The reason for high-performers not showing positive improvement could be ceiling effect (Rifkin, 2005). We infer that TIMeR was more effective for the improvement of mental rotation skills for the low-performers as compared to the non-low performing students.

Reflective Questionnaire Analysis

We analysed students' responses to the reflective questionnaire (Table 5-9). For a gross analysis, we combined the responses of 'mostly' and 'sometimes' into one, as both choices denoting the TIMeR tasks helped while solving the posttest. From the total 294 responses, the

167 (57 %) responses say that they have considered TIMeR tasks when solving posttest, 86 (29%) say that they did not consider, and 41 (14%) chose not to respond, (See Figure 5-4). The possible reasons for 29% students did not consider TIMeR task or 14% not responding are, (1) Either these are the high performers, or (2) they were not able to recall the utility of TIMeR tasks appropriately, which is normal, as on the other hand others (59%) were able to recall it and responded, or (3) the training might not have helped them at all.

Table 5-9: Reflective Questionnaire Analysis (MR1)

		Frequency of use					
		Mostly (M)	Sometimes (S)	M+S	Never (N)	No response (Nr)	Total (M+S+N+Nr)
Tasks	A: Rotation Task	17	17	34	5	3	42
	B: Observation task	12	14	26	10	6	42
	C: Observation task in transfer phase	2	14	16	17	9	42
	D: Rotation about individual axes in transfer phase	14	10	24	13	5	42
	E: Rotation about different axes	12	14	26	12	4	42
	F: Rotation using transform properties feature	9	15	24	11	7	42
	G: Transfer phase all strategies	6	11	17	18	7	42

Figure 5-4: Reflective Questionnaire Analysis (MR1)

Students' Responses on Reflective Questionnaire
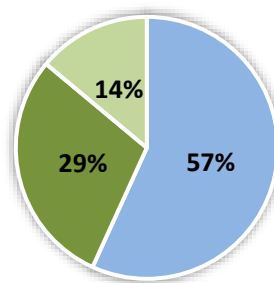
■ Mostly + Sometimes   ■ Never   ■ No Response

The inferences and the analysis of results of MR1 are presented along with the analysis of results of MR2 in section 5.3.

5.2 Research Study 2 (MR2)

In order to verify the consistency of TIMeR, we repeated the research study MR1. We followed the same procedure as in MR1.

Sample: The sample consisted of 55 undergraduate students from first-year engineering course from an engineering institute in Maharashtra, India. Convenience sampling was used as these were volunteers for the training.

5.2.1 Results (MR2)

In this section, we present results of MR2 at two granularities. First, we provide the results of the effect of TIMeR on the whole class (n=55), and then separately for the different pretest achievement levels.

5.2.1.1 Effect of TIMeR on All Students

Test of Normality: First, we did the Shapiro-Wilk test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011) for the pretest and posttest. A Shapiro-Wilk's test results (Table 5-10) and visual inspection of their histograms, normal Q-Q plots (Figure 5-5 and 5-6) showed that the performance scores for pretest and posttest were not normally distributed ($p < 0.05$).

Table 5-10: Test of Normality (MR2)

	Shapiro-Wilk		
	Statistic	**df**	**Sig. (p)**
Pretest	0.920	55	0.001
Posttest	0.927	55	0.002

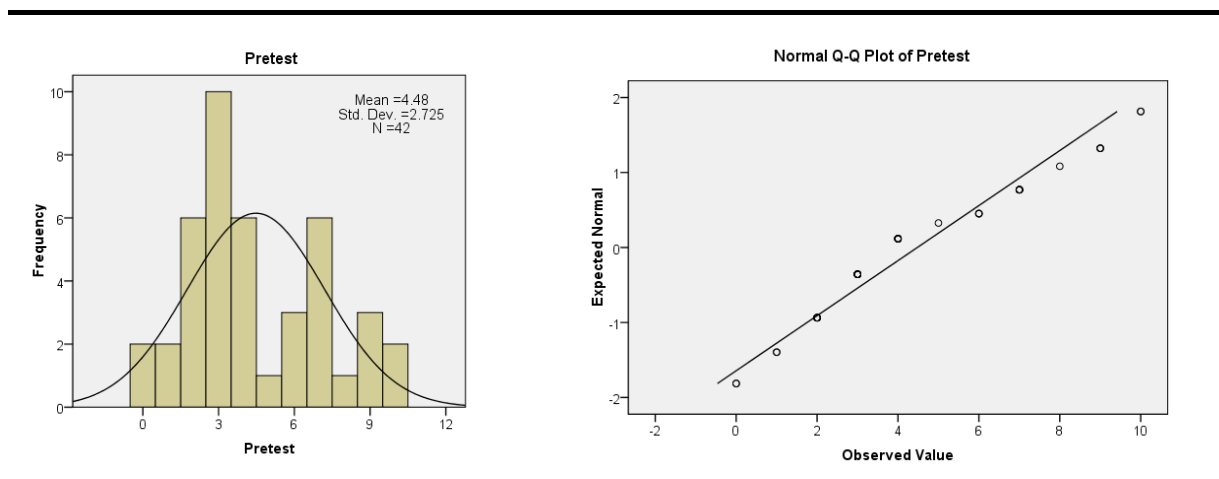Figure 5-5: Histogram & Q-Q Plots for Pretest Data (MR2)
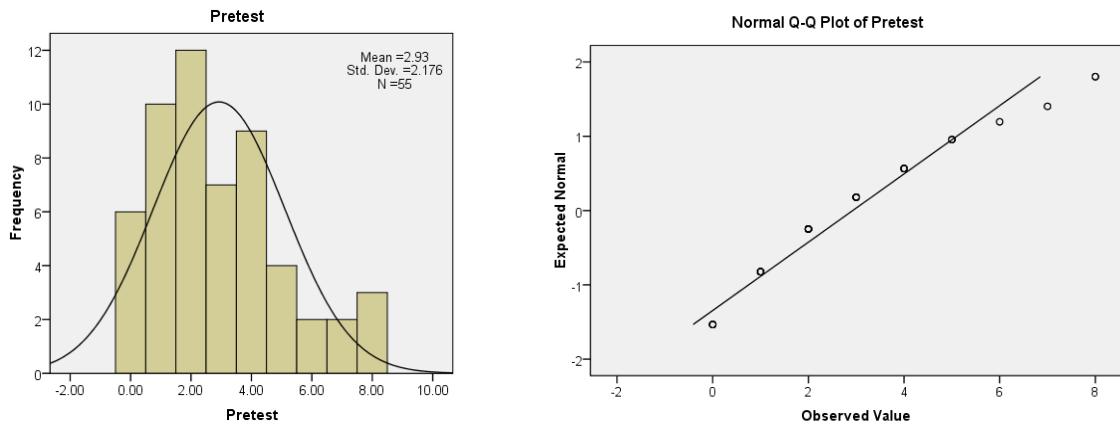
Figure 5-6: Histogram & Q-Q Plots for Posttest Data (MR2)
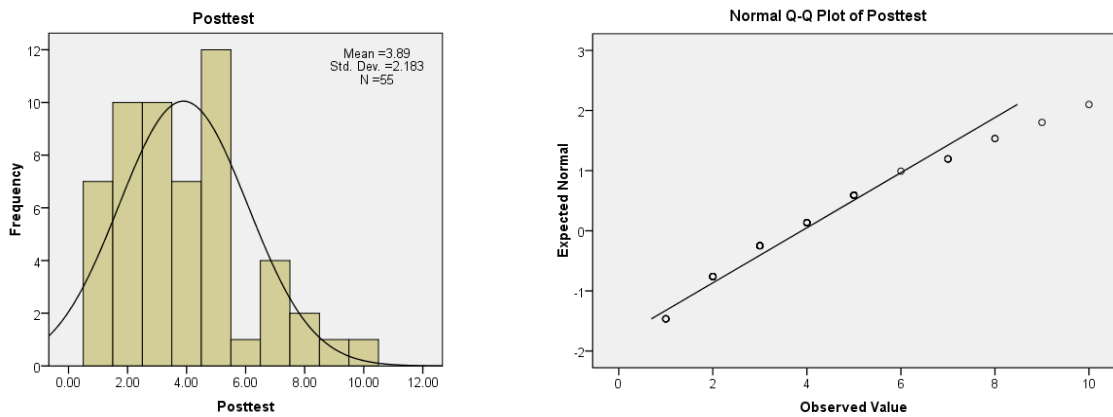
Wilcoxon Signed Rank Test

Since the pretest data showed no normal distribution, we chose to perform Wilcoxon Signed-rank test to analyse the significance of the difference between the pretest and posttest performances. Table 5-11 shows the descriptive statistics for n=55, with posttest mean (3.89) being higher than the pretest mean (2.92).

Table 5-11: Descriptive Statistics for All Students (MR2)

Descriptive Statistics					
	N	Mean	Std. Deviation	Minimum	Maximum
Pretest	55	2.92	2.17	0.00	8.00
Posttest	55	3.89	2.18	1.00	10.00

Test Statistics Table: It can be observed from the Table 5-12 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance (with p=0.006).

Table 5-12: Test Statistics Table for All Students (MR2)

Test Statistics[b]	
	Posttest, Pretest
Z	-2.737[a]
Asymp. Sig. (2-tailed)	**0.006**

a. Based on negative ranks.
b. Wilcoxon Signed Ranks Test

Effect Size: We computed effect size by Cohen's (1988) formula (r = z / square root of N), where N = the number of observations over two-time points. However, in this condition, Z = 2.737, and N = 55 x 2 = 110; therefore, r = 0.2609 indicating a close to medium effect size using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect.

Learning gain: To show the students average improvement, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(posttest\ score - pretest\ score)}{(maxscore - pretest\ score)} = \frac{(3.89 - 2.92)}{(10 - 2.92)} = \frac{0.97}{7.08} = 0.137$$

Students demonstrated an average gain of 9.70 percentage score out of a potential 70.80 percentage score that they could have gained. Thus, they gained 0.137 (or 13.7 %) of the possible percentage scores they could have gained from pretest to posttest assessment.

The overall results show that posttest performance of students is higher than pretest and the difference is statistically significant (p=0.006) with a close to medium effect size (r=0.36) (Cohen, 1988) and a positive gain (13.7 %). We infer that TIMeR was effective for the

improvement of mental rotation skills for the whole group of students. Similar to MR1, to go deeper, we did the same analysis separately for the students at different (pretest) achievement levels as low, medium, and high.

Ranks Table: In Ranks Table 5.13 we can see that 14 participants had a higher Pretest Score than Posttest Score. However, 32 participants had a higher Posttest Score compared to Pretest Score; and 9 participants saw no change in their Pretest and Posttest Score. At this point we postulate that the students with negative ranks are likely to fall into the non-low-performers groups. We examine this in the next section.

Table 5-13: Ranks Table for All Students (MR2)

Ranks				
		N	Mean Rank	Sum of Ranks
Posttest and Pretest	**Negative Ranks**	14[a]	20.89	292.50
	Positive Ranks	32[b]	24.64	788.50
	Ties	9[c]		
	Total	55		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

5.2.1.2 Effect of TIMeR on Students with Different Achievement Levels

We formed three achievement levels in similar way of MR1, as low (0, 1, 2, and 3), medium (4, 5, and 6), and high (7, 8, 9, and 10).

Wilcoxon Signed Rank Test: We performed Wilcoxon signed-rank test as the sample sizes within the three levels were very smaller. Table5-14 shows the descriptive statistics for the group of students with different achievement levels. **Ranks Table:** In Ranks Table 5.15 we can see that, in a **low-performers**' group, 4 participants had a higher Pretest Score than Posttest Score. However, 27 participants had a higher Posttest Score compared to Pretest Score; and 4 participants saw no change in their Pretest and Posttest Score. In a **medium-performers'** group, 8 participants had a higher Pretest Score than Posttest Score. However, 4 participants had a higher Posttest Score compared to Pretest Score; and 3 participants saw no change in their Pretest and Posttest Score. In a **high-performers'** group, 2 participants had a higher Pretest Score than Posttest Score. However, 1 participant had a higher Posttest Score compared to Pretest Score; and 2 participants saw no change in their Pretest and Posttest Score. These results show that maximum number of students with negative score fall into medium and high-

performers group. This suggests that our earlier postulation of negative rank students falling into the non-low-performers groups was correct.

Table 5-14: Descriptive Statistics: Students with Different Achievement Levels (MR2)

Descriptive Statistics						
Pretest Achievement Level		N	Mean	Std. Deviation	Minimum	Maximum
Low Performers	Pretest	35	1.57	1.00	0.00	3.00
	Posttest	35	3.46	1.86	1.00	9.00
Medium Performers	Pretest	15	4.53	0.74	4.00	6.00
	Posttest	15	3.73	2.01	1.00	8.00
High Performers	Pretest	5	7.60	0.54	7.00	8.00
	Posttest	5	7.40	1.81	5.00	10.00

Table 5-15: Ranks Table for the Students with Different Achievement Levels (MR2)

	Pretest Achievement Level	Ranks			
			N	Mean Rank	Sum of Ranks
Pretest and Posttest	Low Performers	Negative Ranks	4[a]	10.50	42.00
		Positive Ranks	27[b]	16.81	454.00
		Ties	4[c]		
		Total	35		
	Medium Performers	Negative Ranks	8[a]	7.25	58.00
		Positive Ranks	4[b]	5.00	20.00
		Ties	3[c]		
		Total	15		
	High Performers	Negative Ranks	2[a]	1.75	3.50
		Positive Ranks	1[b]	2.50	2.50
		Ties	2[c]		
		Total	5		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

Test Statistics Table: It can be observed from the Table 5-16 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance of the low-performers (with

p=0.000) and showed no significant change for the medium and high-performers (with p=0.130 and p=0.785 respectively).

Table 5-16: Test Statistics for the Students with Different Achievement Levels (MR2)

Test Statistics[b]			
	Pretest, Posttest		
Pretest Achievement Level	Low Performers	Medium Performers	High Performers
Z	-4.071[a]	-1.513[a]	-0.272[a]
Asymp. Sig. (2-tailed)	0.000	0.130	0.785

a. Based on negative ranks, b. Wilcoxon Signed Ranks Test

Effect size: We computed effect size by Cohen's (1988) formula ($r = z$ / square root of N), where N = the number of observations over two-time points, and to determine the effect size as Cohen (1988). For low-performers $Z = 4.071$, and $N = 35 \times 2 = 70$; therefore, $r = 0.4865$ indicating a large effect size. For medium-performers $Z = 1.513$, and $N = 15 \times 2 = 30$; therefore, $r = 0.2762$ indicating a small effect size. For high-performers $Z = 0.272$, and $N = 5 \times 2 = 10$; therefore, $r = 0.086$ indicating a small effect size.

Learning gain: To show the students average improvement for each achievement level, we calculated the average gain as (Marx & Cummings, 2007):

For low-performers $g = (3.45 - 1.57) / (10 - 1.57) = (1.88 / 8.43) = 0.22$

For medium-performers $g = (3.73 - 4.53) / (10 - 4.53) = (-0.77 / 5.47) = -0.1$

For high-performers $g = (7.4 - 7.6) / (10 - 7.6) = (-0.20 / 2.40) = -0.08$

Low-performers demonstrated an average gain of 22.00 percentage score out of a potential 84.30 percentage score that they could have gained. Thus, they gained 0.22 (or 22.00 %) of the possible percentage scores they could have gained from pretest to posttest assessment. However, medium and high-performers showed no positive gain. The deeper results show that for low-performers, posttest is higher than pretest and the difference is statistically significant (p=0.000) with large effect size (r=0.4865) and a positive gain (g=0.22). For medium and high-performers even though posttest is lower than pretest the difference is not statistically significant (p=0.130 and p=0.785). The reason for medium and high-performers not showing positive improvement could be ceiling effect (Rifkin, 2005). We infer that TIMeR was more effective for the improvement of mental rotation skills for the low-performers as compared to

the non-low performing students. The inferences and the analysis of results of MR2 are presented along with the analysis of results of MR1 in section 5.3.

5.3 Summary of Results of MR1 and MR2

Table 5-17 provides the summary of quantitative results of MR1 and MR2 for overall class and for different pretest achievement level.

Table 5-17: Summary of Results of MR1 and MR2

	MR1				MR2			
	Overall	Low	Medium	High	Overall	Low	Medium	High
N	42	20	10	12	55	35	15	5
Pretest mean	4.48	2.20	4.70	8.08	2.92	1.57	4.53	7.60
Posttest mean	5.86	5.10	5.50	7.41	3.89	3.46	3.76	7.40
P	0.001	0.000	0.251	0.125	0.006	0.000	0.130	0.785
Effect size r	0.36 (med)	0.54 (large)	0.25 (small)	0.31 (med)	0.26 (med)	0.48 (large)	0.27 (med)	0.10 (small)
Learning gain	0.24	0.37	0.15	-0.34	0.14	0.22	-0.10	-0.08

In MR 1 we wanted to see in what way does the TIMeR intervention effects the students' mental rotation skills. The results show that posttest performance of the class was significantly improved. When we analysed at the more granular level, we saw that most of the students' (N=20, out of 42) fell under the low-performance level, i.e., they scored less than 33% in the pretest. The results show that the TIMeR was significantly effective for this cohort. The cohort (N=10, out of 42) which had medium achievement level (33% < pretest score < 66%) shown improvement but it was not statistically significant. Whereas, the high achievement (66% < pretest score) cohort (N=12) shown negative improvement, which was also not statistically significant. The reason for high-performers showing negative improvement could be ceiling effect (Rifkin, 2005). This deeper analysis helped us to refine our findings that the TIMeR intervention is effective for the students with low initial achievement level. To further validate this result, we conducted similar study (MR2) with a new set of participants. The findings from MR2 corroborated the findings of MR1. We again found that there were the majority of the

students (N=35, out of 55) fell under the low performer category. The improvement in their MR skills, as measured by the posttest, was significant, while the performance differences observed for the medium and high-performers were statistically non-significant.

The results from the students' reflections, in MR1, answers our RQ1 in further detail. These results throw light on which TIMeR tasks, as perceived by the students, were used while students were solving the posttest problems. It was found that "rotation task" (task A) was perceived to be most frequently used, while the "observation task" (task B), "rotation about individual axes in transfer phase" (task D), "Rotation about individual axes in transfer phase" (task E) and "rotation using transform properties feature" (task F), was also used by the majority of the students. The tasks C and task G were less used ones. Since most of the TIMeR tasks were perceived to be used while solving the posttest problem, this shows that the students did not just perform the tasks during the intervention, but they also used them to solve new set problems outside the intervention.

Overall, the TIMeR intervention was effective for improving MR skills. In our next studies, we have used same intervention, which has shown to be effective for improving mental rotation skill, to test if it can help learners to perform better in engineering drawing problem-solving.

Chapter 6

Effect of TIMeR on ED

In the previous chapter, we established that three-hour TIMeR session improves MR skills of first-year undergraduate engineering students. This chapter provides the details of the research studies: **ED1**, **ED2**, and **ED3**. The focus of which was specific to answer **RQ2** and **RQ3** i.e. to investigate the effect of TIMeR intervention on improvement of engineering drawing (ED) problem-solving performance of students. These studies were scoped to following ED problems, (i) Conversion of isometric (3D) view to orthographic views, and (ii) Conversion of orthographic views to an isometric view. The **RQ2** is *"How effective is TIMeR for improving first-year engineering undergraduate students' engineering drawing problem-solving performance?"*, and the **RQ3** is *"In what way does TIMeR resolve the learning difficulties that students face while solving the engineering drawing problems?"*

 In this chapter, we put forward the details of ED1, ED2, and ED3 one by one. In the end we present the discussions coming out of these studies.

6.1 Research Study 3 (ED1)

This study aimed at testing the effectiveness of TIMeR on the ED problem-solving performance of the first-year undergraduate engineering students, who did not have prior knowledge of ED.

Sample: The participants in this study were 114 undergraduate students from first-year engineering course from an engineering institute in Maharashtra, India. Convenience sampling was used as these were the volunteers for the training.

Study Design and Implementation

The research study design applied for ED1 was single-group pretest-posttest. We followed the same training procedure as described in section 4.5, also illustrated in Figure 6-1 and briefed below.

Figure 6-1: TIMeR Procedure for ED1
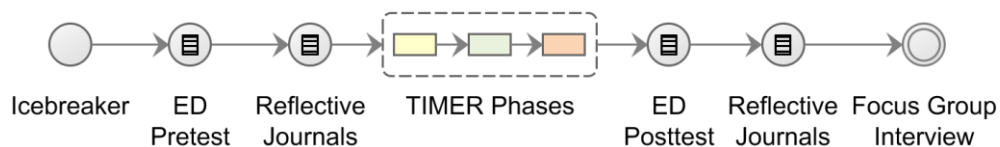
1. **Icebreaker:** It was a fifteen-minute activity conducted to emphasize the importance of mental rotation ability and for practicing the engineering drawing item.
2. **Pretest:** It was a fifteen-minute pretest with four ED items from Spatial Visualization Ability Test Instrument (SVATI), (Alias, 2000). Sample problem is shown in Figure 6-2. Students had to solve the test individually.
3. **Reflective journals after pretest:** Further to the pretest, students were given fifteen-minute to think about pretest problems and their solutions and to reflect (in a written form) about the difficulties faced while solving the pretest.
4. **Treatment:** It was followed by a three-hour TIMeR session. Students performed all the activities of TIMeR phases. In preparatory phase students learnt about Blender interface, in the training phase they performed observation and rotation tasks, and, in Transfer phase, they applied learnings from these phases and verified their pretest solutions.

5. **Posttest:** It was a fifteen-minute pretest with four ED items from SVATI (Alias, 2000).

6. **Reflective journals after posttest:** After the posttest, students were given fifteen-minute to think about posttest problems and their solutions and to reflect (in a written form) about the difficulties faced while solving the pretest. They were also asked to reflect if the training tasks helped them in resolving their difficulties.

7. **Focus Group Interview (FGI):** Further to the reflective journals, volunteer students were asked to participate for the FGI.

Training Objects: For first two phases of TIMeR, the three-dimensional primitive objects were used. For the transfer phase, ED objects based on the pretest were used, see Figure 6-3. For instance, pretest object from Figure 6-2 is modelled in Blender and shown in Figure 6-3 (d), using a quad-view feature.

Figure 6-2: ED Pretest Item (reproduced from SVATI, Alias, 2000)
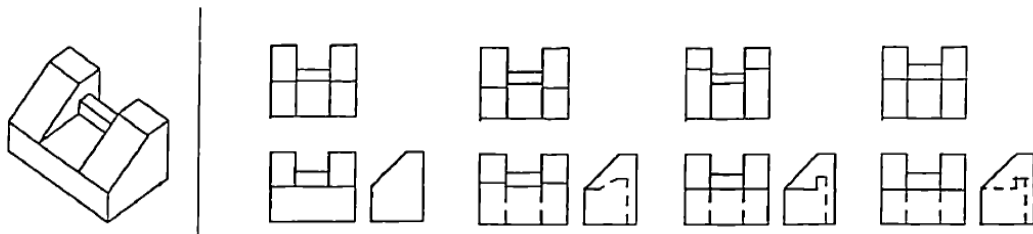
Figure 6-3: ED Pretest Practice Objects

(a) Practice object 1   (c) Practice object 3 in quad-view
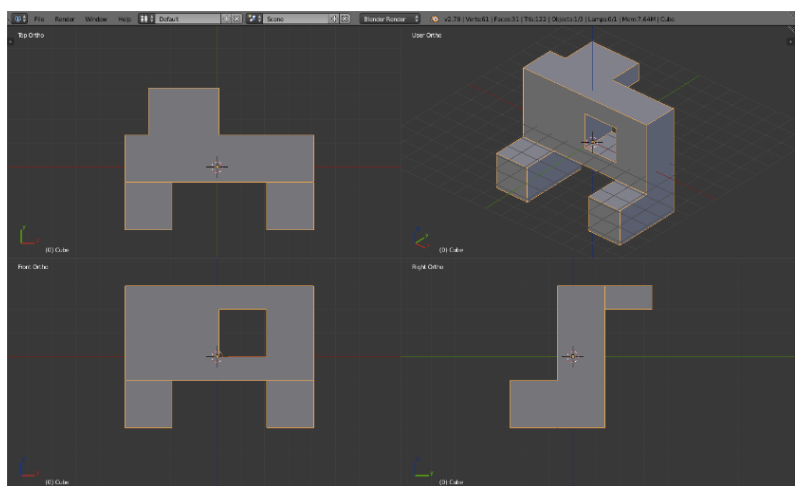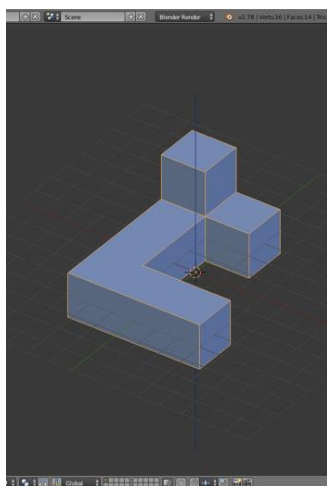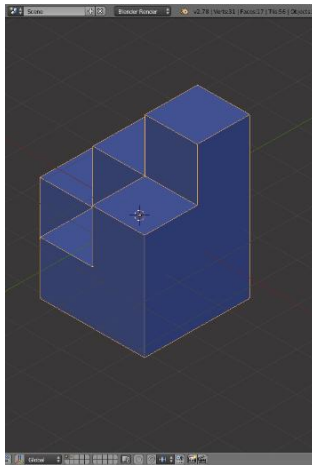
(b) Practice object 2   (d) Practice object 4 in quad view
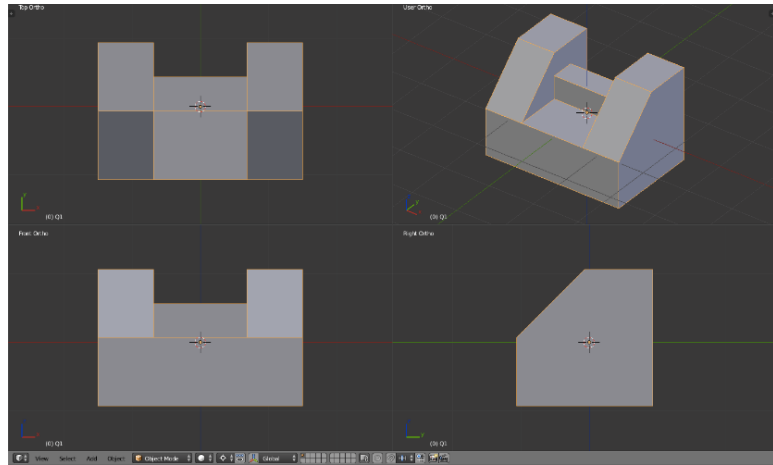
Instrument and Data collection

1) Performance Scores: The data was gathered in the form of performance scores of pretest and posttest of ED problems on the Spatial visualization ability test instrument (SVATI), (Alias, 2000), (Details of SVATI are given in section 3.4.1). We used four items each for the pretest and posttest assessment, two of them were on (i) Conversion of isometric view to orthographic views; in which for a given isometric view students require to identify the correct set of orthographic views. Other two items were on (ii) Conversion of orthographic views to an isometric view; in which for a given set orthographic views, students are to identify the correct isometric view. We used equivalent posttest with four test items from SVATI. Each question carries one mark. (See Appendix III for test questions used for ED1).

2) Reflective Journals: To determine the learning difficulties faced by students while solving pretest, we collected students' responses to an open-ended question in a written form immediately after the pretest. We call it as "pre-responses." Similarly, we collected We "post-responses," i.e., students' responses after the posttest to identify the learning difficulties that remain after training. Post-responses also include students' responses to an open-ended question if training helped them in resolving those problems; and if yes then, how.

3) Focus Group Interviews: In addition to the reflective journal, we conducted focused group interviews for which seven students volunteered. The objective of the focus group interview broadly was to triangulate the results by collecting students' perceptions of the learning

difficulties they faced while solving the pretest items and the effects of TIMeR session on their problem-solving strategies. The interview contained following four questions.

- Talk about your experience of solving the first test BEFORE the training. What difficulties did you face in solving the test problems?
- Do you believe that use of Blender is useful to overcome the difficulties? What was the difference between your solution strategies BEFORE and AFTER the training?
- What were activities from training more helpful in visualizing the object?
- Do you believe that viewing test items in Blender gave you more clarity on 'how to visualize or observe or imagine' the objects from different viewpoints?

Data Analysis Procedure

1) Quantitative Analysis: We followed the same data analysis procedure of as in MR1, to determine the effect of the TIMeR session on students' ED problem-solving performance. We performed quantitative analysis of the pretest and posttest for all 114 students. First, we performed normality test and based on the results we chose to use Wilcoxon Signed Rank Test to see how significant the improvement in students' scores are. For our analysis, we use the significance level 0.05 (5%). We also determined the effect size of the improvement and computed average gain (Marx and Cummings, 2007) for all 114 students. To look into the effects at a more granular level, we also performed the same analysis separately for the students at different pretest-achievement levels (low, medium, and high).

2) Qualitative Analysis: To analyse the reflective journals data, i.e., pre-responses and post-responses, we performed content analysis (the procedure from section 3.5). For pre-responses, we coded the common trend of words, phrases, and statements as a difficulty faced by the students while solving the pretest. We then summarized these codes as a list of difficulties, which is given in results section. Similarly, for post-responses, we extracted different themes which could determine the ways in which training helped them to resolve the difficulties. As far as the analysis of focused group interviews is concerned, we performed the content analysis of the interview transcription to extract the answers to the interview questions and validate if these findings can be mapped to the findings from the reflective journals.

6.1.1 Quantitative Results (ED1)

In this section, we present results of ED1 at two granularities. First, we provide the results of the effect of TIMeR on the whole class (n=114), and then separately for the different pretest achievement levels (low, medium, and high).

6.1.1.1 Effect of TIMeR on All Students

Test of Normality: The Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011), showed that the pretest and posttest data were not normally distributed with p being less than 0.05. **Wilcoxon Signed Rank Test:** As the data showed no normal distribution, we chose to perform Wilcoxon Signed-rank test to analyse the significance of the difference between the pretest and posttest performances. Table 6-1 shows the descriptive statistics for N=114, with posttest mean (2.491) being higher than the pretest mean (2.078).

Table 6-1: Descriptive Statistics for All Students (ED1)

Descriptive Statistics					
	N	Mean	Std. Deviation	Minimum	Maximum
Pretest	114	2.078	1.073	0.00	4.00
Posttest	114	2.491	1.154	0.00	4.00

Test Statistics Table: It can be observed from Table 6-2 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance.

Table 6-2: Test Statistics for All Students (ED1)

Test Statistics[b]	
	Posttest, Pretest
Z	-3.403[a]
Asymp. Sig. (2-tailed)	**0.001**

a. Based on negative ranks, b. Wilcoxon Signed Ranks Test
b. Wilcoxon Signed Ranks Test

Effect Size: We computed effect size by Cohen's (1988) formula (r = z / square root of N), where N = the number of observations over two-time points, which is two-times the sample size. However, in this condition, Z = 3.403, and N = 114 x 2 = 228; therefore, r = 0.2253

indicating an effect size between small and medium using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect, (Pallant, 2005).

Learning gain: To show the students' average improvement, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(posttest\ score\ -\ pretest\ score)}{(maxscore\ -\ pretest\ score)} = \frac{(2.491\ -\ 2.078)}{(4\ -\ 2.078)} = \frac{0.413}{1.922} = 0.215$$

Students demonstrated an average gain of 0.413 (i.e. 10.325 percentage) score out of a potential 1.922 (i.e. 48.05 percentage) score that they could have gained. Thus, they gained 0.215 (or 21.5 %) of the possible percentage scores they could have gained from pretest to posttest assessment. (Note: The *maxscore* in this case is 4, therefore to convert into percentage score the numerator and denominator was multiplied by 25 i.e. 0.413x25 = 10.325, and 1.922x25 = 48.05).

The overall results show that posttest performance of students is higher than pretest and the difference is statistically significant (p=0.001) with effect size between small and medium (r=0.22) (Cohen, 1988) and a positive gain (21.5 %). We infer that TIMeR was effective for the improvement of mental rotation skills for the whole group of students. To go deeper, we did the same analysis separately for the students at different (pretest) achievement levels as low, medium, and high.

Ranks Table: In ranks Table 6-3 we can see from the table's legend that 29 participants had a higher Pretest Score than Posttest Score. However, 49 participants had a higher posttest score compared to pretest score; and 36 participants saw no change in their pretest and posttest score.

Table 6-3: Ranks Table for All Students (ED1)

Ranks				
		N	Mean Rank	Sum of Ranks
Posttest and Pretest	**Negative Ranks**	29[a]	30.40	881.50
	Positive Ranks	49[b]	44.89	2199.50
	Ties	36[c]		
	Total	114		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

At this point, we postulate that the students with negative ranks are likely to fall into the groups other than low-performers. We examine this in the next section.

6.1.1.2 Effect of TIMeR on Students with Different Achievement Levels

The minimum and maximum achievable score for the pretest is zero and four respectively. In order to decide the three achievement levels based on the pretest score, we formed three clusters by dividing maximums score (four) with desired levels (three). It resulted into three ranges of scores that are between 0 to 1.33, between 1.34 to 2.66, and between 2.67 to 4. These values were used to define different achievement levels. So, we get three achievement levels as low (0, 1), medium (2), and high (3, 4). We call students from each level as, low-performers, medium-performers, and high-performers.

Wilcoxon Signed Rank Test

We performed Wilcoxon signed-rank test for each level. Table 6-4 shows the descriptive statistics for the group of students with different achievement levels.

Table 6-4: Descriptive Statistics: Students with Different Achievement Levels (ED1)

Descriptive Statistics						
Pretest Achievement Level		N	Mean	Std. Deviation	Minimum	Maximum
Low-performers	Pretest	32	0.71	0.45	0.00	1.00
	Posttest	32	2.25	1.24	0.00	4.00
Medium-performers	Pretest	43	2.00	0.00	2.00	2.00
	Posttest	43	2.13	1.20	0.00	4.00
High-performers	Pretest	39	3.28	0.45	3.00	4.00
	Posttest	39	3.07	0.73	2.00	4.00

Ranks Table: In Ranks Table 6.5 we can see that, in a **low-performers'** group, zero participants had a higher Pretest Score than Posttest Score. However, 25 participants had a higher Posttest Score compared to Pretest Score; and 7 participants saw no change in their Pretest and Posttest Score. In a **medium-performers'** group, 13 participants had a higher Pretest Score than Posttest Score. However, 16 participants had a higher Posttest Score compared to Pretest Score; and 14 participants saw no change in their Pretest and Posttest Score.

In a **high-performers'** group, 16 participants had a higher Pretest Score than Posttest Score. However, 8 participants had a higher Posttest Score compared to Pretest Score; and 15 participants saw no change in their Pretest and Posttest Score. Based on these results we can see that our earlier postulation of negative rank students falling into the groups other than low-performers was correct.

Table 6-5: Ranks Table for the Students with Different Achievement Levels (ED1)

Pretest Achievement Level		Ranks			
			N	Mean Rank	Sum of Ranks
	Low-performers	Negative Ranks	0[a]	0.00	0.00
		Positive Ranks	25[b]	13.00	325.00
		Ties	7[c]		
		Total	32		
Pretest and Posttest	Medium-performers	Negative Ranks	13[a]	13.96	181.50
		Positive Ranks	16[b]	15.84	253.50
		Ties	14[c]		
		Total	43		
	High-performers	Negative Ranks	16[a]	12.50	200.00
		Positive Ranks	8[b]	12.50	100.00
		Ties	15[c]		
		Total	39		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

Test Statistics Table: It can be observed from the Table 6-6 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance of the low-performers (with p=0.000); and showed no significant change for the medium and high-performers (with p=0.420 and p=0.102 respectively).

Table 6-6: Test Statistics for the Students with Different Achievement Levels (ED1)

Test Statistics[b]			
	Pretest, Posttest		
Pretest Achievement Level	**Low**-performers	**Medium**-performers	**High**-performers
Z	-4.434[a]	-0.807[a]	-1.633[a]
Asymp. Sig. (2-tailed)	0.000	0.420	0.102

a. Based on negative ranks. b. Wilcoxon Signed Ranks Test

Effect size: We computed effect size by Cohen's (1988) formula ($r = z$ / square root of N), where N = the number of observations over two-time points, and to determine the effect size we used Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect. However, in the first condition, for low-performers, Z = 4.434, and N = 32 x 2 = 64; therefore, r = 0.5542 indicating a large effect size. In the second condition, for medium-performers, Z = 0.807, and N = 43 x 2 = 86; therefore, r = 0.0870 indicating close to a small effect size. In the third condition, for high-performers, Z = 1.633, and N = 39 x 2 = 78; therefore, r = 0.18.

Learning gain: To show the students average improvement for each achievement level, we calculated the average gain as (Marx & Cummings, 2007):

For low-performers,   g = (2.25 - 0.71) / (4 - 0.71) = (1.54 / 3.29) = 0.468
For medium-performers, g = (2.13 – 2.00) / (4 – 2.00) = (0.13 / 2.00) = 0.065
For high-performers, g = (3.07 – 3.28) / (4 – 3.28) = (-0.21 / 0.72) = -0.291

Low-performers demonstrated an average gain of 1.54 (i.e. 38.50 percentage) score out of a potential 3.29 (i.e. 82.25 percentage) score that they could have gained. Thus, they gained 0.468 (or 46.80 %) of the possible percentage scores they could have gained from pretest to posttest assessment. Similarly, medium-performers gained 0.065 (or 6.50 %) of the possible percentage scores they could have gained. However, high-performers showed no positive gain. (Note: The *maxscore* in this case is 4, therefore to convert into percentage score the numerator and denominator was multiplied by 25 i.e. for low-performers 1.54x25 = 38.50, and 3.29x25 = 82.25).

The deeper results show that for low-performers, posttest is higher than pretest and the difference is statistically significant (p=0.001) with large effect size (r=0.5542) and a positive gain (g=0.468). For medium-performers even though posttest is higher than pretest the difference is not statistically significant (p=0.420) with small effect size (r=0.087) and a positive gain (g=0.065). For high-performers even though posttest is lower than pretest the difference is not statistically significant (p=0.102). The reason for high-performers not showing positive improvement could be a ceiling effect (Rifkin, 2005).

We infer that TIMeR was more effective for the improvement of ED problem-solving performance for the low-performers as compared to the non-low performing students.

6.1.2 Qualitative Results (ED1)

In this section, we present the qualitative results of ED1. First, we provide the results of reflective journals, and then the results of focus group interview.

6.1.2.1 Analysis of Reflective Journals

We collected the reflective journal data in the form of written text, and then put all the data together into a single data set for analysis. The analysis resulted in the identification of (i) list of the learning difficulties faced by students while solving the pretest items; and (ii) list of ways in which the TIMeR session has effected the students.

Among the 114 students, 52 reported either of the learning difficulties or TIMeR benefits or the both. From these 52 students, 24 reported only difficulties but not the benefits, 12 reported only benefits but not the difficulties. However, 16 students reported both the difficulties and the benefits. This resulted in total 40 (24+16) responses on learning difficulties in ED, and 28 (12+16) responses on the benefits of the TIMeR.

Learning Difficulties in ED (analysis of pre-responses)

Here, we provide analysis of few representative instances from the data of 40 pre-responses, for example, student 403 found difficulty in distinguishing orthographic views; student 409 found it difficult to interpret diagram due to confusion between in dotted line and regular lines; students 419 found it difficult to construct 3D form from given orthographic views, (the complete analysis of pre-responses is given in Table 6-10 at the end of this section). In a similar way, as analysed from the reflective journals of forty students, we found various difficulties with respect to the different aspects that students face while solving ED pretest problems. The set of difficulties identified is listed as coding scheme below and also shown in Figure 6-4. Further, the frequencies of each type of learning difficulties is provided in Table 6-7.

VIEWS: This code indicates the difficulties about orthographic views such as,
1. Difficulty in Identifying and analysing different views.
2. Difficulty in Visualizing different views.
3. Difficulty in distinguishing between views.

SHAPES: This code indicates the difficulties about the shapes of an object.

1. Difficulty in identifying and interpreting shapes of an object.

HIDDEN: This code indicates the difficulties about hidden surfaces and hidden lines.

1. Difficulty in identifying and observing hidden lines.

2. Difficulty in visualizing hidden surfaces from various views.

VISUALIZE: This indicates the difficulty about visualizing 3D objects.

1. Difficulty in visualizing and constructing a 3D form from a 2D drawing.

CONCEPT: This indicates the difficulty about the conceptual understanding.

2. Difficulty in conceptual understanding.

OTHER: This code indicates difficulties about the ED problems solving process such as,

1. Difficulty in the process of finding a correct solution to the problem.

2. Difficulty in identifying the correct solution between the given choices.

3. Time required to solve the problem.

Figure 6-4: Learning Difficulties in ED (Coding Scheme)
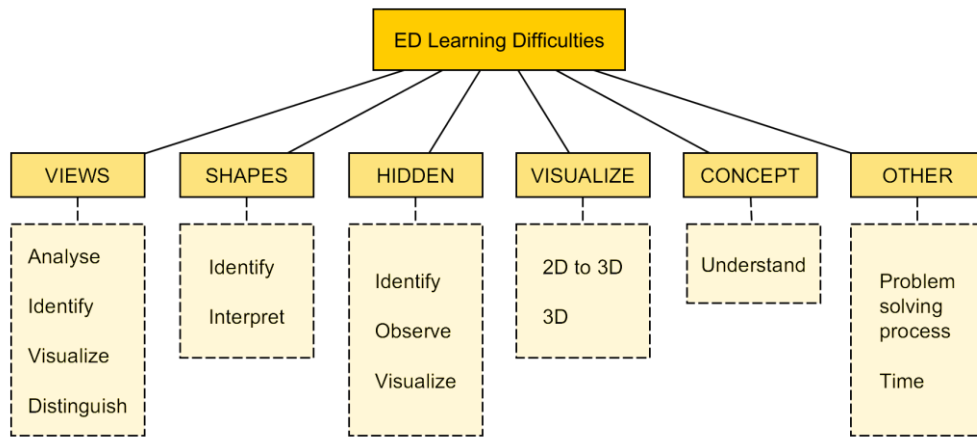
Table 6-7: Frequencies of ED Learning Difficulties (ED1)

Learning Difficulties	Frequency
VIEWS	12
SHAPES	06
HIDDEN	16
VISUALIZE	05
CONCEPT	04
OTHER	09

Our findings answer RQ3.1 and also confirm that the learning difficulties of the students in solving pretest problems are found to be identical to the difficulties stated in the literature

(Garmendia, Guisasola, & Sierra, 2007; Nagy-Kondoor, 2007; Upadhye, Shaikh, & Yalsingikar, 2013).

TIMeR Benefits (analysis of post-responses)

Here, we provide analysis of few representative instances from the data of 28 post-responses, for example, the student 403 mentions that after training he learnt how to concentrate and to identify the front and top views; which means the training benefitted him with respect to the cognitive component of learning, i.e. skill of observing (C7) and skill of identifying different views (C1). In the second example, student 409 mentions that after training he is able to perfectly imagine from the front, top and side; which means the training benefitted him with respect to the cognitive component of learning, i.e. the skill of visualizing different views (C3). In the third example, student 419 mentions that the training has positive effects on him and he enjoyed the training activities; which means the training benefitted him with respect to the affective component (A1), (the complete analysis of post-responses is given in Table 6-10 at the end of this section). In a similar way, as analysed from the reflective journals of twenty-eight students, we found various effects of the training session in both the cognitive and affective dimensions, which we summarise as:

COGNITIVE COMPONENT: The training helped students to learn:

- **C1.** Skill of identifying different views.
- **C2.** Concepts of different views.
- **C3.** Skill of visualizing different views.
- **C4.** Skill of visualizing 3D Objects by rotation.
- **C5.** Skill of visualizing different views and Comparing (Evaluate) with options.
- **C6.** Skill of identifying and visualizing hidden lines and surfaces.
- **C7. Miscellaneous**

    Identification of relevance of the visualization to problem-solving process.

    Learnt visualization skills.

    Learnt about the Environment (Blender) i.e. preparatory phase successful.

    Applying training skills for solving tests.

    Conceptual understanding about "introduction to the domain."

    How to concentrate (observe).

AFFECTIVE COMPONENT: The training helped students as,

> **A1.** Students found the training session to be good, interesting and enjoyable.
>
> **A2.** Training helped students in overcoming the fear arising from the complexity of concepts in ED course.

Table 6-8 provides the frequencies of each type of the training benefits reported by the students. We used the same coding scheme as in ED1 for the analysis of research studies ED2, ED3, and ED4, the details are presented in respective sections.

Table 6-8: Frequencies of TIMeR Benefits (ED1)

TIMeR Benefits (Code and description)	Frequency
C1 Skill of identifying different views	04
C2 Concepts of different views	01
C3 Skill of visualizing different views	11
C4 Skill of visualizing 3D Objects by rotation	05
C5 Skill of visualizing different views and Comparing (Evaluate) with options	06
C6 Skill of identifying and visualizing hidden lines and surfaces	04
C7 Miscellaneous	12
A1 Students found the training session to be good, interesting and enjoyable	04
A2 Overcoming the fear arising from the complexity of concepts in ED course.	02

Comparison of Pre-Responses and Post-Responses

We now compare the data of pre-responses and post-responses to see students' perception about the way training has benefitted them in resolving their ED difficulties. Here, we provide analysis of few representative instances from the data of 16 students who reported both the learning difficulties and the TIMeR benefits. For example, student 403 found difficulty in distinguishing orthographic views before training, but after the training session and posttest he said that, he learned how to concentrate and to identify the front and top views. So, it can be seen that the treatment helped him in resolving his difficulties. Similarly, in the second example, student 409 found it difficult to interpret diagram due to the confusion between dotted lines and regular lines before training. But after training and posttest, he said that he was able to imagine from the front, top and side views perfectly. In the third example, student 419 found it difficult to construct 3D form from given orthographic views before training, but after training and posttest, he said that training has positive effects on him and he enjoyed training activities. Similarly, it can be seen from the complete analysis (which is given in Table 6-10 at the end of

this section) of the comparison of pre-responses and post-responses that, the training helped students in acquiring skills to get over their ED difficulties.

Table 6-9 provides the mapping of learning difficulties and training benefits, such that it shows which benefit resolves a particular difficulty. First column is the learning difficulties, where in bracket we show the code for training benefit that helped in resolving that difficulty. The second column is List of training benefits. For example, VIEWS-1 get resolved by C1, i.e. before the training student found it difficult in identifying different orthographic views (VIEWS-1), but after the training he learned the skill of identifying different views (C1).

Table 6-9: Mapping of Learning Difficulties & TIMeR Benefits

Learning Difficulties in ED	TIMeR Benefits

VIEWS: Difficulties about orthographic views
  1. Difficulty in identifying and analysing different views **(C1)**
  2. Difficulty in visualizing different views **(C3)**
  3. Difficulty in distinguishing between views **(C5)**
SHAPES: Difficulties about the shapes of an object
  1. Difficulty in identifying and interpreting shapes of an object
HIDDEN: Difficulties about hidden surfaces and hidden lines **(C6)**
  1. Difficulty in identifying and observing hidden lines
  2. Difficulty in visualizing hidden surfaces from various views
VISUALIZE: Difficulty about visualizing 3D objects **(C3)**
  1. Difficulty in visualizing and constructing a 3D form from a 2D drawing **(C4)**
CONCEPT: Difficulty about the conceptual understanding
  1. Difficulty in conceptual understanding **(C2, C7)**
OTHER: Difficulties about the ED problems solving process:
  1. Difficulty in the process of finding a correct solution to the problem **(C7)**
  2. Difficulty in identifying the correct solution between the given choices **(C7)**
  3. Time required to solve the problem
	COGNITIVE COMPONENT:
	The training helped students to learn:
	  C1. Skill of identifying different views
	  C2. Concepts of different views
	  C3. Skill of visualizing different views,
	  C4. Skill of visualizing 3D Objects by rotation
	  C5. Skill of visualizing different views and Comparing (Evaluate) with options.
	  C6. Skill of identifying and visualizing hidden lines and surfaces
	  C7. Miscellaneous
	  Identification of relevance of the visualization to problem-solving process.
	  Learnt visualization skills.
	  Learnt about the Environment (Blender) – Training phase 1 successful.
	  Applying training skills for solving tests.
	  Conceptual understanding about "introduction to the domain."
	  How to concentrate (observe).

This analysis answers our RQ3.2. We summarise these findings as, while solving the posttest, comparatively it was easier for the students to:

  1) Identify various orthographic views,

  2) Visualize various views

  3) Distinguish between different views

4) Identify and interpret shapes of surfaces

5) Identify and observe hidden lines

6) Identify and visualize hidden surfaces

7) Visualize an object in 3D

8) Understanding of concepts

9) Students also mentioned that due to the training activities, they learnt various approaches to observe the object such as by rotating.

10) It also took lesser time for them to solve the posttest.

Details of Analysis of Reflective Journal

The detailed analysis is provided in Table 6-10, where the column **ID** is the student identification number. The **Pre-response** column indicates students' reflective journal data collected after the pretest, but before the treatment, it includes students' learning difficulties in solving pretest ED problems. The **Learning difficulties** column indicates the learning difficulties categorized based on the pre-response. The **Code** in a bracket indicates the descriptive code assigned to the category of learning difficulty. For example, the student 402 said that "The last question was time-consuming. Up to certain extent, it was difficult for me to observe the hidden side view." In this text, the first part "The last question was time-consuming" was coded as OTHER-1, which represents the student's difficulty in solving the ED problem in stipulated time. Whereas the second part of the text, "Up to certain extent, it was difficult for me to observe the hidden side view" was coded as HIDDEN-1, which represents the student's difficulty in observing the hidden lines.

The **Post-response** column indicates students' reflective journal data collected after the posttest, and it includes students' responses to the training benefits and additional learning difficulties in solving posttest ED problems if any. The **TIMeR Benefits** column indicates the training benefits categorized based on the post-response. The Code in a bracket denotes the descriptive code assigned to the different learning components, these are affective (An), cognitive (Cn), and behavioural (Bn). For example, the student 403 said that "(Q1-2) By this training, I have got the idea of making concentration. (Q3-4) By this training, we can understand to identify front view and top view." In this text, the first part "By this training, I have got the idea of making concentration" was coded as C7. Code C7 indicates the effect of training in cognitive dimension. Whereas the second part of the text, "By this training, we can understand

to identify front view and top view" was coded as C1, which indicates the effect of training in a cognitive dimension where the student has learned the skill of identifying different views.

Table 6-10: Details of Analysis of Reflective Journals (ED1)

ID	Pre-responses	Learning difficulties (Code)	Post-responses	TIMeR benefits (Code)
402	The last question was time consuming. Up to certain extent, it was difficult for me to observe the hidden side view.	Difficulty in solving problem in stipulated time (OTHER-1) Difficulty in observing hidden lines (HIDDEN-1)		
403	It was confusing to identify the front and top view.	Difficulty or confusion in distinguishing and identifying front and top view (VIEWS-3)	(Q1-2) By this training, I have got the idea of making concentration. (Q3-4) By this training, we can understand to identify front view and top view.	How to concentrate (observe) (C7) Skill of identifying different views (C1)
405	Visualizing the side view was difficult.	Difficulty in viewing side view (VIEWS-1)	(Q1-2) In this training lecture, I understand the concept - how to imagine dotted lines and different views of the figure.	Skill of visualizing different views, (C3) Skill of visualizing hidden lines (C6)
406	Q4 is very difficult. I think option A & C are same. I was confused between A & C. I am very much confused about the dotted line and straight line in the figure. Please clear my problem.	Difficulty in distinguishing views (VIEWS-3) Difficulty or confusion in identifying hidden lines and regular lines (HIDDEN-1)	This seminar helped me to imagine from the front, top and side perfectly.	Skill of visualizing different views (C3)
407	I observed the given three views, and I combined it. But sometimes I got confused between options A, B, and C. Both these structures looked same. Visualizing orthographic views was difficult.	Difficulty in combining views and visualizing it (VISUALIZE-1) Confusion between answer choices (OTHER-1) Difficulty in visualizing orthographic views (VIEWS-2)	3rd question was difficult for me because I was unable to imagine the position of that inclined part. But, when I tried to imagine into Blender software, it made easy for me to find out the answer.	Skill of visualizing different views (C3)
408	Visualizing the 3D form of a given diagram was difficult.	Difficulty in visualizing 3D form for a given diagram (VISUALIZE-1)		
409	For interpreting the diagram, I got confused between dotted lines and regular lines.	Difficulty in interpreting diagram due to confusion between dotted line and regular lines (HIDDEN-1)	Able to correctly imagine from the front, top and side.	Skill of visualizing different views (C3)
410	Q3 (orthographic to isometric) this is very difficult to remember. Difficulty in distinguishing between the options A and C.	Difficulty in remembering Difficulty in distinguishing between answer choices (OTHER-2)		
412	The shape of the surface which looks like steps of the house makes it confusing.	Difficulty or confusion in interpreting shape of the surface (SHAPES-1)		

			After training I able to correctly see the front view, top view, and side view. I understand to identify the correct orthographic views.	Skill of visualizing different views, *(C3)* Skill of identifying different views *(C1)*
413				
414	Some diagrams are difficult. I got confused by many questions.	Difficulty in reading diagrams. *(SHAPES-1)* Confusion in many questions *(SHAPES-2)*		
415	What is the purpose of the dotted lines? Which one is the right side and which one is the left side of an object figure?	Conceptual clarification required *(CONCEPT-1)* Difficulty in interpreting the meaning of dotted lines *(HIDDEN-1)* Difficulty in identifying right and left side views of an object *(HIDDEN-2)*		
416	Constructing 3D form by attaching front view to top view and the side view is difficult. Identifying shapes is difficult.	Difficulty in constructing 3D form from the given orthographic views *(VISUALIZE-1)* Difficulty in identifying shapes *(SHAPES-1)*	This training session has helped me to visualize the object from different views, and it was not that easy nor difficult too.	Skill of visualizing different views *(C3)*
417	Visualizing the side view is difficult.	Difficulty in visualizing side view *(VIEWS-2)*	(Q1-2) Visualize the FV TV and side view. By using Blender, it is good to know what actually can be seen from front view top view and side view.	Skill of visualizing different views, *(C3)* Skill of identifying different views *(C1)*
419	Construction of 3D view from given orthographic views is difficult.	Difficulty in constructing 3D view from the given orthographic views *(VISUALIZE-1)*	This lecture affected me positively, animation of 3D objects and various operations on it, doing this I enjoyed very much, and I got knowledge about it. I would like to attend this lecture again.	Enjoyed, interest *(A1)*
421	Visualizing is difficult, and it consumes time.	Difficulty in visualizing *(VISUALIZE-1)* Found visualizing to be time consuming *(OTHER-3)*	(Q1-2) Because of the training, it gives the idea of how to solve the problems & it was easy to solve but not too easy. By using the idea of imagination, I solve the problems. (Q3-4) From the idea of the training session, I imagine the object in 3D.	Identification of relevance of the visualization to problem-solving process *(C7)* Skill of visualizing 3D object *(C4)*
424	Visualizing side views is difficult.	Difficulty in visualizing side views *(VIEWS-2)*		
426	How to correctly identify an object? How to check which option is correct?	Difficulty in identifying or analysing object *(SHAPES-1)*	(Q1-2) By this training, I have got the idea, but I cannot express or describe.	Benefitted *(C7)*

	I need an easy method to solve the problem and that too in less time.	Difficulty in the process of finding a correct solution to the problem (*OTHER-1*) Mentions need of easy method with lesser time (*OTHER-2*)		
428	Mostly in given views, I couldn't imagine the invisible parts of the object. Therefore, I couldn't match that hidden part in the views.	Difficulty in imagining invisible parts (*HIDDEN-2*)		
429	Some extra time is required for the correct visualization. No other difficulties I faced.	The need of more time for correct visualization (*OTHER-3*)	The lecture was good, and I got sufficient knowledge about Blender software and how to use it. This lecture improved my knowledge at a certain level.	Learnt about the Environment (*C7*) Session was good (*A1*)
430	Q4 I am unable to visualize the shape and front view.	Difficulty in visualizing shape and front view (*SHAPES-1, VIEWS-2*)		
432	Apart from the dotted lines, there was no other difficulty in visualizing the object.	Difficulty in visualizing dotted lines (*HIDDEN-2*)		
434			Before the practical session, I didn't know the front view, side view, and top view. After the session, I get to know that. So, it is the very helpful session for me, the session was enjoyable.	Learnt Concepts of different views (*C2*) Training was enjoyable (*A1*)
435	Triangle shape is difficult to imagine.	Difficulty in imagining triangle shape (*SHAPES-1*)	Because of the training, I understood that how to observe the object by rotating. Imagining object from all side was much easier due to training.	Visualize object using mental rotation (*C4*) Skill of visualizing objects from different sides (*C3*)
437	I cannot understand the front view.	Difficulty in understanding front view (*CONCEPT-1*)		
438	I do not understand the dotted lines for each question.	Difficulty in understanding the dotted lines (*CONCEPT-1*)	(Q1-2) By using training method steps, I imagine top view for that orthographic view and side, front view matching the view. I imagined all views and chose the option.	Skill of visualizing objects from different views (*C3*) & Compare (*C5*)
439	I found difficulty regarding dashed lines.	Difficulty in dashed lines (*HIDDEN-1*)	(Q1-2) After training, I imagined the object in a 3D picture, imagined the top view, side view, front view and tried to figure out the hidden portions of the object in all the views. I	Skill of visualizing objects from different views (*C3*) Skill of identifying hidden portions of Objects (*C6*)

			tried to get the whole visual picture of the object.	
440	It is a very new figure for me.			
442	It was difficult to visualize the views containing hidden lines of a particular view.	Difficulty in visualizing views with hidden lines (*HIDDEN-2*)	By applying it practically on PC, I can recognize it very fast, which are the hidden lines.	Skill of identifying hidden lines (*C6*)
443	Only the shape is visible, and the inner part is not visible. Where to put the dotted lines in 3D view?	Difficulty in visualizing hidden parts (*HIDDEN-2*) Difficulty in putting dotted lines in 3D view (*HIDDEN-2, VISUALIZE-1*)		
444	Visualizing the object in the opposite view was difficult.	Difficulty in visualizing opposite view of the object (*VIEWS-2*)		
445	In Q2 we cannot see the hole from the top and side view.	Difficulty in visualizing the hidden part from the top and side view (*HIDDEN-2*)		
448	I cannot understand.			
449	Q4 I am unable to get the correct side view. Between option A and C which is more accurate that I do not know. I face problem in visualizing back side view, i.e. hidden part.	Difficulty in identifying the correct solution between the given choices (*OTHER-2*) Difficulty in visualizing back side view (*VIEWS-2*)		
450	I don't understand the graphics.	Difficulty in understanding the domain (*CONCEPT*)		
452	I have got a problem in Q2, maybe the reason is dotted lines, but I think I managed it properly.	Difficulty in understating due to the dotted lines (*HIDDEN*)		
453	I found it difficult to understand the hidden part.	Difficulty in understanding hidden part (*HIDDEN*)		
454	The difficulty was with the dotted lines.	Difficulty with dotted lines (*HIDDEN*)		
456	Confusion in watching the view.	Confusion in observing the view (*VIEWS-2*)		
457	Difficult to draw the right-hand side view.	Difficulty in drawing the right-side view (*VIEWS-2*)		
459	The top views are very difficult, the views with dotted lines are very difficult.	Difficulty in analysing top view (*VIEWS-1*) Difficulty in analysing views with dotted lines (*HIDDEN-2*)		

460	I cannot visualize the front view.	Difficulty in visualizing the front view *(VIEWS-2)*	Before attending the training session, I had no idea about it. But during the training, I got involved in it, and got interested to know what is going to happen next? I used to fear about studying graphics subject. The training session was beneficial for me.	Training session interesting *(A1)* Overcome fear about domain *(A2)* Conceptual understanding about "intro to domain." *(C7)*
511			I found the answers with the help of teaching I received in the training session.	Skill of applying training skills for solving test *(C7)*
519			I received additional knowledge about solving questions. More understanding happened by the training.	Skill of applying training skills for solving tests *(C7)*
523			1. The session little-bit helped me to solve the questions 2. I tried to imagine the object, how it will look in 3D and find out the answer 3. it took less time to cover the questions	Skill of applying training skills for solving tests *(C7)* Skill of visualizing different views to compare with the options. *(C5)*
524			I rotated the object for getting the front view, top view and side view, then I got the option C.	Visualize object using mental rotation *(C4)* Skill of visualizing different views to compare with the options. *(C5)*
525			More understanding, fast answering, rotation skill	Conceptual understanding *(C7)* Visualize object using mental rotation *(C4)*
527			Q 1, 2 After training my imagination skill is boosted, and that is 3D imagination. I imagine the figure in different directions. Q3,4 I tried to imagine in same way as seen in Blender software	Student found training session to be encouraging *(A2)* skill of visualizing different views *(C3)* Applying training skills for visualization *(C7)*
537			By rotating I was able to see the side view and front view, and also to conclude the right answer. After training it was very easy to find the answers with no confusion.	Visualize object using mental rotation *(C4)* Skill of visualizing different views to compare with the options *(C5)*

543			Q1 C is the correct answer, because of its hidden lines, the reason is that the better understanding and visualizing happened after seeing it on the computer screen. That helped to imagine perfectly and neatly.	Skill of identifying and visualizing hidden lines and surfaces *(C6)* Skill of applying training skills for solving tests *(C7)* Learnt skill of visualization *(C7)*
546			Using Blender software, I truly realize the top view, front view, and right-hand side view; and I recognized my answers. The strategies used are nothing, but the one learned while using the software. It helped in recognizing the answers.	Skill of identifying different views *(C1)* Skill of visualizing different views to compare with the options *(C5)*
552			The software helped me to imagine an object, and to justify the answer object.	skill of visualizing object and comparing with options *(C5)*

6.1.2.2 Analysis of Focus Group Interview

We followed the procedure as in section 4.5 for the analysis of the focus group interview. Table 6-11 provides the coding scheme and analysis. Seven students volunteered for the focus group interview session. Results of the analysis of the focus group interview corroborated the findings from the analysis of reflective journals. The interview transcript was analysed line by line to see if any difficulty (from the list from Table 6-9) or any benefit (from the list from Table 6-9) is/are also evident from the interview. Table 6-11 lists different chunks from interview transcript which contain any such pieces of evidence.

It can be noted from the Table 6-11 that, for example, the student S7 found it difficult to identify and analyse orthographic views before the training, but after the training and posttest he said that he learned how to identify the front and top view, also he learned the concept of hidden lines. So, it can be seen that the treatment helped him in resolving his difficulties. Students also responded that the training activities and features such as rotation, multiple views, hidden lines, axes of rotation helped them in visualizing an object. Hence the findings of focus group interview confirm our finding from the reflective journals.

Table 6-11: Focus Group Interview (ED1)

ID	Transcript of Students' Response	Learning Difficulties / TIMeR Benefits	Codes
Q	**Talk about your experience of solving the first test BEFORE the Blender training.** **What were the difficulties did you face in solving the test problems?**		
S5	First, I couldn't understand how to solve the questions. How to make the orthographic from the isometric?	Difficulties about the ED problems solving process:	OTHER
S1	Sir, when you gave us the first question, where a top view and side view was shown and asked us to draw front view and 3D view; we thought only of a square with six by three, that is eighteen (6x3=18) blocks; we did only that much.	Cognitive - Concepts of different views	C2
	When we saw solutions on the slides we got to know that, only one part is not ok, many parts can be done by just one top view and one side view.	Cognitive - Lesser time to solve the posttest.	C7
	Again, after a session was over the second test was quite fast that we performed; means we understood things much better than the first one. We performed it really fast.		C4
	The second thing was the rotation method (uses the hand gesture to show rotation) which you taught us in training, that rotation helped us here also, in the second test.	Cognitive - Skill of visualizing 3D Objects by rotation Applying training skills for solving tests	C7
	With rotation method, we can better imagine a view from many sides or any of the needed side. That was the biggest advantage I thought.		
S3	Firstly, I was unable to draw isometric to orthographic, and my difficulty was to draw orthographic from isometric.	Difficulty in Identifying and analysing different views Difficulty in making the drawings	VIEWS-1 OTHER-4
S2	The first thing, we could not imagine the view and the hidden lines. After studying the orthographic, I could identify the hidden lines.........	Difficulty in Visualizing different views Difficulties about hidden lines	VIEWS-2 HIDDEN
S7	I could not understand at first, what is this? With the help of Blender software, we can draw the isometric or orthographic pictures, ...any view, front view, top view.	Difficulty about the conceptual understanding Cognitive - Concepts of different views	CONCEPT C2
S6	While looking at the orthographic views, understanding top view, front view, side view was quite easier. But identifying hidden lines is more important.	Cognitive - Skill of identifying and visualizing hidden lines and surfaces	C6
	While observing from the front, identifying the hidden line of the back is more important. This got more clear due to training.	Cognitive - Applying training skills for solving tests	C7
	From the multiple options it is confusing to identify which are the correct hidden lines, but it can be understood well while visualizing in software.		
S4	I got to understand how to convert isometric to orthographic. It was easier with the tool to view top, front, bottom, back.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful	C7
Q	**Do you believe that use of Blender is useful to overcome those?**		

Q	What was the difference between your solution strategies BEFORE and AFTER the training?		
S1	First, I thought that the projection should meet my front view and top views.... just the projections of the lines… the border or the outer lines of an object. Means what did I view at first was, I thought it was just a projection. First items were seemed simple, so I thought the projections will make my views, but when I saw the session then I got that the rotation is easier than projection. Projections may or may not be true but in the middle or when the hidden kind of things would come, just like angles, slopes, or lines or some spaces, that we cannot manage. Then in the 2nd test's first example, first I got the wrong option because I analysed it using my first method and this method at the first question itself. Then I applied my first method, I thought of four or three levels were there in the first question of the 2nd test; but the behind wall was little-bit down. The projections of 3D view were not so clear to me. But when I rotated or when I visualize the figure to be rotated then I was knowing that the projections are going towards the wrong direction, and rotation will tell me the exact height or something like that. Means I visualize (makes use of hand gestures) in the same way as the picture was shown on the screen; I just rotated it, means.... somewhat I visualized it.	Cognitive - Skill of visualizing 3D Objects by rotation Cognitive - Applying training skills for solving tests	C2 C7
S3	Graphics is a subject which is entirely based on visualization, for visualization you need to plan some strategies	Cognitive - Identification of relevance of the visualization to problem-solving process	C7
S6	There was a difference, in the first test I was able to know what is to be done, but during the second test, I could imagine which I couldn't do in the first one. Visualization was more useful for having more views. There were options that can confuse you, but it was then easier.	Cognitive - Identification of relevance of the visualization to problem-solving process Cognitive - Learnt visualization skills	C7 C7
S4	In the first along with the view, drawing each line was taking too much of time and required lots of visualization. But after Blender training it took lesser time and more quick, to identify the locations of the lines.	Cognitive - Lesser time to solve the posttest.	C7
S2	Generally, drawings are on board or paper, so we can't identify the top view and front view. In Blender it was like that it has four-five types of views also, we can identify that again.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful.	C7
S7	When I saw the first question paper, I couldn't get it how to identify front view, top view. I got to know that there is a concept of hidden lines. I couldn't understand initially, but when you conducted the session, I got to know practically about the top view, front view. It was easier and faster to imagine in the second test than the 1st one.	Difficulty in Identifying and analysing different views Cognitive - Skill of identifying and visualizing hidden lines Cognitive - Lesser time to solve the posttest.	VIEWS-1 C6 C7
S5	While solving the first test, I compared the top view, front view, side view with the given options and selected the answer, but after the training in the second test, I could identify the hidden lines in the options.	Cognitive - Skill of identifying and visualizing hidden lines	C7

Q	**What were activities from training more helpful in visualizing the object?** a. Navigating and observing the object (MMB / Numpad 2,4,6,8) b. Rotation of the object about axes, using manipulator) c. Use of multiple views, and individual views. d. Viewing hidden lines		
	Common responses- Rotation, hidden lines, multiple views	Learnt about the Environment (Blender)	C7
S4	rotating and hidden views	Learnt about the Environment (Blender)	
S1	quad view / multiple view	Learnt about the Environment (Blender)	C7
S2	The quad view was useful to analyse the four views at the same time (making hand gestures to locate four views) and analyse the four directions in that quad view.	Cognitive - Skill of identifying different views Skill of visualizing different views Cognitive - Learnt visualization skills	C1 C3 C7
S1	In the object mode, it was useful for finding the hidden lines, that was very useful.	Cognitive - Skill of identifying and visualizing hidden lines	C6
S6	Axes were useful for the rotation	Learnt about the Environment (Blender)	C7
S7	When we rotate the object, we get to understand more about the section, e.g., right side. If we look at the object from the right side, how does the hidden line will look, or which line is not visible or visible - these things are better to understand with the help of software.	Cognitive - Skill of visualizing 3D Objects by rotation Cognitive - Skill of identifying and visualizing hidden lines	C4 C6
Q	**Do you believe that viewing test items in Blender gave you more clarity on 'how to visualize/ observe/imagine' the objects from different viewpoints?**		
S1	Students commonly responded with yes. Sir, I want to add one thing, I can imagine enough........ But, the thing was, which I thought after the session, this software will help the one who cannot imagine so easily. But I thought about myself, if I am imagining from my mind itself then the thing is, I was getting questions corrected... but after the session, I thought, the session helped me but ... the one who imagines himself or herself may get confused because of more clear he will get, ... (student was not able to explain) but the techniques are different. While imagining with the original mind, it gives an instant reaction, but after the session, it starts analysing the ways like which part of the training to apply at what time?	Cognitive - Identification of relevance of the visualization to problem-solving process Applying training skills for solving tests	C7 C7

6.1.3 Summary of Results of ED1

Table 6-12 provides the summary of quantitative results of ED1 for overall class and for different pretest achievement level.

<p align="center">Table 6-12: Summary of Results of ED1</p>

	ED1			
	Overall	**Low**	**Medium**	**High**
N	114	32	43	39
Pretest mean	2.07	0.71	2.00	3.28
Posttest mean	2.49	2.25	2.13	3.07
p	0.001	0.000	0.420	0.102
Effect size r	0.21 (med)	0.55 (large)	0.08 (small)	0.18
Learning gain	0.22	0.46	0.06	-0.29

The studies (MR1 and MR2) shown in the previous chapter had established that TIMeR session significantly improves the MR performance of the students. As Sorby (2009) and Voyer, et al. (2009) suggest that similar MR skills are needed for solving specific ED problems, we conjectured that the same TIMeR session should be beneficial for improving students' ED problem-solving performance. The study ED1 has proved this hypothesis. The results of ED1 are similar to that we obtained in MR1 and MR2. For the whole class there was a significant improvement in the ED problem-solving performance, but when we looked at a more granular level, we again found that the TIMeR was significantly beneficial for the low-performers only (with large effect size). For the medium and high-performers, we cannot conclude anything from the result, as for the medium-performers the effect was positive (with low effect size) but not statistically significant and for high-performers, the result was negative (with small effect size) but not statistically significant. With this evidence, we claim that TIMeR session has a significantly positive effect on improvement of low-performers' MR and ED problem-solving performances.

The qualitative data collected in ED1 provide more insight into the ways in which the TIMeR affects students' ED problem-solving performance. The analysis of reflective journals has

helped in identifying a list of difficulties that students face while they solve ED problems. The same analysis has also helped in identifying different cognitive and affective benefits of the TIMeR session on the students. The findings from the focused group interview analysis have further validated these identified difficulties and benefits. Looking at the lists of these difficulties and the benefits we can say that the difficulties are being addressed by the TIMeR pedagogy (Table 6-9).

The results from all of the studies (MR1, MR2 and ED1) till this point could not provide us any conclusive inference about the effect of TIMeR pedagogy on the medium and high performers. In the next study (to be discussed in the next section) we would focus on advanced learners, who have already studied the ED course before to investigate the effect of the TIMeR specifically on them. We would be focusing on the advanced learners with a conjecture that most of the advance learners should fall in the category of medium and high-performers.

6.2 Research Study 4 (ED2)

We repeated the research study ED1 with advanced learners, a sample having formally completed ED course. We followed the same procedure as in ED1. Hence, this study aimed at testing the effectiveness of TIMeR on the ED problem-solving performance of the second-year undergraduate engineering students **with** prior knowledge of ED. For ED2, in addition to RQ2, we address following research question: *"How effective is TIMeR for improving second-year engineering undergraduate students' engineering drawing problem-solving performance?"*

Sample: The participants in this study were 59 undergraduate students from second-year engineering course from an engineering institute in Maharashtra, India. These students have completed the ED course in their previous academic semester. Convenience sampling was used as the recruitment was done on a voluntarily basis.

Study Design and Implementation: The research study design applied for ED2 was single-group pretest-posttest. We followed the same procedure as in ED1.

6.2.1 Quantitative Results (ED2)

In this section, we present results of ED2 at two granularities. First, we provide the results of the effect of TIMeR on the whole class (N=59), and then separately for the different pretest achievement levels (high, medium and low).

6.2.1.1 Effect of TIMeR on all Students

Test of Normality: The Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011), showed that the pretest and posttest data were not normally distributed with p being less than 0.05.

Wilcoxon Signed Rank Test: As the data showed no normal distribution, we chose to perform Wilcoxon Signed-rank test to analyse the significance of the difference between the pretest and posttest performances. Table 6-13 shows the descriptive statistics for N=59, with posttest mean (3.288) being higher than the pretest mean (2.983).

Table 6-13: Descriptive Statistics for All Students (ED2)

Descriptive Statistics					
	N	Mean	Std. Deviation	Minimum	Maximum
Pretest	59	2.983	0.991	1.00	4.00
Posttest	59	3.288	0.947	1.00	4.00

Test Statistics Table: It can be observed from test statistics Table 6-14 that, a Wilcoxon signed-rank test did not show a statistically significant change in posttest performance (p = 0.068) for the students having prior ED knowledge.

Table 6-14: Test Statistics for All Students (ED2)

Test Statistics[b]	
	Posttest, Pretest
Z	-1.823[a]
Asymp. Sig. (2-tailed)	**0.068**

a. Based on negative ranks. b. Wilcoxon Signed Ranks Test

Effect Size: We computed effect size by Cohen's (1988) formula (r = z / square root of N), where N = the number of observations over two-time points, which is two-times the sample size, (Pallant, 2005). However, in this condition, Z = 1.823, and N = 59 x 2 = 118; therefore, r = 0.1678 indicating a small effect size (Cohen, 1988).

Learning gain: To show the students average improvement, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(posttest\ score\ -\ pretest\ score)}{(maxscore\ -\ pretest\ score)} = \frac{(3.288\ -\ 2.983)}{(4\ -\ 2.983)} = \frac{0.305}{1.017} = 0.299$$

Students demonstrated an average gain of 0.305 (i.e. 7.625 percentage) score out of a potential 1.017 (i.e. 25.425 percentage) score that they could have gained. Thus, they gained 0.299 (or 29.90 %) of the possible percentage scores they could have gained from pretest to posttest assessment. (Note: The *maxscore* in this case is 4, therefore to convert into percentage score the numerator and denominator was multiplied by 25 i.e. 0.305x25 = 7.625, and 1.017x25 = 25.425). The overall results show that posttest performance of students is higher than pretest and the difference is statistically not significant (p=0.068) with small effect size (r=0.1678)

(Cohen, 1988) and a positive gain (29.9 %). To go deeper, we did the same analysis separately for the students at different (pretest) achievement levels as low, medium, and high.

Ranks Table: In Table 6.15 we can see that 13 participants had a higher Pretest Score than Posttest Score. However, 23 participants had a higher posttest score compared to pretest score; and 23 participants saw no change in their pretest and posttest score. At this point, we postulate that the students with negative ranks are likely to fall into the groups other than low-performers. We examine this in the next section.

Table 6-15: Ranks Table for All Students (ED2)

Ranks				
		N	Mean Rank	Sum of Ranks
Posttest and Pretest	**Negative Ranks**	13[a]	16.96	220.50
	Positive Ranks	23[b]	19.37	445.50
	Ties	23[c]		
	Total	59		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

6.2.1.2 Effect of TIMeR on Students with Different achievement levels

The minimum and maximum achievable score for the pretest is zero and four respectively. The different achievement levels were formed in a same way to ED1. So, we get three achievement levels as low (0, 1), medium (2), and high (3, 4).

Wilcoxon Signed Rank Test: We performed Wilcoxon signed-rank test for each level. Table 6-16 shows the descriptive statistics for the group of students with different achievement levels.

Table 6-16: Descriptive Statistics: Students with Different Achievement Levels (ED2)

Descriptive Statistics						
Pretest Achievement Level		N	Mean	Std. Deviation	Minimum	Maximum
Low- performers	**Pretest**	7	1.000	0.000	1.000	1.000
	Posttest	7	2.857	1.214	1.000	4.000
Medium- performers	**Pretest**	8	2.000	0.000	2.000	2.000
	Posttest	8	3.500	0.925	2.000	4.000
High- performers	**Pretest**	44	3.477	0.505	3.000	4.000
	Posttest	44	3.318	0.909	1.000	4.000

Ranks Table: In Ranks Table 6.17 we can see from the table's legend that, in a **low-performers'** group, zero participants had a higher Pretest Score than Posttest Score. However, 6 participants had a higher Posttest Score compared to Pretest Score; and one participant saw no change in their Pretest and Posttest Score. In a **medium-performers'** group, zero participants had a higher Pretest Score than Posttest Score. However, 6 participants had a higher Posttest Score compared to Pretest Score; and 2 participants saw no change in their Pretest and Posttest Score. In a **high-performers'** group, 13 participants had a higher Pretest Score than Posttest Score. However, 11 participants had a higher Posttest Score compared to Pretest Score; and 20 participants saw no change in their Pretest and Posttest Score. Based on these results we can see that our earlier postulation of negative rank students falling into the groups other than low-performers was correct. However, in this case, only high-performers have negative ranks.

Table 6-17: Ranks Table for the Students with Different Achievement Levels (ED2)

Pretest Achievement Level			N	Mean Rank	Sum of Ranks
Pretest and Posttest	**Low Performers**	Negative Ranks	0[a]	0.00	0.00
		Positive Ranks	6[b]	3.50	21.00
		Ties	1[c]		
		Total	7		
	Medium Performers	Negative Ranks	0[a]	0.00	0.00
		Positive Ranks	6[b]	3.50	21.00
		Ties	2[c]		
		Total	8		
	High Performers	Negative Ranks	13[a]	14.19	184.50
		Positive Ranks	11[b]	10.50	115.50
		Ties	20[c]		
		Total	44		

a. Posttest < Pretest
b. Posttest > Pretest
c. Posttest = Pretest

Test Statistics Table: It can be observed from the Table 6-18 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance of the low and medium performers (with p=0.026, and p=0.014) respectively; and showed no significant change for the high-performers.

Table 6-18: Test Statistics for the Students with Different Achievement Levels (ED2)

Test Statistics[b]			
	Pretest, Posttest		
Pretest Achievement Level	**Low-performers**	**Medium-performers**	**High-performers**
Z	-2.232[a]	-2.449[a]	-1.061[b]
Asymp. Sig. (2-tailed)	**0.026**	**0.014**	0.289

a. Based on negative ranks.
b. Based on positive ranks
c. Wilcoxon Signed Ranks Test

Effect size: We computed effect size by Cohen's (1988) formula (r = z / square root of N), where N = the number of observations over two-time points, and to determine the effect size we used Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect. However, in the first condition, for low-performers Z = 2.232, and N = 7 x 2 = 14; therefore, r = 0.5965 indicating a large effect size. In the second condition, for medium-performers Z = 2.449, and N = 8 x 2 = 16; therefore, r = 0.6122 indicating large effect size. In the third condition, for high-performers Z = 1.061, and N = 44 x 2 = 88; therefore, r = 0.1131.

Learning gain: To show the students average improvement for each achievement level, we calculated the average gain as (Marx & Cummings, 2007):

For low-performers $g = (2.857 - 1.00) / (4 - 1.00) = (1.857) / (3.00) = 0.619$

For medium-performers $g = (3.50 - 2.00) / (4 - 2.00) = (1.50) / (2.00) = 0.75$

For high-performers $g = (3.318 - 3.477) / (4 - 3.477) = (-0.159) / (0.523) = -0.304$

Low-performers demonstrated an average gain of 1.857 (i.e. 46.425 percentage) score out of a potential 3.00 (i.e. 75.00 percentage) score that they could have gained. Thus, they gained 0.619 (or 61.90 %) of the possible percentage scores they could have gained from pretest to posttest assessment. Similarly, medium-performers gained 0.75 (or 75.00 %) of the possible percentage scores they could have gained. However, high-performers showed no positive gain, they showed a gain of -0.304. (Note: The *maxscore* in this case is, therefore to convert into percentage score the numerator and denominator was multiplied by 25 i.e. for low-performers 1.857x25 = 46.425, and 3.00x25 = 75.00).

The deeper results show that for low-performers, posttest is higher than pretest and the difference is statistically significant (p=0.026) with large effect size (r=0.5965) and a positive gain (g=0.619). For medium-performers, posttest is higher than pretest and the difference is statistically significant (p=0.014) with large effect size (r=0.6122) and a positive gain (g=0.75). For high-performers even though posttest is lower than pretest the difference is not statistically significant (p=0.289). The reason for high-performers not showing positive improvement could be a ceiling effect (Rifkin, 2005). We infer that TIMeR was more effective for the improvement of ED problem-solving performance for the low and medium-performers as compared to the high-performers when they have prior ED knowledge. However, majority of the students are high-performers.

6.2.2 Qualitative Results (ED2)

Analysis of Focus Group Interview

Eleven students volunteered for the focus group interview (FGI). We followed same content analysis procedure as section 4.5. In Table 6-19 we present the findings of FGI, where the first column is student number, second is the transcription of students' responses, third is the inference that we drew, and the last one denotes the codes. We applied same coding scheme as in ED1.

Table 6-19: Focus Group Interview (ED2)

ID	Students' response	Learning Difficulties, TIMeR Benefits, Other	Codes
Q.	**Talk about your experience of solving the first test BEFORE the Blender training. What were the difficulties did you face in solving the test problems?**		
All	Mixed reactions, orthographic was bit easy but isometric was difficult.		
S5	Since it was 3D, it was little more difficult.	Difficulty in 3D visualization	VISUALIZE
S3	It was time-consuming, and it required lots of time for analysing the 3D.	Time consuming	Other-3
S9	The allotted time was not sufficient for applying the logic.	Time consuming	Other-3
S5	Exam point of view as well as while drawing our practice sheets, it was difficult to put that front on the isometric plane which is 30 degrees inclined, we have to put those views on those planes. It is not that simple as we have to draw slots and little-little details involved in that drawing. So, it was a little bit difficult to visualize in 3D. You are given a drawing which	Difficulty in visualizing and constructing a 3D view from orthographic drawings.	VISUALIZE-1

	is given in 2D, which is not that detailed, but when we go for the 3D details, visualization for the first time we were doing this subject, we were doing …. that was difficult, to visualize ... to join the lines in orthographic was a bit simple in that. In three dimension you have to imagine that object actually in your mind, and then you have to draw it.		
S3	Drawing the round shapes in isometric is a bit challenging as the original shape is circular and round, that looks ellipse-like shape in isometric. …… part of a drawing curve shapes.	Difficulty in identifying and interpreting shapes of an object	SHAPES-1
		Difficulty in making the drawings	OTHER-4
S1	Isometric, it was difficult to draw an isometric. It was difficult to understand an object.	Difficulty in Identifying and analysing different views	VIEWS-1
		Difficulty in identifying and interpreting shapes of an object	SHAPES-1
S2	While drawing the curved shapes, like if it is a semicircle, then it was a bit difficult to convert into isometric. It was quite easy to imagine in the initial part, but then drawing was bit challenging, mainly the curve shapes.	Difficulty in identifying and interpreting shapes of an object	SHAPES-1
S3	I face difficulty while drawing the object on a sheet by imagining. Whether the slot is correct …., the curve is correct …., by matching everything getting it into that view and with the dimensions.	Difficulty about visualizing 3D objects	VISUALIZE
		Difficulty in making the drawings	OTHER-4
S4	While drawing circles, adding those diagonals…	Difficulties about the shapes of an object	SHAPES
S6	Hidden parts, it is when we try to observe those and when we actually try drawing it; where and how they look like inside the object is difficult to understand at the first moment. Which part of the dotted lines lies inside, and which lies outside, that I could not understand.	Difficulties about hidden surfaces and hidden lines	HIDDEN
S4	Particularly depth	Difficulty about visualizing 3D objects	VISUALIZE
S6	I could not understand about the slots that lie in the middle of the full view.	Difficulty in identifying and interpreting shapes of an object	SHAPES-1
S7	Mainly I face the same problem, sir, the dotted lines in the orthographic views creates a problem for me while drawing it in isometric view. Also, while converting circular shapes to isometric, it looks easy when we see in the tool (Blender), but it becomes tougher while drawing it.	Difficulties about hidden surfaces and hidden lines	HIDDEN
		Difficulties about the shapes of an object	SHAPES
		Difficulty in making the drawings	OTHER-4
S8	In ortho, it is possible to join front view and top view at their positions. But I face problem while drawing it.	Difficulty in making the drawings	OTHER-4
S9	Suppose there is a semicircle followed by a curve, then in a side view it looks like a rectangle, in front view also it looks like a rectangle. Therefore, to identify whether it's a circle or semicircle it requires a top view. If it is not given then there, then it is difficult to understand whether it's a circle or a semicircle.	Difficulty in Identifying and analysing different views	VIEWS-1
		Difficulties about the shapes of an object	SHAPES
S10	When we draw and have to consider the depth, so its bit difficult to understand about how much depth is to be considered, and where and what part it is to be considered.	Difficulty about visualizing 3D objects	VISUALIZE
S11	Sir, the problem is with the dotted lines.	Difficulties about hidden surfaces and hidden lines	HIDDEN
Q	**Do you believe that intervention of Blender like software and this kind of training for these topics will be useful in learning Engineering Drawing?**		
All- s	Yes		
S7	It is a good thing for someone who cannot visualize. Because like everyone here has said the major problem lies in the	Cognitive - Skill of visualizing 3D Objects by rotation	C4

	hidden lines, i.e., dotted lines. Just now when we saw (referring to the training activity) that time, it was showing it correctly.	Cognitive - Skill of identifying and visualizing hidden lines and surfaces	C6
S6	If we rotate the 3D view, then we can view all the four sides… we can draw it directly… I mean we could understand easily and in less time. Otherwise, it is not easy to understand. At first it is not easy to understand the 3D view or side view of the 3D view, but it gets clear after doing the rotation	Cognitive - Skill of visualizing 3D Objects by rotation	C4
Q	**Did you find any differences between the way you solved the two tests? One before the training and the other after the training, as you already have learned the subject before.**		
S1	Before the training, it was not completely clear about how to observe the dotted lines.	Cognitive - Skill of identifying and visualizing hidden lines.	C6
S3	Before training the concept of the dotted line was known, but we were not able to explain it. It was difficult to explain the process of drawing the answer in the first test. But later after using Blender and then solving the test, it was much easier to explain it.	Cognitive - Skill of identifying and visualizing hidden lines. Cognitive – conceptual understanding. Cognitive - Identification of relevance of the visualization to problem-solving process	C6 C7 C7
S9	The later test took lesser time to solve than compared to the earlier one.	Cognitive – lesser time to solve the posttest.	C7
S10	In the first test, we knew lesser ways of observing the given object. But, in posttest, we got to know about observing the object from all the sides, and accordingly, we solved the test.	Cognitive - Skill of visualizing 3D Objects by rotation Cognitive - Identification of relevance of the visualization to problem-solving process	C4 C7
Q	**What were activities from the training most helpful in visualizing the object?**		
S7	The use of keys R, X, Y and Z with their combination was simple and easy to remember.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful,	C7
S5	Numpad keys increase the precision, mouse …it trembles and cannot rotate that precisely as compared to the Numpad keys.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful,	C7
S2	It takes less efforts to do it.		
Q	**What do you think would be the right way for the intervention of this workshop with the graphics course: before or during or after the course?**		
All	Before, during – mixed reactions.		
	Also, if the core concepts can be taught with such kind of training, then it will be very helpful for the students. And at the time when the course is introduced.		

It can be seen from the Table 6-19 that, results of the analysis of the focus group interview are identical with the findings of ED1, where the set of ED learning difficulties and training benefits are identical. In summary, students mentioned that:

- With the help of training activities, it was easier to visualize object in 3D, that helped in solving the problem clearly.
- It was easier to visualize all views clearly, specifically orthographic views.

- Students also mentioned that they rotated object for solving the problem in posttest
- They also applied rotation for joining the views to construct an isometric view.
- It would have been more beneficial to have such training at the beginning of the ED course while learning the concepts.

6.2.3 Summary of Results of ED2

Table 6-20 provides the summary of quantitative results of ED2 for overall class and for different pretest achievement level.

Table 6-20: Summary of Results (ED2)

	ED2			
	Overall	**Low**	**Medium**	**High**
N	59	7	8	44
Pretest mean	2.983	1.000	2.000	3.477
Posttest mean	3.288	2.857	3.500	3.318
P	0.068	**0.026**	**0.014**	0.289
Effect size r	0.167 (small)	0.596 (large)	0.612 (large)	0.113
Learning gain	0.299	0.619	0.75	-0.30

From Table 6-20 we can see that only 7 out of 59 students (i.e. 11.9%) fell in the low-performers group. In fact, low and medium-performers together form only 25% (15 out of 59) of the whole sample, and 75% fell in the high-performers. It was contrary to the experiences in the previous studies MR1, MR2 and ED1, where the high-performers were just 28%, 9% and 34% of the total sample, respectively. This shows that our decision of choosing "advanced learners" as a sample to study more about the high-performers, was right. The results, however for very small sample size seven, again corroborate the findings of ED1 by showing that the low-performers' performance improved significantly.

This time the medium-performers have shown significant improvement, which is an encouraging result about the effect of TIMeR. On the other hand, the 44 high-performers did not show any significant increase or decrease in their performance. This has again strengthened

the claim that TIMeR pedagogy is effective for the low-performers and not particularly effective for the high-performers.

The analysis of the focused group interview re-validated the identified difficulties that the students face during solving ED problems and the identified benefits of the TIMeR pedagogy. It should be noted that this re-validation comes from a cohort of advanced learners, who already have the prior knowledge of ED.

All of the previous studies have consistently shown that TIMeR has no effect on the performance of the high-performers. This may be due to two possible reasons: (i) either TIMeR pedagogy really does not have any effect on the high-performers, or (ii) the assessment items are too simple to gaze the effect on them. In the next study, we explore the second reason. We would repeat the same procedure with a new set of post-test items. These posttest items are more difficult to be answered, as the students would not be given any choices. Instead, they would have to draw the correct answer (front, side, and top views) corresponding to the given isometric view of 3D objects.

6.3 Research Study 5 (ED3)

The purpose of this study is to investigate the effectiveness of the TIMeR on ED problem-solving skills of students with prior knowledge of ED. The only difference between ED2 and ED3 is that, we have used a different assessment instrument where the questions need to be answered in the form of making drawings. For example, students are shown an isometric view of an object and have to draw various orthographic views for the same (Appendix IV). For the study ED3, we followed the same procedure as in ED1 and ED2.

Sample: The participants in this study were 38 undergraduate students from second-year engineering course from an engineering institute in Maharashtra, India. These students have completed the ED course in their previous academic semester. Convenience sampling was used as the recruitment was done on a voluntarily basis.

Study Design and Implementation: The research study design applied for ED2 was single-group pretest-posttest. We followed the same procedure as in ED1 and ED2.

Instrument: We used questions from the standard ED exercise books (Earle, 1967, 1968, 1969; Sorby & Wysocki, 2003). The pretest and the posttest were equivalent and were comprised of three questions each, which has the following format:

1. For a given isometric view, draw all six views (The front view, top view, right-side view, left-side view, back view, and bottom view). (One mark for each correct view, total six marks). A sample question is shown in Figure 6-5.
2. For a given set of orthographic views, draw an isometric view (One mark), and
3. For a given isometric view and two orthographic views, draw the missing view (One mark). (For the complete set of tests, see Appendices IV, V).

Students drawings were evaluated by comparing with the standard solutions.

Data Collection: We collected the data in the following forms: (1) Students' performance scores on pretest with solutions as drawings. (2) Students' performance scores on posttest with solutions as drawings. (3) To get insight on students' perception of the effect of TIMeR, we conducted the focus group interview session in which ten volunteers participated.

Figure 6-5: ED Sample Test Item (Drawing), reproduced from Sorby & Wysocki (2003)

Exercise 1A: Orthographic. SIX View Sketching
Instructions : Sketch SIX orthographic views of the object shown below.
Six views are: TOP, BOTTOM, FRONT, BACK, LEFT, RIGHT.

Practice item

Front
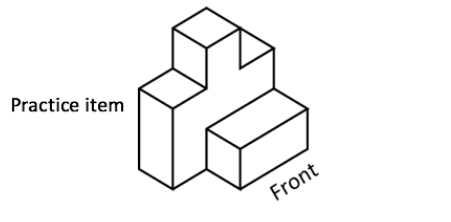
Data analysis procedure: We followed the same data analysis procedure of as ED1 and ED2, to determine the effect of the TIMeR session on students' ED problem-solving performance. We performed quantitative analysis of the pretest and posttest for all 38 students. First, we performed normality test and based on the results we chose to use Wilcoxon Signed Rank Test to see how significant the improvement in students' scores are. For our analysis, we use the significance level 0.05 (5%). We also determined the effect size of the improvement and computed average gain (Marx and Cummings, 2007) for all 38 students. To look into the effects at a more granular level, we also performed the same analysis separately for the students at different pretest-achievement levels (low, medium, and high).

For the qualitative analysis, we followed the same procedure as ED2. We transcribed the focus group interview and performed the content analysis.

6.3.1 Quantitative Results (ED3)

In this section, we present results of ED3 at two granularities. First, we provide the results of the effect of TIMeR on the whole class (N=38), and then separately for the different pretest achievement levels.

6.3.1.1 Effect of TIMeR on All Students

Test of Normality: The Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011), showed that the pretest and posttest data were not normally distributed with p being less than 0.05.

Wilcoxon Signed Rank Test: As the data showed no normal distribution, we chose to perform Wilcoxon Signed-rank test to analyse the significance of the difference between the pretest and posttest performances. Table 6-21 shows the descriptive statistics for N=38, with posttest mean (3.763) being higher than the pretest mean (2.815).

Table 6-21: Descriptive Statistics for All Students (ED3)

Descriptive Statistics					
	N	Mean	Std. Deviation	Minimum	Maximum	Maximum achievable score
Pretest	38	2.815	1.248	0.00	4.00	8
Posttest	38	3.763	1.699	0.00	7.00	8

Test Statistics Table: It can be observed from Table 6-22 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance (with p=0.001).

Table 6-22: Test Statistics for All Students (ED3)

Test Statistics[b]	
	Posttest, Pretest
Z	-3.371[a]
Asymp. Sig. (2-tailed)	**0.001**

a. Based on negative ranks, b. Wilcoxon Signed Ranks Test
b. Wilcoxon Signed Ranks Test

Effect Size: Since the posttest performance was higher than the pretest, we computed effect size by Cohen's (1988) formula (r = z / square root of N), where N = the number of observations over two-time points, which is two-times the sample size, (Pallant, 2005). However, in this condition, Z = 3.371, and N = 38 x 2 = 76; therefore, r = 0.3866 indicating a medium effect size using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect.

Learning Gain: To show the students average improvement, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(posttest\ score - pretest\ score)}{(maxscore - pretest\ score)} = \frac{(3.763 - 2.815)}{(8 - 2.815)} = \frac{0.948}{5.185} = 0.182$$

Students demonstrated an average gain of 0.948 (i.e. 11.85 percentage) score out of a potential 5.185 (i.e. 64.81 percentage) score that they could have gained. Thus, they gained 0.182 (or

18.20 %) of the possible percentage scores they could have gained from pretest to posttest assessment. (Note: The *maxscore* in this case is 8, therefore to convert into percentage score the numerator and denominator was multiplied by 12.5 i.e. 0.948x12.5 = 11.85, and 5.185x12.5 = 64.81).

The overall results show that posttest performance of students is higher than pretest and the difference is statistically significant (p=0.001) with medium effect size (r=0.3866) (Cohen, 1988) and a positive gain (18.2 %). To go deeper, we did the same analysis separately for the students at different (pretest) achievement levels as low, medium, and high.

Ranks Table: In ranks Table 6.23 we can see from the table's legend that 5 participants had a higher Pretest Score than Posttest Score. However, 22 participants had a higher posttest score compared to pretest score; and 11 participants saw no change in their pretest and posttest score. At this point, we postulate that the students with negative ranks are likely to fall into the groups other than low-performers. We examine this in the next section.

Table 6-23: Ranks Table for All Students (ED3)

Ranks				
		N	Mean Rank	Sum of Ranks
Posttest and Pretest	**Negative Ranks**	5[a]	10.50	52.50
	Positive Ranks	22[b]	14.80	325.50
	Ties	11[c]		
	Total	38		

a. Posttest < Pretest, b. Posttest > Pretest, c. Posttest = Pretest

6.3.1.2 Effect of TIMeR on Students with Different Achievement Levels

The minimum and maximum achievable score for the pretest is zero and eight respectively. In order to decide the three achievement levels based on the pretest score, we formed three clusters by dividing maximums score (eight) with desired levels (three). It resulted into three ranges of scores that are between 0 to 2.66, between 2.67 to 5.33, and between 5.34 to 8. These values were used to define different achievement levels. So, we get three achievement levels as low (0, 1, 2), medium (3, 4, 5), and high (6, 7, 8). We call students from each level as, low-performers, medium-performers, and high-performers. However, no student scored in the range of high achievement level i.e., 6, 7, or 8 marks.

Wilcoxon Signed Rank Test: We performed Wilcoxon signed-rank test for each level. Table 6-24 shows the descriptive statistics for the group of students with different achievement levels.

Table 6-24: Descriptive Statistics: Students with Different Achievement Levels (ED3)

Descriptive Statistics						
Pretest Achievement Level		N	Mean	Sd	Minimum	Maximum
Low-performers	**Pretest**	12	1.250	0.866	0.000	2.000
	Posttest	12	2.833	1.466	0.000	4.000
Medium-performers	**Pretest**	26	3.538	0.508	3.000	4.000
	Posttest	26	4.231	1.582	1.000	7.000

Ranks Table: In Ranks Table 6.25 we can see from the table's legend that, in a **low-performers'** group, zero participants had a higher Pretest Score than Posttest Score. However, 10 participants had a higher Posttest Score compared to Pretest Score; and 2 participants saw no change in their Pretest and Posttest Score. In a **medium-performers'** group, 5 participants had a higher Pretest Score than Posttest Score. However, 12 participants had a higher Posttest Score compared to Pretest Score; and 9 participants saw no change in their Pretest and Posttest Score. Based on these results we can see that our earlier postulation of negative rank students falling into the groups other than low-performers was correct. However, in this case, only medium-performers have negative ranks, and there are no high-performers.

Table 6-25: Ranks Table for the Students with Different Achievement Levels (ED3)

Pretest Achievement Level		Ranks			
			N	Mean Rank	Sum of Ranks
Pretest and Posttest / **Low Performers**	Negative Ranks		0[a]	0.00	0.00
	Positive Ranks		10[b]	5.50	55.00
	Ties		2[c]		
	Total		12		
Medium Performers	Negative Ranks		5[a]	6.30	31.50
	Positive Ranks		12[b]	10.13	121.50
	Ties		9[c]		
	Total		26		

a. Posttest < Pretest

b. Posttest > Pretest

c. Posttest = Pretest

Test Statistics Table: It can be observed from the Table 6-26 that, a Wilcoxon signed-rank test showed a statistically significant change in posttest performance of the low-performers and also for the medium-performers (with p=0.002, and p=0.030). We can infer that TIMeR was effective for the improvement of the ED performance for the both the low and medium-performers.

Table 6-26: Test Statistics for the Students with Different Achievement Levels (ED3)

Test Statistics[b]		
	Pretest, Posttest	
Pretest Achievement Level	**Low-performers**	**Medium-performers**
Z	-3.051[a]	-2.167[a]
Asymp. Sig. (2-tailed)	**0.002**	**0.030**

a. Based on negative ranks. b. Wilcoxon Signed Ranks Test

Effect Size: We computed effect size by Cohen's (1988) formula ($r = z$ / square root of N), where N = the number of observations over two-time points, and to determine the effect size we used Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect. However, in the first condition, for low-performers Z = 3.051, and N = 12 x 2 = 24; therefore, r = 0.6227 indicating a large effect size. In the second condition, for medium-performers Z = 2.167, and N = 26 x 2 = 52; therefore, r = 0.3005 indicating medium effect size.

Learning Gain: To show the students average improvement for each achievement level, we calculated the average gain as (Marx & Cummings, 2007):

For low-performers $\quad$ g = (2.833 - 1.250) / (8 – 1.250) = 1.583 / 6.75 = 0.234
For medium-performers g = (4.231 – 3.538) / (8 – 3.538) = 0.693 / 4.462 = 0.155

Low-performers demonstrated an average gain of 1.583 (i.e. 12.66 percentage) score out of a potential 6.75 (i.e 84.37 percentage) score that they could have gained. Thus, they gained 0.234 (or 23.40 %) of the possible percentage scores they could have gained from pretest to posttest assessment. Similarly, medium-performers gained 0.155 (or 15.50%) of the possible percentage scores they could have gained. Thus, it can be seen that TIMeR was effective for both the low and medium-performers. (Note: The *maxscore* in this case is 8, therefore to convert into percentage score the numerator and denominator was multiplied by 12.5 i.e. for low-performers 1.583x12.5 = 12.66, and 6.75x12.5 = 84.37).

The deeper results show that for low-performers, posttest is higher than pretest and the difference is statistically significant (p=0.002) with large effect size (r=0.6227) and a positive gain (g=0.234). For medium-performers, posttest is higher than pretest and the difference is statistically significant (p=0.030) with medium effect size (r=0.3005) and a positive gain (g=0.155). We infer that TIMeR was more effective for the improvement of ED problem-solving performance for the low and medium-performers when they have prior ED knowledge and when the more difficult test items are given.

6.3.2 Qualitative Results (ED3)

Analysis of Focus Group Interview

Eleven students volunteered for the focus group interview (FGI). We followed same content analysis procedure as ED2. In Table 6-27 we present the findings of FGI, where the first column is student number, second is the transcription of students' responses, third is the inference that we drew and the last one denotes the codes. We applied the same coding scheme as in ED1.

It can be noted from the Table 6-27 that, for example, student S11 mentioned that he was not able to visualize efficiently before the training, but after the training and posttest, he said that he learned how to imagine in a better way because of the tool. Student S1 mentioned that it was difficult to visualize the hidden lines and different views before the training, but after training and posttest, he said that he learned how to visualize hidden lines and views.

The student S6 mentioned that, while converting orthographic into isometric, he was not able to imagine the isometric before training, but after the training he learned more ways of visualizing the object. So, it can be seen that the treatment helped students in resolving their difficulties.

The analysis of the focused group interview has again validated the findings of the previous qualitative studies in ED1 and ED2. Hence the analysis of focus group interview confirms our findings from the reflective journals of ED3.

Table 6-27: Focus Group Interview (ED3)

ID	Students' response	Difficulties / Benefits / Other	Codes
Q	**Students were asked to reflect on their experience of solving pretest (and then posttest), and also to reflect on the difficulties if they have faced.**		
S3	It was a bit difficult for imagination.	Difficulty in visualization	VISUALIZE
S2	Here we were not having the proper perspective in the earlier view. Later on, by viewing a 3D view that is isometric view in the software, the views got more clear. You can get angle and perspective more clearly by moving which side is right or left or top, and the perspective from which angle and of what length, it clarifies. The software clarifies this, and it helped us in visualization.	Difficulty in visualizing perspective view. Cognitive - Skill of identifying and visualizing different views	VIEWS-1 C1, C3
S4	While going from orthographic to an isometric arrangement of the first view with respect to the other views, like the front view and top view side view was difficult. We could not imagine the actual object.	Difficulty in visualizing and constructing a 3D view from orthographic drawings.	VISUALIZE-1
S9	While writing the steps of converting isometric to orthographic what happened was that I wrote those steps in detail, almost for a page. But after working on the software and after learning this session the steps for the last drawing problem were less as compared to the earlier steps. Before using the software when we were supposed to write steps by describing each and every smallest step such as I saw it from this angle, I saw it from that angle, I draw that view et cetera, that's how we wrote the steps. After using this software, I could imagine that there are other possibilities of looking at the same object so as to make the drawing.	Cognitive - Identification of relevance of the visualization to problem-solving process Cognitive - Learnt visualization skills Cognitive - Applying training skills for solving tests	C7
S5	Before the training when I had to draw isometric view based on the orthographic views I made the drawings without imagining it, but while I was using the software I could see the accuracy and detailing in the object	Cognitive - Skill of visualizing an object	C3
S11	Before using this software, I was not able to imagine that much. Maybe because of the gap of six months I was not able to imagine efficiently. As I kept on solving the question I was able to imagine bit more. But after using the software, I could imagine completely.	Difficulty in visualization. Cognitive - Learnt visualization skills	VISUALIZE C7
S1	It was difficult to view or visualize hidden lines. Before using the software, I could not see the hidden sides, like back view, the bottom view and other side views. By using the software, we can see they all six views.	Difficulty in visualizing hidden lines and surfaces. Cognitive - Skill of visualizing hidden lines and hidden surfaces.	HIDDEN-1 HIDDEN-2 C6
S9	There was a difficulty in imagining the bottom view.	Difficulty in visualizing the hidden surfaces.	HIDDEN-2
S10	While converting from orthographic to isometric, there was a difficulty with the slanted edges, also it was problematic to show the extended part in the front.	Difficulty about the shapes of an object.	SHAPES-1
S6	While converting orthographic into isometric, I couldn't imagine the isometric; I mean that is before using the software. So, after using the software, I got to know more ways of how to imagine the object.	Difficulty in visualizing and constructing a 3D view from orthographic drawings. Cognitive - Skill of visualizing different views	VISUALIZE-1 C3, C7
S9	At first, it was not easy to visualize the various views of the isometric drawing, like side views and all. It was not clear about from where to look at the object. Sir, in the first problem where the front view and isometric views were given, and we were supposed to draw a top view, and side view was also given; the front view was given and also the isometric view was given. At first, I was	Difficulty in analysing different views. Difficulty in visualizing different views	VIEWS-1 VIEWS-2

	not able to visualize where to look at the front view or side view. So that is why at least I felt problem while drawing the top view.		
Q	**What activities from the training were most helpful in visualizing the object?**		
S7	Rotation about the axis, by doing this now I have got more clarity about how does each view look like. How does exactly top view look like, how to locate hidden lines. For me, I was not able to understand the right-side view, but now by doing rotations, I could clearly understand it.	Cognitive – skill of identifying different views Cognitive – skill of identifying and visualizing hidden lines. Cognitive – skill of visualizing by rotation	C1 C6 C4
S4	The main difficulty is to visualize an object, and that is while drawing an isometric view based on the given orthographic views. But by using such techniques, I think it is much more convenient to have a better visualization, mainly by performing the rotation or using different key functions, that can help in more ways.	Difficulty in visualizing and constructing a 3D form from a 2D drawing Cognitive – skill of visualizing by rotation Cognitive- Applying training skills for solving tests	VISUALIZE-1 C4 C7
S11	Because of the rotation, it is possible to see both the sides or more views at the same time.	Cognitive – skill of visualizing by rotation	C4
S9	Normally I used to draw the front view from the right-side direction only; even while drawing an isometric, but now I can visualize it from both the sides.	Cognitive - Skill of identifying different views Cognitive- Applying training skills for solving tests	C1 C7
S4	While drawing the isometric view, I tried to create its image in my mind, and I was able to create it up to 90 to 95 percent.	Cognitive- Applying training skills for solving tests	C7
Q. What do you think would be the right way for the intervention of this workshop with the graphics course: before or during or after the course?			
All	during		

6.3.3 Summary of Results ED3

Table 6-28 provides the summary of quantitative results of ED for overall class and for different pretest achievement level.

Table 6-28: Summary of Results (ED3)

	ED3			
	Overall	**Low**	**Medium**	**High**
N	38	12	26	0
Pretest mean	2.815	1.25	3.538	-
Posttest mean	3.763	2.833	4.231	-
P	**0.001**	**0.002**	**0.030**	-
Effect size r	0.386 (medium)	0.622 (large)	0.300 (medium)	-
Learning gain	0.182	0.234	0.155	-

This study has revealed a new result about the effect of TIMeR on the advanced learners. The quantitative result shows a significant positive effect of the TIMeR pedagogy on these learners. It should be noted that the low, medium and high-performers are stratified using the pretest scores, and we did not get any student in the high-performers category. This shows that the new assessment instrument is difficult for all of the participants.

The primary objective of the current study (ED3) was to examine the effect of TIMeR on the high-performers. But the high-performers that we are interested in are those who are high-performers according to the original assessment instrument (i.e. multiple choice questions - MCQ), and not according to the new instrument (i.e. drawing questions). We cannot use the original instrument (MCQ) as the pretest in the current study, because we needed to keep both post and pretest instruments equivalent. Therefore, the only way to comment on the effect of TIMeR on the high-performers was to use the finding (from the ED2) that most (75%) of the advanced learners fell in the high-performers category. With this we can comfortably assume that the current advanced learners should have mostly fallen into the high-performers category, had there been the original assessment instrument used in the pretest. So, we use the results for all of the advanced learners in ED3 to comment on the effect of TIMeR on the high-performers.

The significant positive effect of the TIMeR pedagogy on these advanced learners shows that TIMeR has positive effects on the ED performance of even high-performers, but the effects on them is evident only when we use a difficult pretest and posttest assessment instruments.

The analysis of the focused group interview has again validated the findings of the previous qualitative studies in ED1 and ED2.

The experimental studies ED1, ED2, and ED3 had certain limitations such as lack of a control group or having no comparison group. Though we have significant results for single group pretest-posttest research design, comparison with the other group couldn't be done. We also have not tested the effect of TIMeR when incorporated in the ED course. We address these limitations in study ED4, the details are provided in the next chapter.

Chapter 7

Incorporation of TIMeR in ED Course

In previous sections, through results of studies MR1 and MR2, we showed that TIMeR was effective for improving students' MR skills. Similarly, the results of studies ED1, ED2, and ED3 showed that TIMeR was also effective for improving students' ED problem-solving performance.

In this chapter, we provide details of the incorporation of TIMeR in ED course. Similar to ED1, we have selected orthographic projection and isometric projection as the topics of interest from ED. The conventional teaching of these topic involves blackboard teaching, demonstration of drawings, and sometimes use of PowerPoint presentation. It requires approximately four classroom hours to teach each of the topics, resulting in the total 8 hours of teaching. To maintain the balance of teaching hours without disturbing the course timetable, we have customized TIMeR structure that can fit into the eight hours of teaching. The eight hours were divided into four sessions, with approximately two hours of teaching in each session on separate days. Therefore, for teaching each topic, two sessions are necessary.

In the Table 7-1, we present the TIMeR structure that is suitable for inclusion in the ED course. Besides, we also revisit the structure of three-hour TIMeR for MR and ED (as given in section 4.11) for comparison.

To evaluate the effectiveness of TIMeR incorporation in ED course, we conducted research study ED4. ED4 research design involved two groups, where one group received TIMeR, and the other group received the conventional teaching of ED. The details of ED4 with our finding are presented in the next section.

Table 7-1: TIMeR Structures

TIMeR	Three-hour TIMeR for MR	Three-hour TIMeR for ED	TIMeR for ED Course
Total Sessions	1	1	4
Duration (hours per session)	~3	~3	~2
Total hours	~3	~3	~8
Timespan (in days)	One day	One day	Four days
No of phases (total tasks)	3 (11)	3 (11)	3 (11)
Instructional strategy	DDP	DDP	DDP
Study design	Single group pretest-posttest	Single group pretest-posttest	Two groups posttest
Total practice items	12	8	22
Pretest (total items)	1 (10)	1 (4)	-
Posttest (total items)	1 (10)	1 (4)	4 (16)
Assessment Instrument	VMRT	SVATI	SVATI, Textbook Problems

7.1 Research Study 6 (ED4)

This study aimed at testing the effectiveness of TIMeR, when incorporated in the ED course, on the ED problem-solving performance of the first-year undergraduate engineering students, who did not have prior knowledge of ED. This study also aims at comparing the results with the students who receive the conventional teaching of ED. We address the same research questions **RQ2**: *"How effective is TIMeR for improving first-year engineering undergraduate*

students' engineering drawing problem-solving performance?", and **RQ3**: *"In what way does TIMeR resolve the learning difficulties that students face while solving the engineering drawing problems?"*

Sample

The participants in this study were 42 undergraduate students from first-year engineering course from an engineering institute in Maharashtra, India. Convenience sampling was used as these were the volunteers for the training.

Study Design and Implementation

The research study design applied for ED4 was two groups with posttests. The groups were created by randomized assignment and named as TIMeR group and Conventional group. The TIMeR is a group of participants who received TIMeR training. A Conventional group is a group of participants who received conventional classroom teaching of ED. The group size was 21 for each group. Three students from TIMeR group and five from the conventional group were not able to attend all the sessions, resulting in the actual group size of 18 and 16 respectively. The details of the procedure for both the groups are given below.

Procedure for the TIMeR Group

Figure 7-1 shows the procedure for the TIMeR group. We conducted two implementations of TIMeR. Both implementations required four sessions of lab hours, i.e., two sessions per implementation. For each implementation, there were two assessments administered, one at the end of the first session, i.e., in the mid of the TIMeR implementation, and second at the end of the second session. The first assessment, i.e., intermediate test (Test1 and Test3) was administered, such that the students can use those items and their responses in phase 3 of the TIMeR (section 4.8). The second assessment was used as the posttest (Test2 and Test4), as it was administered at the end of an implementation. This splitting of the TIMeR implementation in two sessions was done because the study was to be done in an in-situ condition, where in case of the conventional teaching of the same ED topic also requires two sessions of regular lab hours.

Figure 7-1: Instructions for TIMeR Group
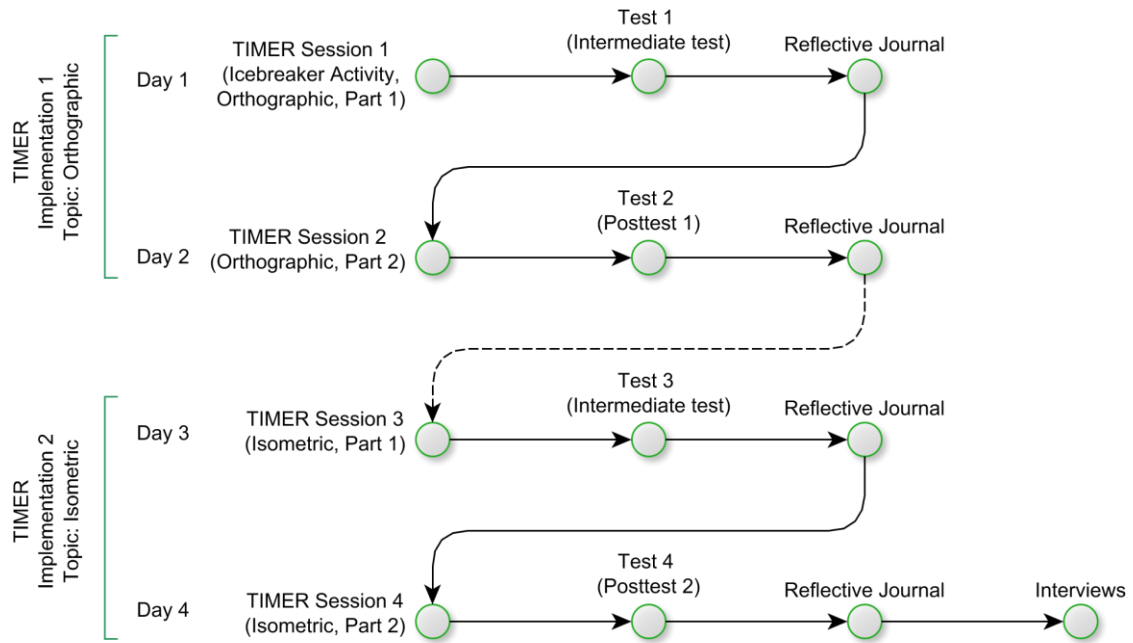
TIMeR Group Implementation Part 1

TIMeR Group Session 1: We started with an icebreaker activity and highlighted the importance of MR in ED. We then executed the preparatory phase of TIMeR, where students learned about Blender user interface. We then introduced the concept of orthographic projection to the students, followed by them getting trained for the training phase of TIMeR. In the training phase, students performed observation and rotation tasks by using 3D models of objects for the topic of orthographic projections. These 3D models were created based on the objects from ED textbook (Bhatt, 2011). These tasks were executed by instruction strategy DDP, where initially the teacher showed the demo, followed by students doing drill and independent practice. The total duration of the session was approximately two hours. At the end of the session, we conducted the intermediate test (Test1), which consisted four test items on orthographic projections, (See Appendix III for Test1 questions).

TIMeR group Session 2: This session was the continuation of TIMeR for orthographic projection. The transfer phase of TIMeR was executed first, where students verified their solutions of Test1 by applying the learnings of training phase from session1. The 3D models of the Test1 items were created and used for this purpose. Each question was discussed by the

instructor for further clarification. Further training phase was repeated with two additional objects from ED textbook (Bhatt, 2011). The total duration of the session was approximately two hours. This session completes the orthographic projection topic. At the end of session, we conducted posttest1 (Test2) equivalent to Test1. (See Appendix III for Test2 questions).

TIMeR group implementation part 2

TIMeR group Session 3: In this session, first, the transfer phase of TIMeR was executed, where students verified their solutions of Test2 by applying the learnings of the previous sessions. The questions and answers were discussed by the instructor for further clarification. Then we explained the concept of isometric projection. The objects of the Test2 items were used for the training purpose along with the two additional objects from ED textbook (Bhatt, 2011). The total duration of this session was approximately two hours. At the end of session, we conducted intermediate test (Test3), with four test items on isometric projections. (See Appendix IIII for Test3 questions).

TIMeR group Session 4: This session was the continuation of TIMeR for isometric projection. Here, first, the transfer phase of TIMeR was executed, where students verified their solutions of Test3 by applying the learnings of the previous sessions. The questions and answers were discussed by the instructor for further clarification. The objects of the Test3 items and two additional objects from ED textbook (Bhatt, 2011) were used for the training purpose. The total duration of the session was approximately two hours. At the end of session, we conducted posttest2 (Test4) equivalent to Test3. (See Appendix III for Test4 questions).

Procedure for the Conventional group

Figure 7-2 shows the procedure for the conventional group. The students of conventional group (N=16) received conventional teaching of ED for four sessions on four separate days, and the duration of each session was approximately two hours. The sessions 1 and 2 were comprised of orthographic projection topic. The sessions 3 and 4 were comprised of isometric projections topic. At the end of every session, we conducted same tests on ED problems. Here also, after each test, we collected students' reflective journals to understand students' reflection on the learning difficulties in ED while solving the tests. Additionally, at the end of all sessions, to triangulate the results we conducted students' interviews.

Figure 7-2: Instructions for Conventional Group
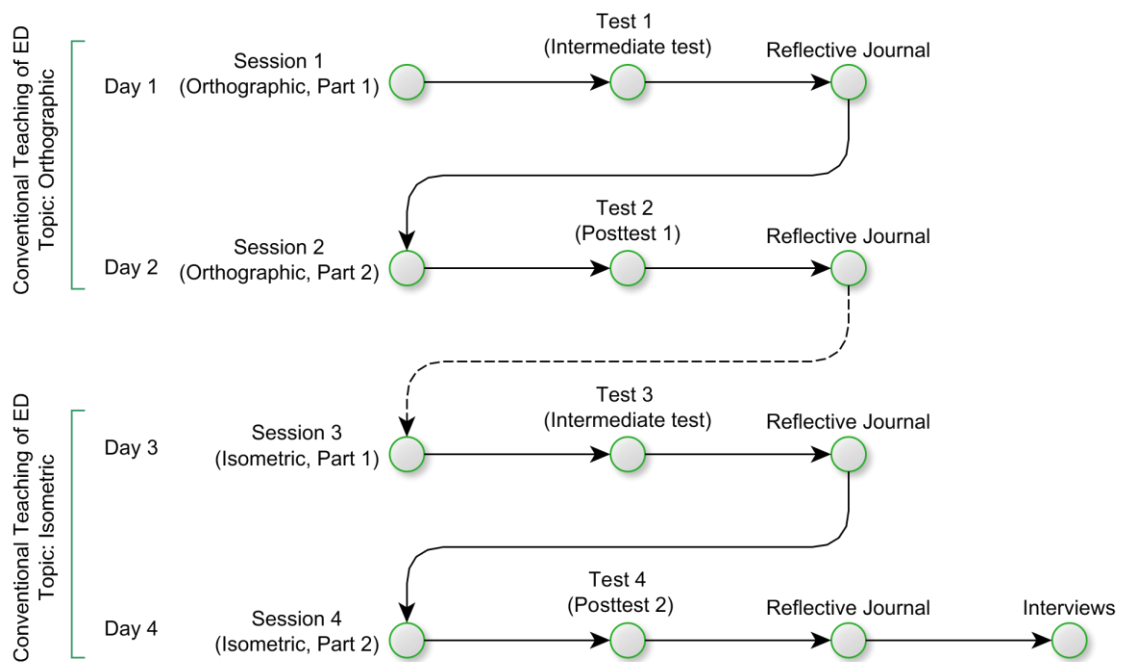
Conventional Group Session 1: At first, the students were introduced to the concept of orthographic projection using blackboard teaching and power-point presentation. It was then followed by explaining the conversion process of the 3D view of an object into its different orthographic views, which was done by showing a worked example. Then students use the same example to understand the process of orthographic projection. After this, the students were required to learn and apply the conversion process for three more objects. The example objects used here are the same objects used for TIMeR group. The total duration of this session was approximately two hours. At the end of this session, we conducted the same intermediate test (Test1), which was used for TIMeR group. After the test, students were asked to write their learning difficulties of the session 1 and the Test1.

Conventional Group Session 2: This session was the continuation of orthographic projection topic and begins with the recap of the previous session. After that, the solutions of the Test1 were discussed with students. The discussion involved verifying students answers and clarifying their doubts by assisting. Further, the students were taught with two more objects as used for TIMeR group. This session completes the orthographic projection topic. The total duration of this session was approximately two hours. At the end of this session, we conducted

the same posttest1 (Test2), used for TIMeR group. Then students were asked to write their learning difficulties of the session 2 and the Test2.

Conventional Group Session 3: This session begins with the recap of session 2 and the discussion of solutions of the Test2. The discussion involved verifying students answers of Test2 and clarifying their doubts about orthographic projection by assisting. Then the students were introduced to the concept of isometric projection using blackboard teaching and power-point presentation. It was then followed by explaining the conversion process of the orthographic views of an object into its isometric view, which was done by showing a worked example. Then students use the same example to understand the process. After this, the students were required to learn and apply the conversion process for three more objects. The example objects used here are same as which were used for TIMeR group. The total duration of the session was approximately two hours. At the end of this session, we conducted the same intermediate test (Test3), which was used for TIMeR group. Then students were asked to write their learning difficulties of the session 3 and the Test3.

Conventional Group Session 4: This session was the continuation of isometric projection topic and begins with the recap of session 3. After that, the solutions of the Test3 were discussed with students. The discussion process is same as used for earlier sessions. Further, the students were taught with two more objects as used for TIMeR group. This session completes the isometric projection topic. The total duration of this session was approximately two hours. At the end of this session, we conducted the same posttest2 (Test4) used for TIMeR group. Then students were asked to write their learning difficulties of the session 4 and the Test4. Additionally, students were asked to participate in the interview session, the purpose of which was to triangulate the findings.

Instrument and Data collection

1) Performance Scores: The data for both the groups was gathered in the form of performance score of tests of ED problems which were based on the Spatial visualization ability test instrument (SVATI), (Alias, 2000) and ED exercise book questions (Earle, 1967; Earle, 1968; Sorby & Wysocki, 2003). Total four tests were conducted, and each test consists of four items. Test1 and Test2 questions were based on the orthographic projections, where for a given isometric view, students must identify the correct set of orthographic views. Test3 and Test4

questions were based on the isometric projections, where for a given set orthographic views, students must identify the correct isometric view. For each correct answer, they get one mark. Test duration was twenty-minute.

2) Reflective Journals: Students data regarding the learning difficulties faced while solving test of each session, was collected in the form of reflective journals immediately after the test. In the reflective journals, students from both the groups were requested to write their learning difficulties. In addition, TIMeR group students were asked to reflect on TIMeR benefits.

3) Semi-structured Interviews: At the end of all sessions, to triangulate our results we also conducted semi-structured interviews with individual participants. Eight participants from TIMeR and four participants from the conventional group volunteered for the interview session.

Data Analysis Procedure

1) Quantitative Analysis: We performed quantitative analysis by first doing the normality test. Since the data showed no normal distribution, to test the differences between two independent groups (TIMeR and Conventional group) we performed the non-parametric Mann-Whitney test. We calculated the means, standard deviations, effect size, and learning gain. To see if there is a significant difference between the performance of two tests for each topic, we also performed Wilcoxon signed rank test within the group for both the groups. For our analysis, we use the significance level 0.05 (5%).

2) Qualitative Analysis: To analyse the reflective journal data and interview data, we followed the same content analysis procedure of ED1, ED2, and ED3.

7.1.1 Quantitative Results (ED4)

In this section, we present results of ED4. First, we provide the results of the effect of TIMeR on TIMeR group (N=18) and its comparison with the conventional group (N=16). Then we investigate the significance within the group for each topic, i.e., orthographic and isometric projection.

Test of Normality: The Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011), showed that the data for both the groups were not normally distributed with p being less than 0.05.

7.1.1.1 Results Between the Groups

First, we provide the means and standard deviations of all the tests for both the groups, then we present the results for the differences between two independent groups on test measures. The means and standard deviations are shown in Table 7-2, where the mean value for all the tests is higher for the TIMeR group than that of the conventional group.

Table 7-2: Descriptive Statistics, Between Groups (ED4)

Topic →	Test Means			
	Orthographic Projections (Sessions 1 and 2)		Isometric Projections (Sessions 3 and 4)	
	Test1	Test2	Test3	Test4
TIMeR group (N=18)	4.00	7.44	5.77	7.00
Conventional group (N=16)	3.87	6.12	4.75	4.25
Std dev. (TIMeR)	1.70	1.99	1.91	1.61
Std dev. (Conventional)	2.24	0.92	1.15	1.57

Mann Whitney Test

As the data shown no normal distribution, we chose to perform Mann-Whitney test to analyse the significance between the two independent groups i.e., TIMeR and the conventional group.

Ranks table

Table 7-3 provides information regarding the output of the Mann-Whitney test. It shows mean rank and sum of ranks for the two groups tested (i.e., the TIMeR and conventional group) for all tests (Test1, Test2, Test3, and Test4). The table indicates which group can be considered as having the higher ED problem-solving performance, overall; namely, the group with the highest mean rank. Since the TIMeR has the highest mean rank for all the tests, it has the highest ED problem-solving performance thorough all the tests.

Table 7-3: Ranks Table, Between Groups (ED4)

	Group	N	Mean Rank	Sum of Ranks
Test1	TIMeR	18	**17.81**	320.50
	Conventional	16	17.16	274.50
	Total	34		
Test2	TIMeR	18	**20.47**	368.50
	Conventional	16	14.16	226.50
	Total	34		
Test3	TIMeR	18	**19.67**	354.00
	Conventional	16	15.06	241.00
	Total	34		
Test4	TIMeR	18	**23.50**	423.00
	Conventional	16	10.75	172.00
	Total	34		

Test Statistics Table: Table 7-4 shows us the significance value of the test. Specifically, the Test Statistics table provides the test statistic, U statistic, as well as the asymptotic significance (2-tailed) p-value. From this data, it can be concluded that treatment for the TIMeR was statistically significantly higher than the conventional group for the Test2 ($p = 0.036$), and after the Test4 ($p = 0.000$).

Table 7-4: Test Statistics Between Groups (ED4)

	Test1	Test2	Test3	Test4
Mann-Whitney U	138.500	90.500	105.000	36.000
Wilcoxon W	274.500	226.500	241.000	172.000
Z	-0.210	-2.094	-1.440	-3.928
Asymp. Sig. (2-tailed)	0.834	**0.036**	0.150	**0.000**

a. Not corrected for ties. b. Grouping Variable: grouping variable

Table 7-5: Median (ED4)

Median			Test1	Test2	Test3	Test4
Group			Test1	Test2	Test3	Test4
TIMeR	N1		18	18	18	18
	Median		4.0000	8.0000	6.0000	8.0000
Conventional	N2		16	16	16	16
	Median		4.0000	6.0000	6.0000	4.0000
Total	N		34	34	34	34
	Median		4.0000	8.0000	6.0000	6.0000

Effect Size

Since the test performance of TIMeR group was higher than the conventional group, we computed effect size by Cohen's (1988) formula (r = z / square root of N), where N = total number of cases, and also using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect. (Pallant, 2005).

For Test1, Z = 0.210, and N = 34; therefore, r = 0.0360 indicating very small effect size.
For Test2, Z = 2.094, and N = 34; therefore, r = 0.3591 indicating medium effect size.
For Test3, Z = 1.440, and N = 34; therefore, r = 0.2469 indicating effect size close to medium.
For Test4, Z = 3.928, and N = 34; therefore, r = 0.6736 indicating large effect size.

7.1.1.2 Results Within the Group

Here, we investigate the significance within the group for each topic, i.e., orthographic and isometric projection.

Wilcoxon Signed Rank Test

We performed Wilcoxon signed rank test for both the group, as to see if there is a significant difference between the two tests for each topic.

Orthographic Projection (Test1 and Test2)

Ranks Table: In Table 7-6, for the TIMeR group, 0 participants had a higher Test1 Score than Test 2 Score. However, 15 participants had a higher Test2 Score compared to Test1 Score; and 3 participants saw no change in their Test1 and Test2 Score. For the conventional group, we can see from the table's legend that 1 participant had a higher Test1 Score than Test2 Score. However, 9 participants had a higher Test2 Score compared to Test1 Score; and 6 participants saw no change in their Test1 and Test2 Score.

Table 7-6: Ranks Table, Within Group, Test1 & Test2 (ED4)

			N	Mean Rank	Sum of Ranks
Ranks					
Test2 – Test1	**TIMeR Group**	Negative Ranks	0[a]	0.00	0.00
		Positive Ranks	15[b]	8.00	120.00
		Ties	3[c]		
		Total	18		
	Conventional Group	Negative Ranks	1[a]	2.50	2.50
		Positive Ranks	9[b]	5.83	52.50
		Ties	6[c]		
		Total	16		

a. Test2 < Test1

b. Test2 > Test1

c. Test2 = Test1

Test Statistics Table

It can be observed from Table 7-7 that, a Wilcoxon signed-rank test showed a statistically significant change in performance of individuals for the topic of Orthographic Projection for the Experimental group with Z = -2.573, p = 0.001; and for the conventional group with Z = -2.573, p = 0.010.

Compared to the conventional group (mean = 3.875), participants from the TIMeR group (mean = 4.00) to some extent showed a larger improvement in their performance. We can infer that TIMeR is more effective as compared to the conventional teaching of ED for the Orthographic Projection topic.

Table 7-7: Test Statistics, Within Group, Test1 & Test2 (ED4)

Test Statistics[b]		
	Test2 – Test1	
	TIMeR	**Conventional Group**
Z	-3.453[a]	-2.573[a]
Asymp. Sig. (2-tailed)	0.001	0.010

a. Based on negative ranks.

b. Wilcoxon Signed Ranks Test

Effect Size

Since the Test2 performances was higher than the Test1, we computed effect size by Cohen's (1988) formula ($r = z$ / square root of N), where N = the number of observations over two-time points, which is two-times the sample size, (Pallant, 2005).

For the TIMeR group, Z = 3.453, and N = 18 x 2 = 36; therefore, r = 0.5755 indicating a large effect size using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect. For the conventional group, Z = 2.573, and N = 16 x 2 = 32; therefore, r = 0.4548 indicating an effect size close to large.

Learning Gain

To show the students average improvement for orthographic projection in each group, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain\ g = \frac{(Test2\ score\ -\ Test1\ score)}{(maxscore\ -\ Test1\ score)}$$

For the students of TIMeR group   g = (7.44 - 4) / (8 - 4) = 0.86
For the students of conventional group g = (6.12 – 3.87) / (8 – 3.87) = 0.54

The learning gains of the students from the TIMeR group for the orthographic projections (86%) is significantly higher than for the students from the conventional group (54.4%). Results show that our TIMeR was more effective as compared to the conventional teaching of ED.

Isometric Projection (Test3 and Test4)

Ranks Table: In Table 7-8, For the TIMeR, 3 participants had a higher Test3 Score than Test4 Score. However, 11 participants had a higher Test4 Score compared to Test3 Score; and 4 participants saw no change in their Test3 and Test4 Score. For the conventional group, we can see from the table's legend that 7 participants had a higher Test3 Score than Test4 Score. However, 4 participants had a higher Test4 Score compared to Test3 Score; and 5 participants saw no change in their Test3 and Test4 Score.

Table 7-8: Ranks Table, Within Group, Test3 & Test4 (ED4)

Ranks			N	Mean Rank	Sum of Ranks
Test4 – Test3	**TIMeR Group**	Negative Ranks	3[a]	6.00	18
		Positive Ranks	11[b]	7.91	87
		Ties	4[c]		
		Total	18		
	Conventional Group	Negative Ranks	7[a]	5.86	41
		Positive Ranks	4[b]	6.25	25.00
		Ties	5[c]		
		Total	16		

a. Test4 < Test3, b. Test4 > Test3, c. Test4 = Test3

Test Statistics Table

It can be observed from Table 7-9 that, for the Experimental group, a Wilcoxon signed-rank test showed a statistically significant change in performance of individuals for the topic of Isometric Projection with $Z = -2.296$, $p = 0.022$. However, for the conventional group, a Wilcoxon signed-rank test shows no statistically significant change in performance of individuals for the topic of Isometric Projection with $Z = -0.758$, $p = 0.449$.

Participants from TIMeR showed larger improvement in their performance. Whereas, the conventional group participants did not show any improvement. We can infer that TIMeR is more effective than the conventional teaching of ED for Isometric projection topic.

Table 7-9: Test Statistics, Within Group, Test4 & Test4 (ED4)

Test Statistics[b]		
	Test4 – Test3	
	TIMeR	**Conventional Group**
Z	-2.296[a]	-0.758[c]
Asymp. Sig. (2-tailed)	0.022	0.449

a. Based on negative ranks.
b. Wilcoxon Signed Ranks Test
c. Based on positive ranks

Effect size: For the TIMeR group, Z = 2.296, and N = 18 x 2 = 36; therefore, r = 0.3826 indicating an effect size larger than medium using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect. For the conventional group, Z = 0.758, and N = 16 x 2 = 32; therefore, r = 0.1339 indicating a small negative effect size, as the Test4 (4.25) mean was lesser than the Test3 mean (4.75).

Learning Gain:

To show the students average improvement for isometric projection in each group, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(Test4\ score - Test3\ score)}{(maxscore - Test3\ score)}$$

For the students of TIMeR group   g = (7 − 5.77) / (8 − 5.77) = 0.55
For the students of conventional group   g = (4.25 − 4.75) / (8 − 4.75) = -0.15

The learning gain of the students from the TIMeR group for the isometric projections is 55%, whereas for the conventional group students it is negative, i.e. -15.4%. Results show that our treatment was indeed effective for the isometric projection topic, whereas conventional teaching found negative effect. The possible reasons for this could be that the students might have found the topic difficult or might have lost interest, or the teaching method was not adequate.

7.1.2 Qualitative Results (ED4)

We followed the same procedure as in section 4.5 for performing the content analysis of students' responses of reflective journals and for the focus group journal as well. We used the same coding system as in ED1 for identifying the ED learning difficulties and for determining the training benefits.

7.1.2.1 Analysis of Reflective Journals

First, we present the inferences from the analysis based on the content analysis of students' responses. The ED learning difficulties are same as what we found in the research studies ED1, ED2, ED3. Our findings confirm that the difficulties faced by the students in solving ED

problems are identical to the difficulties mentioned in various research articles from literature (Akasah & Alias, 2010; Garmendia, Guisasola, & Sierra, 2007; Jiannan, 1998; Kosse, 2005; Nagy-Kondoor, 2007).

Students from the conventional group mentioned the need of more time to solve the tests as well as the need of different approach. Students from the TIMeR group faced these challenges during the Test1 only. The analysis revealed that training activities helped them in getting over the difficulties and motivated them for learning ED concepts. While solving the tests 2, 3 and 4, comparatively it was easier for the students to (i) identify orthographic views distinctly, (ii) identify surfaces with hidden lines with more accuracy, (iii) visualize the object in 3D. Students also mentioned that due to the training activities, they learned various approaches to observe the object, majorly the rotations. The details of the analysis are presented in a tabular form in the following sections.

Analysis of Reflective Journals (Conventional group)

Table 7-10 shows the analysis of reflective journals for the students from conventional group, where student ID is the identification number, test indicates the tests. Other columns indicate transcripts of reflective journals, inferences, and codes. For the conventional group, we only have data about ED learning difficulties as they did not receive treatment.

It can be noted from the Table 7-10 that, for example, student D7 found it difficult to identify various orthographic views and to visualize hidden lines in Test1 and Test2, (tests based on the topic of orthographic projection). He also mentioned that in Test3 and Test4 (i.e. tests based on the isometric projection topic) it was difficult for him to visualize hidden lines and shapes of the object. Student D10 mentioned difficulties in interpreting the shape with inclined lines, and also said that it was difficult to interpret the top view while constructing an isometric view.

Similarly, as analysed the data of the reflective journals of the students from the conventional group, we found difficulties with respect to the different aspects that students face while solving ED problems. The set of difficulties is identical to the ones from ED1.

Table 7-10: Reflective Journals: Conventional Group (ED4)

ID	Test	Reflective journal data	Learning Difficulties	Codes
D1	Test3	I get confused with the orthographic projection of the complex objects while drawing.	Difficulty in visualizing and constructing 3D form from 2D, i.e., orthographic views.	VISUALIZE-1
D3		-	-	-
D4		-	-	-
D6	Test1	For 3rd question, it was a bit difficult to imagine the side view and the projection lines as well.	Difficulty in visualizing side view and projection lines.	VIEWS-2
	Test2	It was a bit difficult to find the side view of the question 4 due to variation in length of the shape.	In analysing side view and identifying the shapes.	VIEWS-1 SHAPES-1
	Test3	It is difficult to imagine the whole figure as compared to only views, in question 3. I could recognise the exact figure.	In visualizing the 3D form of the object.	VISUALIZE-1
	Test4	It is a bit difficult to find the isometric view when the front, top and side view is not given. I felt question 2 a bit difficult because I was not able to imagine a proper view, may be due to variations in length, height, and sides.	In forming an isometric view.	VISUALIZE-1
D7	Test1	I found difficulties in solving question 3 and 4, as I found it to be little complicated, mainly marking the hidden areas.	In identifying various orthographic views. In visualizing hidden surfaces.	VIEWS HIDDEN-2
	Test2	I got a problem with drawing hidden lines in question 3 and 4.	In identifying hidden lines	HIDDEN-1
	Test3	In solving questions 1, 2, and 3, I found difficulties in imagining the hidden portion. There are difficulties in imagining the projection and drawing them.	In visualizing hidden surfaces. In visualizing orthographic views.	HIDDEN-2 VIEWS-1
	Test4	The difficulties in solving the first problem are drawing the upper portion and imagining it. In solving the last question, the problem is that I couldn't imagine that curve.	In visualizing 3D form from orthographic views. In visualizing the curved shape.	SHAPES-1
D8	Test3	I have solved three questions, and I did not understand the hidden lines. In question number 4 it was difficult to draw the isometric view.	In interpreting hidden lines. In forming isometric view from orthographic views.	HIDDEN-1 VISUALIZE-1
D9	Test1	I got confused by question number 3 and 4, as I could not understand the side views.	in identifying and analysing side view	VIEWS-1
	Test2	Question number 4 is difficult, and I could not understand the side view. By observing the hidden lines, I will try to solve the question.	In identifying side view and to analyse hidden lines.	VIEWS-1 HIDDEN-1
	Test3	In all the three questions I could not understand the hidden lines because of which I am not able to solve the questions.	Identifying and analyzing hidden lines	HIDDEN-1
	Test4	I could not understand the question number 4 as I get confused about all the different type of views.	Confusion in identifying and distinguishing different views in order to for an isometric view.	VIEWS-1 VIEWS-3 VISUALIZE-1
D10	Test1	I have confusion on inclined lines.	In interpreting the shape with inclined lines.	SHAPES-1
	Test2	Problems were very easy, but I faced a problem with the open space.		

	Test3	I could not understand the top view in question number 3. Problems were very simple.	In interpreting the top view while constructing the isometric view.	VIEWS-1
D11	Test1	I was not able to find the correct hidden lines due to some difficulty with it.	In identifying the hidden lines.	HIDDEN-1
	Test2	Difficulty in finding hidden lines.	In finding the hidden lines.	HIDDEN-1
	Test3	Based on the given 2D views it was difficult to figure out the exact isometric view because of its 3D nature. Drawing the top portion of an isometric projection was difficult.	In forming the isometric view.	VISUALIZE-1
	Test4	There is a difficulty in drawing an isometric view from the given front, top and side views.	In forming the isometric view.	VISUALIZE-1
D13	Test1	I am not able to see and draw the projection lines correctly in front, top and side view.	In analyzing different views.	VIEWS-1
	Test2	The side view can be seen properly, but there is a confusion in hidden lines.	Confusion in observing hidden lines.	HIDDEN-1
	Test4	The hidden lines are confusing. I am not able to draw the isometric view.	In observing and identifying hidden lines.	HIDDEN-1
			In forming an isometric view.	VISUALIZE-1
D14	Test1	The figures are so much hard. While watching, the lines were getting mixed with each other.	In identifying and analysing orthographic views.	VIEWS-1
	Test2	Finding hidden lines was quite difficult. When the arrow is not given, then the task becomes more difficult. Identifying side views from the top and front view are difficult.	In identifying hidden lines. In identifying and analyzing orthographic views.	HIDDEN-1 VIEWS-1
	Test3	I can't find hidden lines quickly. Finding them is quite difficult. The third problem is difficult than other two.	In identifying hidden lines. Constructing isometric view.	HIDDEN-1 VISUALIZE-1
	Test4	I think objects are easy. Isometric views are difficult.	In forming an isometric view.	VISUALIZE-1
D15	Test2	Front view is not easy to draw.	In analyzing front view.	VIEWS-1
	Test3	Need more problems. I am not able to select the position of the top, front and side views.	Needs more practice items of constructing isometric views. In forming the isometric view.	OTHER-4 VISUALIZE-1
D17	Test1	Sometimes the direction or projection of top view. Determination of too many hidden portions. Projection of hidden portion.	In visualizing top view. In analyzing hidden lines and hidden surfaces.	VIEWS-2 HIDDEN-1 HIDDEN-2
	Test2	The direction of top view but sometimes only. Identification of hidden lines.	In visualizing top view. In analyzing hidden lines and hidden surfaces.	VIEWS-2 HIDDEN-1
	Test4	To draw the exact projection of a plane showing all the three views.	In forming the isometric view.	VISUALIZE-1
D19	Test1	Not able to understand projection lines. The problem in understanding the top view.	In visualizing top view. In analyzing projection lines.	VIEWS-1
	Test2	To draw projection lines.	In analyzing projection lines.	VIEWS-1
	Test3	Not able to draw the front view. Could not understand how to draw top view and side view.	In identifying and analyzing orthographic views.	VIEWS-2
	Test4	Not able to draw the isometric views properly and also its projection lines.	In forming the isometric view.	VISUALIZE-1

Analysis of Reflective Journals (TIMeR Group)

Table 7-11 shows the analysis for the TIMeR group. We received students' responses about ED learning difficulties and training benefits as well. It can be noted from the Table 7-11 that, for example, student D57 mentioned of difficulties in visualizing views and hidden lines, but after completing the training program and Test4, he said that he found Blender tool helpful for orthographic views. Similarly, student D59 mentioned of difficulties in interpreting shapes with inclined lines, but after training and Test3 and Test4, he said that he found training to be more useful to understand isometric views easily. Since students were specifically asked to mention about ED difficulties, most of them responded with the same, and only a few responded with the training benefits. However, we found that the set of difficulties is identical to the learning difficulties from our earlier studies ED1, ED2, and ED3.

Table 7-11: Reflective Journals: TIMeR Group (ED4)

ID	Test	Reflective journal data	Difficulties / Benefits	Codes
D41	Test2	To draw some hidden lines.	In drawing hidden lines	HIDDEN-1
	Test3	Some void space. Bottom part are quite difficult to imagine.	Forming isometric view.	VISUALIZE-1
	Test4	More time is required to solve question 4.	Requirement of more time to solve problems.	OTHER-3
D42	Test1	I felt problem in hidden lines.	Identifying hidden lines	HIDDEN-1
	Test3	While drawing top view, faced some problem.	Visualizing top view while forming isometric view.	VISUALIZE-1
D43	Test1	Here the given direction by arrow and front view is different. Hence the diagram is difficult to understand.	Identifying and analyzing the orthographic views.	VIEWS-1
	Test3	Not until now. Drawing side view.	No difficulty	
D44	Test1	No any difficulty.	No difficulty	-
D45	Test1	I can't draw hidden lines surely	In drawing hidden lines	HIDEDN-1
	Test3	There is no difficulty.	No difficulty	
D46	Test1	Don't understand the views and diagrams.	Identifying and analyzing the views.	VIEWS-1
	Test2	No difficulty at all.	No difficulty	
D47	Test1	Confused in hidden lines and to draw some type of top view. Could not understand how to draw the hidden lines.	In identifying and drawing hidden lines	HIDDEN-1
	Test2	Difficult to draw the hidden lines.	In drawing hidden lines	HIDDEN-1
	Test3	In question number 1 and 3, it is difficult to draw the top view.	In drawing top view while forming isometric view.	VIEWS-1 VISUALIZE-1
D48	Test1	Not much, but faced a problem in question 3, I got confused about right side view	In visualizing right-side view.	VIEWS-2
D49	Test1	Identifying hidden lines.	Identifying hidden lines	HIDDEN-1

	Test3	The difficulty faced only in 3rd question. It was difficult to view the 3D figure of the given front view, top view side view.	Visualizing 3D view based on the orthographic views.	VISUALIZE-1
D50	Test1	To view backside view. To imagine dotted lines.	In visualizing hidden surfaces and hidden lines.	HIDDEN-2 HIDDEN-1
	Test3	While solving problem 3, to draw side view is quite difficult.	In forming a 3D view, specifically a side view in 3D form.	VISUALIZE-1
D51	Test1	No difficulty.		
	Test3	I am getting a problem in 3rd example. I am not able to do the exact imagination.	In visualizing 3D form of the object.	VISUALIZE-1
	Test4	No difficulties faced.		
D52	Test1	Specifically, for question 2 I was not getting about where to draw the hidden lines and the top view. Otherwise no other difficulty.	In identifying hidden lines and analysing the top view.	HIDDEN-1 VIEWS-1
	Test2	No difficulties.		
	Test3	I faced difficulty in 3 as it was tilted, I was not able to get the proper front view, the top view and hence I found a bit difficult. In question 4 there are no difficulties.	Analysing different views while forming an isometric view.	VISULAIZE-1
	Test4	A little difficulty in question 1, rest all is good to analyse.		
D53	Test1	Sometimes I got jumbled to show projections. I got confused about that where should I draw the dotted lines.	In identifying hidden lines.	HIDDEN-1
	Test3	I got confused for hidden lines. It was somewhat difficult for me to draw 3D view or camera view.	In identifying hidden lines. Constructing 3D view.	HIDDEN-1 VISULAIZE-1
D54	Test1	To imagine hidden lines.	In visualizing hidden lines.	HIDDEN-1
D55	Test1	To see hidden lines.	In observing hidden lines.	HIDDEN-1
	Test4	To see exact or imagine top view in 3D.	In visualizing 3D view, specifically top view.	VISULAIZE-1
D57	Test1	I have difficulty with imagination to draw proper views.	In visualizing views.	VIEWS-1
		I could not identify the exact position of hidden lines while drawing the top view, front view and side view.	In visualizing hidden lines.	HIDDEN-1
		So, I feel the whole graphics subject difficult.	Subject itself is difficult.	CONCEPT
	Test2	Imagination.	In visualizing.	VISUALIZE-1
	Test3	I could not draw the isometric view.	In forming an isometric view.	VISUALIZE-1
	Test4	The app of Blender is so helpful for orthographic drawings.	In visualizing	C7
D58	Test1	It was hard to imagine a back-side view in the 3rd question. I got jumbled with the figure for a fraction of a time.	In visualizing views, especially back side view.	VIEWS-1 HIDDEN-2

D59	Test1	I was not able to understand an actual because the projection lines were drawn dotted. The right-hand side view in question 3 was difficult as due to the view behind the upper part.	In identifying hidden lines. In visualizing back side view.	VIEWS-1 HIDDEN-2
	Test3	In question number 3 the shape of an object was a slightly different and it was slanting in the view, and hence it was difficult. Also, it was difficult to judge the question 3 as compared to the question 1 and 2. After session 4, it was easier to get the concepts clarified.	In interpreting the shape with inclined lines. *Clarification in conceptual understanding*	SHAPES-1 C7
	Test4	Compared to learning on paper-based tests, using such software was in a sense more useful. The actual views from all the sides were unable to view in theory session but using software like Blender it was more useful, especially isometric views, it was easier to understand.	*Tool based training was more useful as compared to the theory and paper based sessions.* *Skill of visualizing different views including isometric view.*	C7 C3
D60	Test1	It was common to all the problems that the dotted lines create confusion.	Observing hidden lines.	HIDDEN-1
	Test3	Dotted lines	Observing hidden lines.	HIDDEN-1

To triangulate the reflective journal results and also to investigate more about the training benefits, we conducted interviews with volunteers. The details are presented in the next part.

7.1.2.2 Analysis of Interviews

We conducted semi-structured interviews with the individual participants who volunteered for it, for both the group. From conventional group, four students volunteered, and from TIMeR group eight students volunteered. The interview questions were mainly based on students' experience and perception of ED difficulties and training benefits if any. The interview has two parts with the same set of questions. As to get insight on the specific concepts which are, 1) orthographic projection (responses on Test1 and Test2) and 2) isometric projection (responses on the Test3 and Test4). We transcribed the interviews, and the transcripts were coded, categorized and classified to identify student perceptions regarding ED difficulties (for the conventional group) and, students' perception on learning with TIMeR (TIMeR group). We found these results to be identical and re-validated the results acquired from the analysis of the reflective journals. The set of interview questionnaire is given below. During the interview session, whenever it was required, we manipulated the sequence of questions based on the responses given by the students.

1. How was the Test 1? (easy/hard/moderate)

2. What technique did you use for solving Test1? (give answer sheet for reference)

3. Which question was difficult? And what was the difficulty?

4. How did you resolve that difficulty?

5. How did you visualize the object? And why in that way?

6. How was the Test 2? (easy/hard/moderate)

7. Compare test 1 and test 2

8. Did you use extra strategy for solving test 2? If yes, then what?

9. Which question was difficult? And what was the difficulty?

10. How did you resolve that difficulty?

11. How did you visualize the object? And why in that way?

12. Did training help you? If yes, then in what way?

13. Do you believe that viewing the object in Blender helped you understand how an object in an isometric view looks when rotated to an orthographic view?

14. What activity/part of the training did you use more frequently? In what way it was useful to you?

First, we present details of the analysis for the conventional group.

Analysis of Interview (Conventional group)

Four students from conventional group volunteered for the interview session. A student with id D3 and D4 did not respond to the reflective journal activity but participated in the interview session. However, students with id D6 and D13 have already given their responses in reflective journals. Additionally, they volunteered for the interview session. We used the same coding scheme from ED1. The details for the individual student are presented in the Tabular form below.

Table 7-12: Analysis of Interview, Student D3

	Conventional group Student 1 - D3		
Q.	Student's responses for Test 1 and Test 2: Isometric to Orthographic	Learning Difficulties in ED	Codes
1	The test was normal, couldn't find anything difficult.		
2	By comparing the given options.		
3	There wasn't a much problem with the orthographic. In test 1, I face a problem with identifying the side view and hidden faces.	Difficulty in Identifying and analyzing different views	VIEWS-1

		Difficulty in visualizing hidden surfaces from various views	HIDDEN-2
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	It was difficult. I was not able to get about how to show hidden lines in isometric view. Also, it was tough to construct an isometric.	Difficulty in visualizing hidden lines from various views.	HIDDEN-2
		Difficulty in visualizing and constructing a 3D form from a 2D drawing	VISUALIZE-1
2	By combining the given views.		
3	It was problematic to imagine. May require more practice.	Difficulty in visualizing	VISUALIZE
	The tests were difficult but were interesting.		

It can be seen that the student D3 found difficulties in identifying and analysing different views and visualizing hidden lines for the Test1 and Test2. However, these problems remained till Test3 and Test4, along with constructing 3D view. We can infer that the conventional teaching did not help the student in addressing and resolving these difficulties.

Table 7-13: Analysis of Interview, Student D4

	Conventional group Student 2 - D4		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Learning Difficulties in ED**	**Codes**
1	Easy		
3	It was hidden lines that were bit tough.	Difficulties about hidden lines	HIDDEN
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	It was quite difficult. Identifying the figure was a bit difficult, mainly right-hand side view.	Difficulty in Identifying and analyzing different views	VIEWS-1
2	I tried to solve it by reverse processing.		
3	While trying to analyze the top view, I was not able to understand the shape of an object.	Difficulty in identifying and interpreting shapes of an object	SHAPES-1
4	In test 4, I found it difficult to imagine the object.	Difficulty in visualizing the 3D object	VISUALIZE

Similarly, for student D4, he found Test3 and Test4 more difficult as compared to Test1 and Test2, which means it was difficult for him to understand the conversion of orthographic views to an isometric view. Also, it can be seen that conventional method did not help in resolving these difficulties.

Table 7-14: Analysis of Interview, Student D6

	Conventional group Student 3 - D6		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Learning Difficulties in** **ED**	**Codes**
1	The first and second was kind of easy, changing isometric to orthographic, but while doing the other thing that is orthographic to isometric was difficult. I mean I was not being able to imagine the exact figure.	Difficulty in visualizing and constructing a 3D form from a 2D drawing	**VISUALIZE-1**
3	I had this confusion about the right-hand side and left-hand side views. How do we imagine the view which is not given?	Difficulty in distinguishing between views	VIEWS-3
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	This test was difficult for me. Maybe I didn't have the practice of doing this. But taking all these three views and making one object was difficult.	Difficulty in constructing a 3D form from a 2D drawing	VISUALIZE-1
2	I had taken the views of these four options and the one which matches with the given view I had ticked that. Actually, that takes a lot of time and because of that orthographic was easier.	Time required to solve the problem	OTHER-3
3	When the surfaces are straight, it is easier, but for some inclined surfaces it is difficult. I don't get which horizontal line should be drawn into front view and which one should be drawn in the side view.	Difficulty in identifying and interpreting shapes of an object	SHAPES-1
	Time, ortho – ok, for iso - may be 10 more minutes.		

Table 7-15: Analysis of Interview, Student D13

	Conventional group Student 4 – D13		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Learning Difficulties in** **ED**	**Codes**
1	Not good		
2	First, I checked the options to see the possibilities. I also tried to think about the projection of top view based on the front view.		
3	The invisible part which is shown by hidden lines, it was problematic for me to see that part.	Difficulty in identifying and observing hidden lines and surfaces	Hidden-1
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	I did not understand this problem at all.		

The ED difficulties based on the analysis of students' response to interviews shows findings identical to that of reflective journals and results from study ED1. We can say that the conventional group teaching method is not sufficient to resolve ED difficulties, though it addresses ED concepts, it does not deal with the development of spatial skills.

Analysis of Interviews (TIMeR Group)

Eight students from TIMeR group volunteered for the interview session. All these students have already given their responses in reflective journals. Additionally, they volunteered for the interview session. The focus of interview session is to identify training benefits. We used same coding scheme from ED1. The details for an individual student are presented in the tabular form.

Table 7-16: Analysis of Interview, Student D41

	TIMeR Group Student 1 – D41		
Q. no	Students' responses for Test 1 and Test 2: Isometric to Orthographic	Difficulties / Benefits / Other	Codes
1	Initially, when you showed it on a computer at that time, I got to know how to imagine.	Cognitive - Learnt visualization skills	C7
2	When we are given a complete object in an isometric, at that time while viewing from the front side, the visible surfaces can be numbered or lettered. And then can be drawn from the front view.	-	-
3	It was difficult while identifying the answers and took more time. Imagination part was time-consuming. The hidden lines were difficult to understand at first.	Difficulty in identifying the correct solution between the given choices. Time required to solve the problem. Difficulties about hidden lines	OTHER-2 OTHER-3 HIDDEN
7	During the test 1, to do the imagination, it took more time. However, it took less time during test 2.	Cognitive - Lesser time to solve the posttest.	C7
12	Yes, it made a difference. The function and the technique for viewing hidden lines, I tried to apply the same process while solving the test.	Cognitive - Applying training skills for solving tests	C7
	Students' responses for Test 3 and Test4: Orthographic to Isometric		
1	Since it was the reverse process, it was a bit tough at the beginning; but afterward, it was easy.	-	-
2	It was possible to tally with the given options. It would have been a bit difficult if the options were not there.	-	-
12	The activities were useful in viewing the hidden lines. Now it will be easier for me to identify hidden lines.	Cognitive - Skill of identifying and visualizing hidden lines	C6
14	The feature in which we can view the complete front view, top view and other views; the activity in which all the four views can be seen. Activity about the hidden lines. If it is a single view, then it can be viewed using rotation.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful	C7

It can be noted that student D41 found difficulties in identifying hidden lines (Table 7-16), but after training, he said that he applied training techniques to view the hidden lines and his problems got resolved. So, it can be seen that the treatment helped him in resolving his difficulties.

Due to the training, student D43 learned the skill of identifying and visualizing hidden lines, which he mentioned in reflective journals response (Table 7-17) was difficult.

Table 7-17: Analysis of Interview, Student D43

Experimental Group Student 2 – D43			
Q	**Students' responses for** **Test 1, Test 2, Test 3, and Test4**	**Difficulties / Benefits**	**Codes**
1	Orthographic was a little bit easier. I always wanted some technique to know about the hidden lines, hidden views and its exact locations which I got to learn in the training sessions.	Cognitive - Skill of identifying and visualizing hidden lines and surfaces	C6
2	In isometric, I was not able to understand the 3D nature of the diagram. But when we got to see the answers of the 3rd test during the last session, then I exactly got to know from where and how to start so as to get the correct isometric view or solutions to the problem. (according to me, there should have been one more session for the isometric)	Cognitive - Identification of relevance of the visualization to problem-solving process Cognitive - Learnt about the Environment (Blender) - Phase 1 successful	C7 C7

Students D45 responded less in reflective journals, but in an interview, it can be seen that he learned the skill of identifying and visualizing hidden lines, which was difficult for him. He also learned visualization skills of rotation, (Table 7-18). So, it can be seen that the treatment helped him in resolving his difficulties and increased his confidence.

Table 7-18: Analysis of Interview, Student D45

Experimental Group Student 3 –D45			
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Difficulties / Benefits /** **Other**	**Codes**
1	Test was good. I was not able to identify the hidden lines correctly, due to which I got two problems wrong. I was not able to understand the positions of the hidden lines.	Difficulty in identifying and observing hidden lines	HIDDEN-1
2	Initially, I couldn't solve the first two questions because of the hidden lines. So, I ignored it. I tried to compare the given options. If there were no options available, I would have tried to solve it by observing whatever is visible.	Difficulty in identifying and observing hidden lines	HIDDEN-1
4	I got to understand about hidden lines because of the functions of the app (Blender) that you gave us. Previously I was not sure about it, but now because of the app, I can do it perfectly.	Cognitive - Skill of identifying and visualizing hidden lines Cognitive - Applying training skills for solving tests	C6 C7
6	I think due to practice my performance got improved. Training might have helped a bit.		
8	During the first test, I used to rotate myself around the object by keeping it stationary.	Cognitive - Skill of visualizing 3D Objects by rotation	C4 C7

166

	But later on, I started remaining stationary and learned to rotate the object.	Cognitive - Learnt visualization skills	
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	Isometric was easy.		
3	No, I was not able to understand the dimensions.		
14	Most of the time I used hidden line features.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful	C7
	MCQs were interesting.		
24	My confidence is increased, and I got to learn something new.	Affective - student found the training session to be interesting.	A1
		Affective – increase in confidence	A3

Students D46 also responded less in reflective journals, but in an interview (Table 7-19), he said that Blender features helped him in resolving the hidden line difficulties, and problems in construction 3D view. He also said that training helped him in getting more clarity about the process of solving ED problems. So, it can be seen that the treatment helped him in resolving his difficulties and learning visualization skills.

Table 7-19: Analysis of Interview, Student D46

	Experimental Group Student 4 - D46		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Difficulties / Benefits**	**Codes**
1	In orthographic, I had a problem with hidden lines and background geometry. Because of the software, I got to understand the process of visualization. I got to learn about how to visualize in 3D.	Difficulty in identifying and observing hidden lines and hidden surfaces.	HIDDEN
		Cognitive - Learnt visualization skills	C7
2	Blender feature which allows us to view the hidden portion benefitted me in resolving it. Also, the rotation part, rotating from all the sides was beneficial in understanding the hidden lines.	Cognitive - Skill of identifying and visualizing hidden lines and surfaces	C6
		Cognitive - Skill of visualizing 3D Objects by rotation	C4
3	The training helped in getting more clarity about the process of solving the problems.	Cognitive - Identification of relevance of the visualization to problem-solving process	C7
4	Most of the time I made use of a mouse to view the object from all the angle and all the views, as I was comfortable with that.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful	C7
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	It was a bit challenging to construct isometric, as there were many possible views or options that I could think of. But after seeing it in the software, there was more clarity on the various possibilities and how to have an exact view of the object.	Difficulty in visualizing and constructing a 3D form from a 2D drawing	VISUALIZE-1
		Cognitive - Skill of visualizing different views	C3

Similarly, student 48 also did not respond much in the reflective journal. In an interview (Table 7-20), he mentioned that he found difficulties about orthographic views and hidden lines, but also said that training helped him in resolving these problems.

Table 7-20: Analysis of Interview, Student D48

	Experimental Group Student 5 – D48		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Difficulties / Benefits**	**Codes**
1	Decent (moderate)		
2	I have used a real object, that means you have shown the picture of that object. I just imagined that object is in front of me, and I just visualized that how the front view it must be and How the top view, everything? If you give this side a front view of a proper object and **just rotated it** and seen the top view, likewise the side and front view (makes use of hand gestures).	Cognitive - Skill of visualizing different views, Cognitive - Skill of visualizing 3D Objects by rotation	C3 C4
3	(referring the answer sheet) No sir. But there was only in third one, the view was tough. The third one. The **side view was a little bit confusing**. I thought that it was a square block which was attached to the lower side of the back. Then I just thoroughly went through it, then I got the perfect view, that was a real step.	Difficulty in Identifying and analyzing side view.	VIEWS-1
7	It was much easier than the test 1. No difficulty everything was ok.		
12	Yes, in the first test. Accordingly, imagination part, which I had previously increased much more. Right, and using that software, yes it was pretty beneficial.	Cognitive - Learnt visualization skills	C7
13	Isometric to orthographic? Yes, the other controls that, in Blender software, the control plus alt plus 2 I think so. The three views were shown, and the separate view of an object was shown on the left-hand side, and through it. The isometric projections, we can project the orthographic projections as per, correctly through the software.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful	C7
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	It was a bit difficult.		
2	Same technique I think, I just went through the options and gone through the question and options thoroughly. And, tried to draw those projections and then got the perfect answer.		
3	The exact difficulty was, without the option, means the question number 3 – practice problem. It was a bit difficult to identify. I didn't get the perfect projection, where must be the top view. I got jumbled with the top view and side view. The front view was a little bit easy, and rest was good.	Difficulty in Identifying and analyzing different views Difficulty in distinguishing between views	VIEWS-1 VIEWS-3
4	Then I viewed the right-side view thoroughly then I got object a little bit clear that it was projected out. The smaller object was little projected out, and then I got the perfect answer.		
7	By solving the test 3 it was much easier in test 4.		
8	No, the same strategy.		
12	Yes, very much. The dotted lines, the hidden lines were not known. I just couldn't get where the exact position of lines is. Then I got the perfect view from the software. The software,	Difficulty in identifying and observing hidden lines	HIDDEN-1

	through the wireframe options I got the perfect dotted lines. I just imagined how the dotted lines would be seen.	Cognitive - Skill of identifying and visualizing hidden lines	C6
14	Yes, rotation through axes; x-axis, y-axis, mostly the key and mouse.	Cognitive - Learnt visualization skills	C7
17	Simultaneously.		
18	One hour is sufficient, for each session.		
24	It remained same.		

Student 49 mentioned that he found difficulties about hidden lines and surfaces, but also said that training helped him in resolving these problems. (Table 7-21)

Table 7-21: Analysis of Interview, Student D49

	Experimental Group Student 6 – D49		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Difficulties / Benefits**	**Codes**
1	Easy		
2	Firstly, I decided the front view, then saw the side view and then hidden lines. As per this, I did.		
7	The difficulty, only the hidden lines.	Difficulty in about the hidden lines	HIDDEN
12	To visualize objects, to look for hidden lines was difficult on paper and using software it was easy.	Difficulty in about the hidden lines Cognitive - Learnt visualization skills	HIDDEN C7
13	The part which is not looking from the front side, the overlapping of the lines, cleared the view by rotating the object.	Cognitive - Skill of visualizing 3D Objects by rotation	C4
	Students' responses for **Test 3 and Test4: Orthographic to Isometric**		
1	Isometric was difficult than orthographic. I solved by box method. Fourth test only.		
12	Yes, it helped me a lot because of parts which we are not able to see like hidden parts can be seen. I was confident with my answers, and the verification using software was good.	Cognitive - Skill of identifying and visualizing hidden lines and hidden surfaces.	HIDDEN-1 C6
13	We get a 3D view, and it clears the idea.		
14	By numbers, numpad keys. Easier because, directly we get the front view, the top view and side view with shortcut keys. The regular rotation, with the mouse.	Cognitive - Learnt about the Environment (Blender) - Phase 1 successful,	C7
24	Yes, most of the questions I got the correct answers, so confidence got increased.		

Student D50 (Table 7-22) mentioned that he found difficulties in identifying correct solution from given options and construction 3D view, but also said that training helped him in resolving these issues and enhanced his imagination skills.

Table 7-22: Analysis of Interview, Student D50

	Experimental Group Student 7 – D50		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Difficulties / Benefits**	**Codes**
1	Due to the training, while I was solving the tests I can think of the ways in which I can imagine the object.	Cognitive - Identification of relevance of the visualization to problem-solving process	C7
2	The rotation activity was kind of helpful for me in visualizing the object. I mean consider a front view of an object; that front view also has got different parts in it, and if we rotate it then we actually get to understand about it.	Cognitive - Skill of visualizing 3D Objects by rotation	C4
3	I found pictorial to orthographic was easy. But the other where different orthographic views were given, that time it was quite difficult to visualize the different views for constructing the pictorial view or 3D view. Also, the question has different options, that also created some confusion. I found session 3 to be useful in resolving these issues and I think it helped me enhance my imagination.	Difficulty in identifying the correct solution between the given choices Difficulty in visualizing and constructing a 3D form from a 2D drawing Cognitive - Applying training skills for solving tests	Other-2 Visualize-1 C7
4	It helped in verifying the answers.	Cognitive - Applying training skills for solving tests	C7
5	If we rotate the object in multiple views, then actually we get to see different views at the same time, so I prefer the multiple views option. Also in a single view, the rotation function is useful for viewing different views.	Cognitive - Learnt about the Environment (Blender) - Phase 1, 3 successful	C7
6	The session was good. It may enhance visualization skills.		

Student D51 (Table 7-23) mentioned that he found difficulties about hidden lines and visualizing 3D form, but due to training it got resolved. He also mentioned of applying training skills to solve tests and increase in confidence.

Table 7-23: Analysis of Interview, Student D51

	Experimental Group Student 8 –D51		
Q	**Students' responses for** **Test 1 and Test 2: Isometric to Orthographic**	**Difficulties / Benefits**	**Codes**
1	I had problems with hidden lines, but now I do not have any problem with the hidden lines. During the first two sessions and tests, most of the answers I got it wrong. But after session 3 and 4, I did not get any wrong answers, and it got reduced.	Difficulty in identifying and observing hidden lines Cognitive - Skill of identifying and visualizing hidden lines	Hidden-1 C6
2	I learned on a computer about how to identify and see the hidden lines. Then according to that, I tried to solve the other tests, and I also got the right answers.	Cognitive - Skill of identifying and visualizing hidden lines Cognitive - Applying training skills for solving tests	C6 C7

3	First, I'll talk about orthographic, after the session, now I think I do not have any problems with it, and I feel I can solve any related question now. (confidence)	Affective - increase in confidence	A3
	About isometric, I am not completely sure about it. I think there is no problem while imagination but maybe I may face some problem while drawing it. If not drawing, then I am sure about the imagination.		
4	I found multiple views to be more useful. Then for hidden lines pressing z or tab, that was helpful.	Cognitive - Learnt about the Environment (Blender) – Phase 2 successful	C7
	I was not knowing the difference between the perspective view and orthographic view, I learned it during the session.		

7.1.3 Summary of Results (ED4)

Table 7-24 and 7-25 provides the summary of quantitative results of ED4 for between group and within group respectively.

Table 7-24: Summary of Results of ED4 (Between Group)

ED4 Between Group Statistics Summary				
	Test1	Test2	Test3	Test4
TIMeR Group (Mean)	4.00	7.44	5.77	7.00
Conventional Group (Mean)	3.87	6.12	4.75	4.25
P	0.834	**0.036**	0.150	**0.000**
Effect size r	0.036	0.359	0.246	0.673
	Small	Medium	Close to medium	Large

Table 7-25: Summary of Results of ED4 (Within Group, Topic-wise)

Orthographic Projection		
	TIMeR group	**Conventional Group**
N	18	16
Test1	4.00	3.87
Test2	7.44	6.12
P	0.001	0.010
Effect size r	0.575	0.454
	Large	Close to large
Learning gain	0.86	0.55

Isometric Projection		
	TIMeR group	**Conventional Group**
N	18	16
Test3	5.77	4.75
Test4	7.00	4.25
p	0.022	0.449
Effect size r	0.382	0.133
	Medium	Negative
Learning gain	0.54	-0.15

In the current study, it has been shown that only partial execution of a TIMeR session cannot give the desired improvement, as the TIMeR group did not score statistically different than the conventional group in the intermediate tests. Another usefulness of the results of the intermediate test is that they validate the fact that both TIMeR group and the conventional group were equivalent, and the random sampling has produced the desired group equivalence.

The analysis of the tests for both implementations show that the students undergone the TIMeR sessions have outperformed the conventional group students. This has further corroborated the results obtained in all previous studies that the TIMeR pedagogy is effective in improving students ED problem-solving performance. This time it has been shown to be more effective than the traditional teaching method.

This study has demonstrated one instance of how to incorporate TIMeR in regular lab curriculum. Normally, a single implementation of full TIMeR pedagogy takes around 3 hours. We see that, in the current implementations, we split the TIMeR implementation into two sessions. We also see that if students have undergone the preparatory phase once, i.e., they have got familiarization with the 3D environment of Blender, then next implementations of TIMeR do not need the preparatory phase again.

From the analysis of the interviews and the reflective journals, we conclude that the training helped students of the TIMeR group in resolving their difficulties in learning ED concepts of orthographic and isometric projections, whereas difficulties of conventional group students did not get resolved completely. The set of difficulties and benefits are identical to the previous result from research studies ED1, ED2, and ED3. As mentioned by students, the training helped them in acquiring visualizing skills and applying them to ED problems. Also, students' confidence of ED got increased.

Chapter 8

Effect of TIMeR on CG

We established that three-hour TIMeR improves MR skills and ED problem-solving performance of first-year undergraduate engineering students. This chapter provides the details of the research study **CG1**. The focus of which was specific to answer **RQ4** by investigating the effect of TIMeR intervention on improvement of computer graphics (CG) problem-solving performance of the students. The study was scoped to the CG problems of transformations. The **RQ4** is *"How effective is TIMeR for improving students' computer graphics problem-solving performance?"*

8.1 Research Study 7 (CG1)

This study aimed at testing the effectiveness of TIMeR on the CG problem-solving performance of the students, learning basic CG course.

Sample: The participants in this study were 18 students from second-year Masters of Computer Application (MCA) course from an institute in India. Convenience sampling was used as these were the volunteers for the training. These students had taken Computer Graphics course as an elective and they had prior knowledge of the transformation topic.

Study Design and Implementation

The research study design applied for CG1 was two group pretest-posttest. We conducted a CG pretest for all 18 students. The groups were created based on pretest scores while ensuring the equal distribution in each group. The group size for experimental group and control group was nine each. However, one student was unable to be present for the training, this resulted in actual group size as eight and nine for the experimental and control group respectively.

Experimental Group Procedure: For the experimental group (N=8), we followed the same training procedure as described in section 4.5, also briefed below.

1. **Ice-breaker:** It was a fifteen-minute activity to highlight the importance of MR skill.
2. **Pretest:** It was a twenty-minute pretest with two CG problems on transformations. Sample problems is shown in Figure 8-1. Complete set of test items is given in Appendix V.
3. **Treatment**: The pretest was followed by a three-hour TIMeR session. The solutions of pretest were also discussed during the session.
4. **Posttest**: It was also a twenty-minute test with two CG problems on transformations, equivalent to pretest.
5. **Interview / Reflection Question**: Further to the posttest, students from both the group were asked to reflect on their experience on solving pretest and posttest, whereas students from experimental group were asked to reflect about their perception of TIMeR benefits on solving posttest problems.

Training objects: In the TIMeR module, we replaced VMRT training objects with computer graphics objects (mainly 3D cube) for 3D transformations, and 2D planes for 3D transformations.

Control Group Procedure: Control group (N=9) received formal classroom teaching. The teaching was done by using presentations and blackboard teaching. It involved, explaining the

concepts of transformations, transformation matrices, and performing transformations using matrices. The solutions of pretest were also discussed during the session. The duration and topics were identical to that of the experimental group.

Instrument and Data collection: The questions for 2D and 3D transformations based on the CG textbook (Marschner & Shirley, 2013) were used as the instrument to measure the improvement in CG problem-solving performance. The pretest and posttest were equivalent. Each test consists of two items. Test duration was twenty-minute. Figure 8-1 illustrates the sample test item.

Marking scheme: Each test carried two questions, one about the 2D transformations and the other one was about the 3D transformations. Each question carried a total of four marks. The solution for each question was divided into four parts.

1. One mark for identifying the rotation transformation.
2. One mark for identifying the other transformation.
3. One mark for identifying the correct order of transformations.
4. One mark for predicting the correct parameters.

Based on this marking scheme the lowest possible score to achieve would be four as part 1 and 2 can be answered easily by observation. We also collected data related to students' reflections on solving pretest and posttest.

Figure 8-1: CG Test Item

Q. 3D Transformations
Figure-A shows initial orientation of an object, which is then transformed to an orientation shown in Figure-B. Identify transformations required, with correct order.
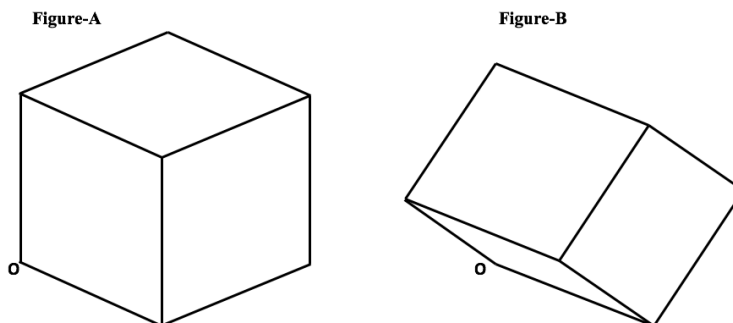
Data Analysis Procedure: We performed quantitative analysis by first doing the normality test. Since the data showed no normal distribution, to test the differences between two independent groups (experimental and control group) we performed the non-parametric Mann-Whitney test. We calculated the means, standard deviations, effect size, and learning gain. To see if there is a significant difference between the performance of pretest and posttest of each group, we also performed Wilcoxon signed rank test within the group, which was done for both the groups. For our analysis, we use the significance level 0.05 (5%). We also analysed the reflective questions data.

8.2 Quantitative Results

In this section, we present results of CG1. First, we provide the results of the effect of on experimental TIMeR (N=9) and its comparison with the control group (N=8). Then we investigate the significance within the group for each group.

Test of Normality: The Shapiro-Wilk's test of normality (Shapiro & Wilk, 1965; Razali & Wah, 2011), showed that the data for both the groups were not normally distributed with p being less than 0.05.

8.2.1 Results Between the Groups

First, we provide the means and standard deviations for both the groups, then we present the results for the differences between two independent groups on the posttest measures. The means and standard deviations are shown in Table 8-1, where the mean value for posttest is higher for the experimental group than that of the control group. Also mean of posttest is higher than pretest within the experimental group. Means for pretest and posttest for control group shows no difference.

Table 8-1: Descriptive Statistics, Between Groups (CG1)

Descriptive Statistics						
Group		N	Mean	Std. Deviation	Minimum	Maximum
Experimental	Pretest	8	3.62	1.40	1.00	5.00
	Posttest	8	7.00	0.75	6.00	8.00
Control	Pretest	9	3.88	1.45	1.00	6.00
	Posttest	9	3.88	1.27	2.00	6.00

Mann Whitney Test: As the data shown no normal distribution, we chose to perform Mann-Whitney test to analyse the significance between the two independent groups i.e., experimental and the control group.

Ranks table: Table 8-2 provides information regarding the output of the Mann-Whitney test. It shows mean rank and sum of ranks for the two groups tested (i.e., the control and experimental groups). The table indicates which group can be considered as having the higher CG problem-solving performance, overall, the group with the highest mean rank. In this case, the experimental group had the highest CG problem-solving performance.

Table 8-2: Ranks Table, Between Groups (CG1)

Ranks				
	Group variable	N	Mean Rank	Sum of Ranks
Independent Variable	Experimental	8	13.375	107
	Control	9	5.111	46
	Total	17		

Test Statistics Table: Table 8-3 shows us the significance value of the test. From this data, it can be concluded that treatment for the experimental group was statistically significantly higher than the control group (p = 0.001).

Table 8-3: Test Statistics, Between Groups (CG1)

Test Statistics[b]	Ind Var
Mann-Whitney U	1.0
Wilcoxon W	46.0
Z	-3.412
Asymp. Sig. (2-tailed)	0.001

a. Not corrected for ties, b. Grouping Variable: Group_var

Effect Size: Since the results are statistically significant, we computed effect size by Cohen's (1988) formula ($r = z$ / square root of N), where N = total number of cases, and also using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect, (Pallant, 2005). For Posttest, Z = 3.412, and N = 17; therefore, r = 0.8275 indicating large effect size.

8.2.2 Results Within the Group

Here, we investigate the significance within the group for each group.

Wilcoxon Signed Rank Test: We performed Wilcoxon signed rank test for both the group, as to see if there is a significant difference between before and after the treatment within the group i.e., the difference between the pretest and posttest for each group.

Ranks Table: In Table 8-4, for the experimental group zero participants had a higher pretest score than posttest score. However, all the 8 participants had a higher posttest score compared to pretest score; and zero participants saw no change in their pretest and posttest score.

However, For the control group 2 participants had a higher pretest score than posttest score, 2 participants had a higher posttest score compared to pretest score; and 5 participants saw no change in their pretest and posttest score.

Table 8-4: Ranks Table, Within Group (CG1)

			N	Mean Rank	Sum of Ranks
Pretest and Posttest Data	**Experimental Group**	Negative Ranks	0[a]	0.00	0.00
		Positive Ranks	8[b]	4.50	36.00
		Ties	0[c]		
		Total	8		
	Control Group	Negative Ranks	2[a]	2.50	5.00
		Positive Ranks	2[b]	2.50	5.00
		Ties	5[c]		
		Total	9		

a. posttest < pretest
b. posttest > pretest
c. posttest = pretest

Test Statistics Table:

It can be observed from test statistics Table 8-5 that, for an experimental group a Wilcoxon signed-rank test showed a statistically significant change in posttest performance of individuals (with p=0.011). Compared to the pretest, participants showed larger improvement in their performance of posttest. We can infer that TIMeR was effective for the improvement of CG problem-solving performance. However, for the control group a Wilcoxon signed-rank test shown no statistically significant change in posttest performance (with p = 1.000).

Table 8-5: Test Statistics, Within Group (CG1)

Test Statistics[b]		
	posttest - pretest	
Group	**Experimental**	**Control**
Z	-2.536[a]	0.000[c]
Asymp. Sig. (2-tailed)	0.011	1.000

a. Based on negative ranks. b. Wilcoxon Signed Ranks Test
c. The sum of negative ranks equals the sum of positive ranks

Effect Size: We computed effect size by Cohen's (1988) formula (r = z / square root of N), where N = the number of observations over two-time points, which is two-times the sample size (Pallant, 2005). However, in this condition, Z = 2.536, and N = 8 x 2 = 16; therefore, r = 0.634 indicating a large effect size using Cohen (1988) criteria of 0.1 = small effect, 0.3 = medium effect, and 0.5 = large effect.

Learning Gain: To show the students average improvement in each group, we calculated the average gain as (Marx & Cummings, 2007):

$$Average\ gain = \frac{(Posttest\ score - Pretest\ score)}{(maxscore - Pretest\ score)}$$

For the students of Experimental group g = (7 – 3.62) / (8 – 3.62) = 0.7716
For the students of control group g = (3.88 – 3.88) / (8 – 3.88) = 0.000

The learning gain of the students from the Experimental group for the isometric projections is 77%, whereas for the control group students it is none, i.e. zero. Results show that our treatment was indeed effective for the Experimental group, whereas conventional teaching found no effect.

8.3 Qualitative Results (CG1)

We analysed the students' reflection data for both the control and experimental groups, and the findings are presented below.

Control group: Students of the control group mentioned that they found the tests easy. However, we found that their performance scores were low. The learning difficulties for CG problems in pretest they faced and mentioned were: (i) Difficulty in the identifying the correct sequence of transformation, (ii) Difficulty in the identifying the transformation when axes are not given, and (iii) Difficulty in solving the three-dimensional transformations problem. Students also mentioned that these difficulties remained same during the posttest.

Experimental group: Students of the experimental group mentioned that they also found the tests easy and they reported the same difficulties in solving CG problems in the pretest. However, they were able to get over these difficulties after the TIMeR session. They revealed that after the training session they were able to, (i) Identify the correct sequence of transformations, (ii) Imagine the axes of transformations, (iii) Visualize the 3D transformations quickly, and (iv) Visualize the different 3D orientations of an object by rotation. The mapping of learning difficulties and benefits is shown in Table 8-6. Also, it was found that their posttest scores were significantly higher than the score of the control group and were also higher than their pretest scores.

Table 8-6: Mapping of CG Learning Difficulties and TIMeR Benefits

CG Learning Difficulties	TIMeR Benefits
Difficulty in identifying the correct sequence of transformation	Identifying the correct sequence of transformations
Difficulty in identifying the transformation when axes are not given	Imagining the axes of transformations
Difficulty in solving three-dimensional transformations problem	Visualizing the 3D transformations quickly
	Visualizing the different 3D orientations of an object by rotation

8.4 Summary of Results (CG1)

Table 8-7: Summary of Results, Between Group (CG1)

CG1 Between Group Statistics Summary	
	Posttest
Experimental Group	7.00
Control Group	3.88
P	0.001
Effect size *r*	0.8275
	large

Table 8-8: Summary of Results, Within Group (CG1)

	Experimental group	Control Group
N	8	9
Pretest	3.62	3.88
Posttest	7.00	3.88
P	0.011	1.000
Effect size r	0.634	-
	Large	-
Learning gain	0.7716	0.00

In this study, we examined if the same TIMeR pedagogy is also effective for the specific problems from the domain of computer graphics or not. We found that the students undergone the TIMeR session had significantly overperformed the control group students. However, the qualitative findings suggest that students' perception about the easiness of the test were same across both experimental and the control groups. The qualitative analysis has helped us in identifying primary difficulties that students face specific to the CG problems. The interviews of the experimental group students have also helped us to understand the benefits of the TIMeR pedagogy, i.e., how the pedagogy has helped the students to overcome the difficulties. It should be noted that there seems to be a clear mapping between the difficulties and benefits found in this study, with those found in the case of CG study (Table 8-6).

In the next chapter we discuss our findings of all research studies.

Chapter 9

Discussion

The thesis work was set to design the operationalization of cognitive steps of mental rotation in the form of a three-hour training workshop TIMeR, and evaluate its effectiveness in improving students' performances.

In addition to examining the effects of the TIMeR on the improvement of MR skill, we evaluated the effectiveness of TIMeR on the problem-solving performance in two different domains. The first type of the evaluations was about the improvements in ED problem-solving skills and the second one was for computer graphics problem-solving. In addition to varying domain and therefore types of problems, we also evaluated TIMeR for the different target population. We administered studies for both novice learners, who had no prior knowledge of the domain content and the advanced learners, who had prior knowledge of the domain content.

9.1 Answering Research Questions

RQ1: How effective is TIMeR for improving students' MR skill?

The first research question addressed the issue related to the effectiveness of TIMeR on the improvement of the mental rotation skills of the students. Research studies MR1 and MR2 answered RQ1. The results from both MR1 and MR2 have shown that the TIMeR session significantly improves the MR skill in the first-year engineering undergraduates. More granular results show that the TIMeR is significantly effective for the low-performers. Froese et al. (2013) also had found that visualization based trainings have benefits only on low-performers.

We also found that the TIMeR tasks were perceived to be used while solving the posttest problem. This shows that the students did not just perform the tasks during the intervention, but they also used them to solve new set problems outside the intervention. This strengthens our claim that the TIMeR is effective in improving students' MR skill, especially for low-performers.

RQ2: How effective is TIMeR for improving first-year engineering undergraduate students' engineering drawing problem-solving performance?

The second research question (RQ2) addressed the issue related to the effectiveness of the TIMeR on the improvement of students' engineering drawing problem-solving performance. Research studies ED1, ED2, ED3 and ED4 answered this research question. The results from ED1 has shown that the TIMeR is significantly effective in improving students' ED problem-solving performance.

Similar to the RQ1, more granular results show that TIMeR was statistically significantly effective for the low-performers. Due to statistically insignificant results for the medium and high-performers, we could not infer anything about the effect of TIMeR on this cohort. Study ED2 helped in confirming this no-effect result on the non-low-performers. ED2 has shown that most of the advanced learners who had prior knowledge of the topic, fell in the strata of the medium or high-performers, and there was no statistically significant effect on their improvement of the ED problem-solving performance. ED3, on the other hand, has shown that

equivalent cohort of the advanced learners demonstrated significant improvement in the ED problem-solving performance when we made the assessment items more difficult. The study ED4 had a two-group design and has shown that the TIMeR is significantly more effective in improving students' ED problem-solving performance as compared to the conventional ED teaching.

All the four studies (ED1, ED2, ED3, and ED4) together confirm that TIMeR is effective in improving ED problem-solving performance for not just low-performers but also the non-low-performers. These results address the imitations of our previous studies (MR1 and MR2) and also the studies from literature (Froese 2013; Norman 1994) where the training has been found to be effective only for the low-performers. However, to bring out the effects on the non-low-performers, we need to have more difficult assessment questions, as we did in study ED3. This also means that the assessment instrument SVATI, that we used in ED1 and ED2 is unable to test the real effects on the non-low-performers in its current form. The SVATI assessment items need to be made more difficult, as done for ED3.

Looking at the results for the RQ2 in the light of the results of RQ1, we conclude that TIMeR improves the ED problem-solving performance of the students by providing same MR training. The qualitative findings from the ED studies (ED1, ED2, ED3, and ED4) also confirm this. This has probed us to test the effect TIMeR for problems from another domain that also require MR skills and lead us to the RQ4.

RQ3: In what way does TIMeR resolve the learning difficulties that students face while solving the engineering drawing problems?

This research question inquires into the possible reasons of why the TIMeR sessions are effective in improving the ED performance of the students. It was answered by the research studies ED1, ED2, ED3, and ED4. To answer this research question, we answered two sub-RQs (RQ3.1 and RQ3.2), as follows. RQ3.1: What are the learning difficulties that students face while solving the engineering drawing problems? RQ3.2: What are the benefits of TIMeR as perceived by the students? RQ3.1 was answered by extracting the list of difficulties from the reflective journals obtained in the study ED1 and confirmed it from the similar data obtained in ED2, ED3, and ED4.

It was found that the list of difficulties reported by the students in the pretest was not reported in the posttest.

The list of difficulties obtained from our results found to be similar to the ones mentioned in the literature (Garmendia, Guisasola, & Sierra, 2007; Nagy-Kondoor, 2007). RQ 3.2. was answered by extracting the list of benefits from the reflective journals obtained in the study ED1 and confirmed it from the similar data obtained in ED2, ED3, and ED4. To answer RQ3, the obtained list of difficulties (RQ3.1) were mapped to the TIMeR features, and this mapping was confirmed by the list of benefits (RQ3.2) reported by the students.

Results show that students face various difficulties while solving the ED problems and these difficulties were mitigated and addressed after the students completed by the TIMeR features.

RQ4: How effective is TIMeR for improving students' computer graphics (CG) problem-solving performance?

This research question was meant to re-validate if the TIMeR improves students' problem-solving performance for the problems involving mental rotation by training them using TIMeR. This research question was answered by the research study CG1. We found that the students who underwent the TIMeR training performed significantly better than the students who had undergone traditional lecture for the same duration.

If we compare the assessment problems used in study-CG1 with those used in the ED-studies (ED1, ED2, ED3 and ED4), we would see that the ED problems require students to perform several sets of mental actions to identify or extract a final visualization associated with a 3D object; whereas in the CG problems, it requires students to perform several sets of mental actions to identify or extract an ordered set of operations that can transform one 3D object into another.

Therefore, this RQ does not only throws light on the generalizability of the effect of TIMeR on two various domains, but also across the problems with different complexity and difficulty.

Based on the answers to our four research questions we present the summary of findings of this thesis. The results along with the corresponding pointer to evidence are listed in Table 9.1

Table 9-1: Summary of Findings

RQs	Research Study	Findings	Claims
RQ1	**MR1**: Effect of Three-hour TIMeR on MR skill N=42	TIMeR improved students' MR skill. TIMeR is significantly effective for the low-performers. TIMeR tasks were perceived to be used by the students while solving the posttest problem.	Blender based MR training (TIMeR) improves MR skill of first year engineering undergraduates, especially low-performers.
RQ1	**MR2**: repetition of experiment MR1 N=55	Findings showed the consistency to the MR1 findings.	
RQ2, RQ3	**ED1**: Effect of Three-hour TIMeR on ED problem-solving performance of the students with NO prior knowledge of ED. N=114	TIMeR improved the ED problem-solving performance. TIMeR is significantly effective for the low-performers. TIMeR tasks as perceived by the students resolved their ED learning difficulties of visualizing 3D object, different views, shapes, hidden surfaces, and conceptual understanding.	Blender based MR training (TIMeR) improves ED problem-solving performance, especially low-performers. TIMeR help in resolving learning difficulties in ED concepts of orthographic and isometric projections.
RQ2, RQ3	**ED2**: Effect of Three-hour TIMeR on ED problem-solving performance of the students having prior knowledge of ED. N=59	TIMeR is significantly effective for the low-performers, but not for non-low-performers.	TIMeR improves ED problem-solving performance of students having ED prior knowledge. TIMeR is beneficial for low-performers.
RQ2, RQ3	**ED3**: Effect of Three-hour TIMeR on ED problem-solving performance the students having prior knowledge of ED on advance assessment instrument. N=38	TIMeR improved the ED problem-solving performance on advance assessment instrument.	TIMeR improves ED problem-solving performance of students having ED prior knowledge. TIMeR is beneficial for low and medium-performers.
RQ2, RQ3	**ED4**: comparative study, TIMeR group vs conventional group, students with NO prior knowledge of ED. N1=16, N2=18	1. Students from the TIMeR group outperformed the students from conventional group. Findings showed the consistency to the ED1 findings.	Compared to the conventional group, TIMeR group did well in tests due to TIMeR. MR training improves ED problem-solving skills As compared to the conventional method TIMeR help in resolving difficulties in learning ED concepts of orthographic and isometric views/ projections. MR training is essential
RQ4	**CG1**: Effect of Three-hour TIMeR on CG problem-solving performance, a comparative study	Students from the experimental group outperformed the students from control group.	MR training improves CG problem-solving performance.

9.2 Applying Common Coding Theory to TIMeR

Our broadest claim, that Blender based MR training (TIMeR) improves MR skill of first year engineering undergraduates can be explained using common coding theory.

Common coding is a cognitive science theory which theorizes that perception, execution, and imagination of movements (actions or events) are connected by a common neural representation (i.e. common code). This connection allows movements in any of the modality (say perception) to activate movements in the other two modalities (execution and/or imagination) (Chandrasekharan, et al., 2010). Moreover, this connection also allows movements in any two modalities (say perception and execution) to activate movements in the other modality (imagination).

The movement of interest in this thesis is "rotation of Three-dimensional objects". Mental rotation is an imagination process of visualizing rotations of a three-dimensional object. By linking it back to the common coding theory, we can say that imagination of mental rotation can be triggered if we make the learner to observe (perceive) the rotation of a 3D object. We can also say that the imagination of mental rotation can be reinforced more if we make the learner to both observe (perceive) the rotation of 3D objects and also perform (execute) the rotation of 3D objects.

TIMeR has made the learners to observe and perform active manipulation of a three-dimensional object, through controllers (mouse and keyboard), by applying an instructional strategy demo-drill-practice (DDP). We explain (Table 9.2) the association of occurrences of common coding events (perception, execution, and imagination) at various stages of DDP. The first column lists the three stages of DDP, the second column lists the corresponding actions performed by the student at each stage, and the third column marks the corresponding common-coding events. We see that the demo stages in the TIMeR have made the students watch (perceive) the demonstration of mental rotation task shown by an instructor that allows them to perceive the process involved in mental rotation. During the drill stages in the TIMeR, the students perform (execute) the mental rotation task using keyboard and mouse; and at the same time, they also observe (perceive) it on the computer screen. During the Practice stage, they

repeat all the training actions of drill stage but on different objects, which again allows them to do the execution and perception of the mental rotation task.

Table 9-2: Occurrences of Action-Perception-Imagination in Demo-Drill-Practice (DDP)

DDP Stages	Student Action	Corresponding Common Coding Event		
		Perception	Execution	Imagination
Demo	Watches demo of MR task	✓		
Drill	Repeats steps of the task in-tandem with instructor	✓	✓	
Practice	Independent practice with multiple objects	✓	✓	

The repeated episodes of perception and execution of rotation of 3D objects throughout the TIMeR session lead to repeated activation of the imagination of 3D object in students' mind. Since all the actions that students perceive and execute are covertly replicated, students covertly imagine the actions performed, both when they perceive them and execute them. They also imagine their actions and would apply to other conditions, e.g. either during performing the similar tasks (such as other phases of TIMeR) or while solving the posttest (such as mental rotation problems).

9.3 Establishing Generalizability

We examine the thesis work for generalizability primarily on the two dimensions of domain and target population.

Generalizability across different domains

Our studies have shown that the TIMeR improves students' mental rotation (MR) performance, and the same training can affect students' problem-solving performances in the two different domains of engineering drawing (ED) and computer graphics (CG). The primary focus of this research work was on the ED domain, but the last study in the CG domain was done to examine if the same MR training can impact problem-solving in a domain other than ED. The problems used from the CG domain also required mental rotation. We did not just vary the domains, but

we also included variations of problem difficulty and complexity. In the first two ED studies we used standard assessment items from SVATI, where the students were required to visualize and identify the correct orthographic view given an isometric view, and vice-versa. In the next ED study, we increased the difficulty by converting the MCQ structure of the SVATI assessment items into the non-MCQ drawing problems. The complexity of the problems used as the assessment items in the CG study was also different. The CG problems expected the students to visualize and identify the processes of 3D transformations, given the initial and final states of a 3D object, undergone some unknown series of transformations. Hence, we believe that our results are generalizable across various types of problems which involve MR. The possible domains where MR would be essential are chemistry (molecular structures, morphemes), Architecture, 3D Modelling, Sculpture Artists, Animators, etc.

Generalizability across different population

The target population in this thesis were the engineering undergraduates. Except for the three studies, ED1, ED4, and CG1, all other studies were administered with the 1st year engineering undergraduates. The two studies ED2 and ED3 had second-year engineering undergraduates, which were considered as the advanced learners, as they had already studied engineering drawing before. The CG1 study was done on the Masters of Computer Applications (MCA) 1st year students, which are considered to be equivalent to the third-year engineering undergraduates according to the MCA curriculum and the Indian education system. The results from the studies have shown several generalizability trends across different student categories. With respect to the SVATI assessment items, it was seen that most of the novices fell in the category of low-performers as per their pretest scores in various studies, contrary to which, most of the advanced learners fell in the high-performers category. The results of ED studies have thus demonstrated that the effects of the TIMeR session are significant on both low as well as high-performers, one just needs to assess the high-performers with the more difficult set of assessment items. This brings us to the generalizability claim that the TIMeR is effective for the range of the learners, including high and low-performers, and advanced and novice learners. The results from the CG1 study extends this generalizability further and shows that the TIMeR is even effective for the students from disciplines which are not exactly engineering but are equivalent. This generalizability limits to the engineering undergraduate (and equivalent) students, and we cannot claim anything about postgraduate students (and equivalent), and the school.

Generalizability across different durations of implementation

Through the research study ED4, we demonstrated how to incorporate the TIMeR pedagogy in a regular class. The normal duration of a complete TIMeR pedagogy is around three hours. In ED 4, we demonstrated how to split the TIMeR phases into two sessions (90 minutes each) and still yield similar effectiveness. We have shown this using two instances of TIMeR pedagogy for two different topics. However, we could not split the TIMeR pedagogy below 90 minutes, and therefore this brings us to believe that the pedagogy is implementable for the classroom sessions equivalent to the typical lab durations which are equal to or more than two hours.

9.4 Limitations of the Thesis

While there are limitations to this work, we believe that these offer the potential for new perspectives and research directions to carry forward this work.

Limitations related to learner characteristics

Learners at different levels would have different characteristics such as motivation, interest, self-efficacy, etc., related to problem-solving and even related to the ease of working in any 3D graphing environment. This thesis does not provide insights into the how these learner characteristics play a role into students' achievements in the TIMeR session. Moreover, this research focuses only on engineering undergraduate target population and has not explored if the same TIMeR pedagogy would be effective for the learners at the postgraduate level or school level.

All of the participants in this research were from second-tier (Hewner & Mishra, 2016) Indian engineering undergraduate colleges. The generalizability of the results of this thesis is delimited to the learner population coming from similar colleges. This research also does not comment anything about the population of learners who are familiar with the 3D graphing environments. Also, the undergraduate learners from other disciplines, such as arts, life sciences, design, etc. were out of the scope of this research.

Limitations related to topics and domains

This research focuses on training students for one spatial skill, i.e. MR. We have not tested the effect of TIMeR on other spatial skills such as spatial perception, spatial visualization, spatial orientation or spatial relation, this can be investigated in future. As far as the topics and domains are concerned, this research has demonstrated that the TIMeR is effective in improving student's learning performance for the problems that involve cognitive actions of mental rotation, for example problems in engineering drawing and some problems in computer graphics. Beyond these problems this thesis cannot claim about the TIMeR's effects on the problems from other domains such as architecture, chemistry, etc., because we have not tested TIMeR for these domains.

In the study ED4, we administered two implementations of TIMeR, where each of them had two-two tests in each (one pretest and one posttest). The results had shown that even after getting TIMeR training on the topic (orthographic) of the first implementation, the TIMeR group learners did not perform significantly better than the conventional group learners in the pretest in the second implementation, which was on another topic (isometric).

This shows that getting trained in TIMeR sessions using one topic does not necessarily ensure that the learner would also perform significantly better on another topic. This thesis doesn't throw empirical light on how many cycles of TIMeR are needed to make sure that the learner develops enough MR skill, that can help him/her to perform better (as compared to other conventional learners) in all the problems involving MR skill.

Another limitation of this thesis is about the topic of the problems used in the "transfer phase" of TIMeR. As per our TIMeR pedagogy, in the transfer phase (phase3), learners have to work on the "pretest" problems again, but in the 3D Blender environment (section 4.8). The domain and the topic of these problems are consistently same in all the phases, including pretest, TIMeR-phase 1, TIMeR-phase 2 and TIMeR-phase 3.

This thesis doesn't explore the case if the topic of the pretest problems and the phase 3 problems are not same as that of the topic used in phase 1 and phase 2.

Limitations related to research method

This research has used mixed method research design where the primary inquiry is quantitative. Qualitative inquiries have been done, but mostly to triangulate the quantitative findings. If there would have been more in-depth inductive qualitative studies, we could have gained more insight into the mechanisms of learning, or local instructional theories.

This research has used single group pre-post design for most of the studies (MR1, MR2, ED1, ED2, ED3, and CG1). Study ED4 has addressed this limitation by having two-group posttest design.

TIMeR has a short duration, i.e. approximately 3 hours of training. The pretest was administered just before the training, and the posttest was administered immediately after the training. Literature has shown similar study designs where pretest and posttest were administered just before and immediately after the treatment respectively, and the duration between pretest and posttest varied as six hours (Contero, et al., 2005), four to five weeks (Kinsey, et al., 2008; Onyancha et al., 2009; Samsudin & Ismail, 2004; Zaiyouna, 1995), ten weeks (Gillespie, 1995), twelve weeks (Turner, 1997), thirteen weeks (Thomas, 1996), fifteen weeks (Leopold, et al., 2001). However, we did not administer the posttest after a longer duration and is one of the limitations of this research. Another limitation is that we did not perform the longitudinal studies. These limitations can be addressed and tested in future work.

Limitations related to the test instruments

Studies ED1 and ED2 have two limitations about the test instrument. First, it has four test items for the pretest and the posttest each. Second, the questions have four choices for answers for each item, one of the four represents chance. The first limitation was addressed in the study ED4, by having total sixteen test items. The second limitation was addressed in the study ED3 by having more difficult test items, where the students were not given choices. Instead, they had to draw the correct answer (front, side, and top views) corresponding to the given isometric view of 3D objects.

Limitations related to instructor and instructional strategies

Another limitation of this thesis is with respect to the role of instructors. In this era of growing online and self-learning environments, we limit our research to a semi-computer based pedagogy design. In this research, we do not comment anything about how to convert the whole training model into a self-learning environment. This could be a plausible future educational design problem.

Limitations related to the tools and technology

This research uses Blender as the tool for 3D visualization. There are certain limitations about the user interface, as its primary purpose is to develop 3D modelling and animations. However, due to easy customization, we were able to customize it to fit the training purpose, along with the systematic execution and the training procedure it minimises those limitations. For example, if students are meant to perform the rotation, then the other features can be disabled or locked so that it will not distract the user.

9.5 Thesis Contribution

This thesis contributes to the field of spatial skills research and also to its application domains such as in engineering drawing and computer graphics. The contributions are enlisted below.

Pedagogy: We contributed with the 3D visualization tool based pedagogy that develops students' mental rotation skills and the learning of relevant concepts such as engineering drawing and computer graphics.

- TIMeR and results are supporting the common-coding theory.
- This pedagogy has shown an instance of how to operationalize the cognitive steps of MR.
- Moreover, the thesis also demonstrates an integration of a technology tool (Blender, which is traditionally not an educational tool) to achieve an educational goal.

Workshop Models: This thesis has shown various instantiations of the TIMeR pedagogy in the form of workshop models as follows.

- **Three-hour TIMeR model:** We have instantiated the TIMeR pedagogy as a short-length workshop model which we successfully incorporated into an engineering drawing curriculum, and students got benefited from it in learning of ED concepts of orthographic and isometric projections. Thus, the three-hour MR training material (TIMeR), can be easily included as a tutorial within an ED course or a course relevant to mental rotation skills.
- **Recommendation for incorporating TIMeR in regular curriculum:** In addition to the three-hour workshop model, the thesis also has shown another instantiation of the pedagogy which can fit in a regular ED curriculum.

Research: A pedagogy meant for the improvement of MR skills can also be used to improve ED and CG performances, for the topics involving mental rotation skills. Hence this thesis demonstrates that training learners only on conceptual knowledge may not suffice and it should be important to also focus on training the learners on the underlying cognitive skills.

Social Outreach: Throughout the research we able to conduct a total of seven TIMeR workshops within the different engineering institutes from India, with training 360 students from engineering and computer graphics domain.

9.6 Future Work

In this section, we provide possible future directions, for which we consider the limitations of this thesis.

Learner characteristics
- This thesis does not provide insights into how the learner characteristics (such as motivation, interest, self-efficacy, etc.) play a role into students' achievements in the TIMeR session. Hence the effects of TIMeR on students with different learner characteristics can be further investigated.
- This research focuses only on engineering undergraduate target population and has not explored the effects of TIMeR on other learners. Thus, it would be interesting future scope to investigate the effect of TIMeR for the different population such as at the school level.

Topics and domains

- This research investigated the effect of TIMeR on ED topics (orthographic and isometric projections) and CG topics (transformations), further research with other types of ED and CG problems could be done. The other parameters need to be considered are the complexity of these problems.

- Other possible domains where mental rotation would be essential, and the effect of TIMeR can be examined are chemistry (molecular structures, morphemes), Architecture, 3D Modelling, Sculpture Artists, Animators, etc.

Research method

- This thesis focusses more on a quantitative evaluation of the TIMeR pedagogy. It would be desired to do a further in-depth qualitative examination of the cognitive processes that were triggered while a student interacts with the learning environment and the pedagogy which lead to the enhancement of MR skill. For example, which individual TIMeR task lead to what individual effect(s)?

- Eye tracking: It would also be possible to extend the current work for understanding the student behaviour especially their eye movement and focus on the screen while they perform TIMeR tasks. The initial investigation can be achieved through a qualitative investigation where the learner can wear an eye tracker while performing TIMeR tasks.

Instructor

- Our research is scoped to a semi-computer based pedagogy design, where the involvement of the instructor is essential. TIMeR pedagogy is suitable for the classroom and/or lab settings. However, the same can be transformed into a self-learning mental rotation training module with appropriate customizations and further can be tested for the effectiveness. For that purpose, the instructor's role can be executed by means of self-explanatory videos or other appropriate instruction medium.

- The possible self-learning training environments would be a standalone or a web application and can run on computers or other devices such as tablets or similar devices. Another possibility to develop a self-learning mobile application that can run on smartphones. Developing a self-learning environment could be a plausible future educational design problem.

- Interactivity: In the current TIMeR, the interactivity with the 3D environment for manipulating 3D objects is achieved by using the mouse and keyboard controllers. This can further be examined with the other types of controllers, e.g., Touch-screens, Joystick, Gesture-Based, etc.

Scaling

- The training method can be implemented for a large scale spatial skill development program for first-year engineering students. TIMeR can be made a part of first-year engineering drawing curriculum. The various possibilities of the execution include a short-term training program for the teachers, and an online mental rotation training program for students/teachers.

9.7 Conclusion

Spatial skills form an important role for learning concepts that involve 3D visualization. In order to improve the learning in courses that require 3D visualization such as engineering drawing (ED), it is not enough to simply use 3D tools, but it is necessary to address the underlying spatial skills such as mental rotation (MR) which form the basis of multiple ED abilities. Improvement of MR skills leads to improvement of learning in subjects like ED. In this thesis, we have developed TIMeR a program for MR development, using Blender, an open source 3D visualization tool. We tested the effectiveness of TIMeR and its impact on the development of MR skills, ED problems, and additionally on computer graphics (CG) problems on the Indian engineering undergraduate students and the equivalent population. We found TIMeR to be effective in developing MR skills, in enhancing the learning of ED and CG problems, especially for the low-performers. Thus, we recommend the inclusion of TIMeR as a tutorial within courses like ED.

This thesis work serves the purpose of strengthening the belief that students need to be trained in spatial skills prior to the commencements of courses such as ED for enhancing their learning abilities. This would be of immense benefit to all the students undertaking the course, especially to low-performers.

Appendix I

Instruction Sheet (Handout)

1: BLENDER USER INTERFACE

Sr.	Instructions	Actions: Mouse / Keyboard
1.	Open Blender and observe the screen	Double click blender icon on desktop
2.	Quit Blender	Ctrl + Q or File menu –> Quit
3.	Again open Blender, press 'Esc' to remove the splash screen	Esc
4.	Deselect object or Select All	Hit 'A'
5.	Select object	Right mouse click
6.	Zoom in – Zoom out	Scroll

7.	Pan view – Click and hold the middle mouse button and by holding it move the mouse in various directions such as,
	   a. Horizontal
	   b. Vertical
	   c. diagonal
	Observe the change in view.
	Practice this as many times.
		Middle mouse hold + move mouse

8.	Quit Blender and reopen. Or open new file.	Ctrl + N
9.	Observe at up left corner 'user persp', Hit num key '5' and observe the change in view.	Num pad key '5'
10.	Quit Blender	
11.	Double click & open file *'chair.blend'* from the folder **'Practice'** on desktop. Repeat actions 4,5,6,7	
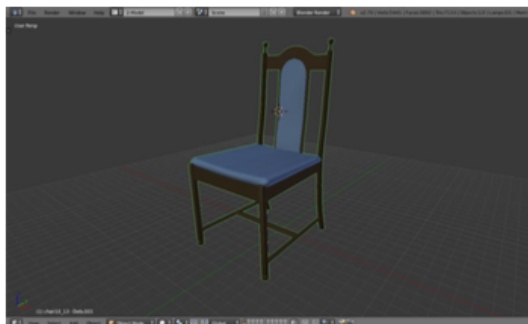
Figure 1: chair.blend

2: VIEWING & OBSERVING

Sr.	Instructions	Actions: Mouse / Keyboard
12	Reopen *'chair.blend'* and press keys 2,4,6,8 one by one from numpad (see figure below) and observe the object.	Num pad 4 – orbit left Num pad 6 – orbit right Num pad 2 – orbit down Num pad 8 – orbit up
13	Reopen *'chair.blend file'*	
14	Hit Num keys 1, 3, 7, 0 and observe the object from different views. (or click on view menu from panel and select the respective view.)	Num pad 7 – Top view Num pad 1 – Front view Num pad 3 – Right side view Num pad 0 – Camera view
15	Reverse views: Hit Ctrl + num keys 1, 3, and 7, one by one	Ctrl + Num pad 7 – Bottom view Ctrl + Num pad 1 – Back view Ctrl + Num pad 3 – Left side view
16	Multiple views together: hit the combination of keys 'Ctrl + Alt + Q' and observe the object in each window	'Ctrl + Alt + Q' – Quad view (Top, Front, Side, Camera views)
17	Move mouse pointer to each view and press num pad '.' (period key).	Num pad '.' – Zoom to object

Num pad
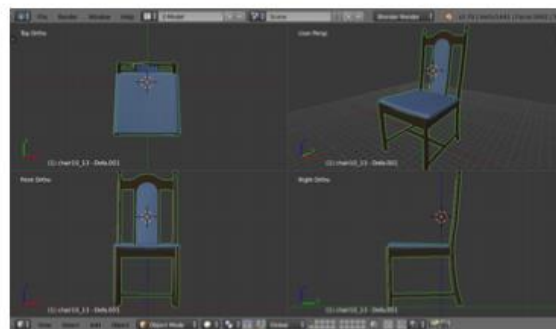
Quad view

Figure 2: quad view

200

3: ROTATION

Sr.	Instructions	Actions: Mouse / Keyboard
18	Quit Blender and reopen *'chair.blend file'*	
19	Rotation using Keyboard and mouse: a. Select chair object if not selected. b. For rotating about X axis Hit R + X and move mouse. c. For rotating about Y axis Hit R + Y and move mouse. d. For rotating about Z axis Hit R + Z and move mouse.	Rotate − R and move mouse Rotate − R + X/Y/Z and move mouse See Fig 3 below
20	Rotation using manipulator: see Fig. 4 below a. Click and drag on respective axis curve to rotate object.	
21	Rotation in multiple views. a. Reopen *'chair.blend'* file, enter in quad view by pressing 'alt + ctrl + q' and then perform all rotation actions.	'alt + ctrl + q' And rotations
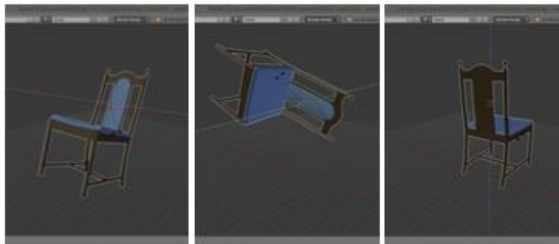
Figure 3: Rotation about X, Y, Z axes   Figure 4: Rotation manipulator
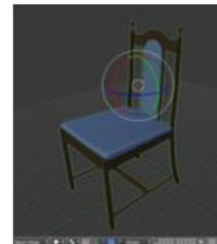
4. MORE PRACTICE WITH DIFFERENT OBJECTS
Exercise 4.1:
  a. Open *'practice 1.blend'* file and perform all the operations you have learnt by now.
  b. Open *'practice 2.blend'* file and perform all the operations you have learnt by now.
  c. Open *'practice 3.blend'* file and perform all the operations you have learnt by now.

5. HIDDEN LINES

Sr.	Instructions	Actions: Mouse / Keyboard
22.	Open new file and hit 'Tab' to switch between Object mode and Edit mode	Tab
23.	In Edit mode, a. Hit A to select all vertices then as shown in a Fig 5 click and enable **'Limit Selection to Visible'** button. Repeat and observe the hidden edges of object.	
24.	Pressing Z will enable wire frame mode.	
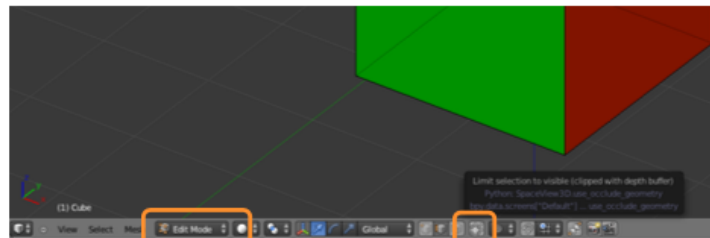
Figure 5: Hidden lines

Exercise 5.1:

    a. Reopen *'practice 1.blend'* file and observe hidden lines and also do the rotations.

    b. Repeat for *'practice 2.blend'* and *'practice 3.blend'*.

202
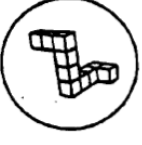
Appendix II
MR Test Set (MR1, MR2)
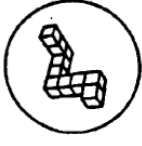
Sample items from VMRT.
These items are reproduced from Vandenbergs' & Kuse 1978, some of the items are shown here. The entire VMRT can be found at Gurney, (2003).

Question: Which two drawings of the four on the right show the same object as the one on the left? There are always two and only two correct answers for each problem. Put an X under the two correct drawings.

The correct options for question 1 are option one and option three.
The correct options for question 2 are option one and option four.
The correct options for question 3 are option two and option four.

Appendix III

# ED Test Set 1 (ED1, ED2, ED4)

Sample items from SVATI

Some of the SVATI items used for studies ED1 and ED2 are shown here. The entire set can be found at Alias, (2000).

EXERCISE 1A: ISOMETRIC TO ORTHOGRAPHIC.

Instructions : Identify the correct orthographic views for the isometric view given on the left.

Class:
Div:

Roll No.

1.

FRONT
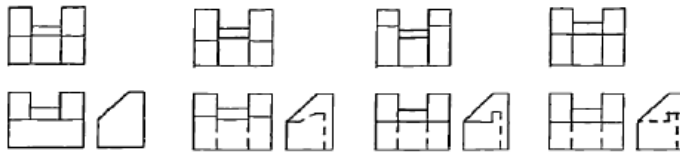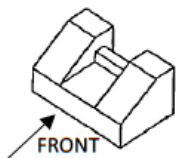
a   b   c   d

2.
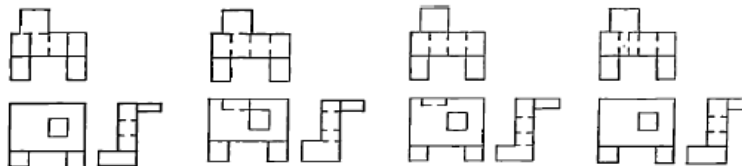
a   b   c   d

Write Difficulties you faced in solving question 1 and 2

Sample items from SVATI

Some of the SVATI items used for studies ED1 and ED2 are shown here. The entire set can be found at Alias, (2000).

EXERCISE 1B: ORTHOGRAPHIC TO ISOMETRIC.
Instructions : Identify the correct isometric view for the orthographic views given on the left.

Class: Div:

Roll No.

3.
Top View
Front View   Right View
a   b   c   d

4.
a   b   c   d
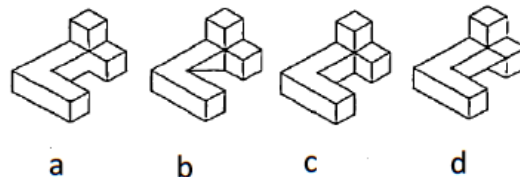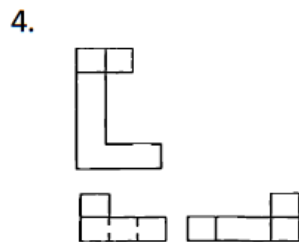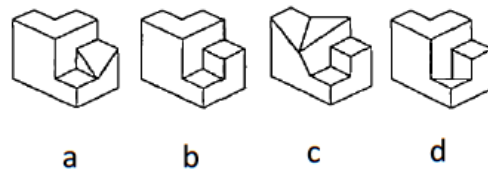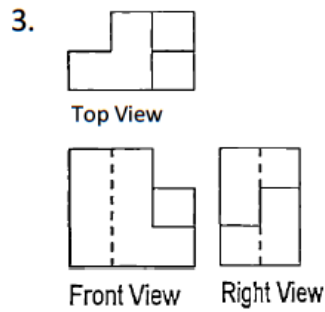
Write Difficulties you faced in solving question 3 and 4

Appendix IV

ED Test Set 2 (ED3)

Sample items from ED Exercise book.
Some of the items used for studies ED3 are shown here. The entire set can be found at Earle, (1967, 1968, 1969).
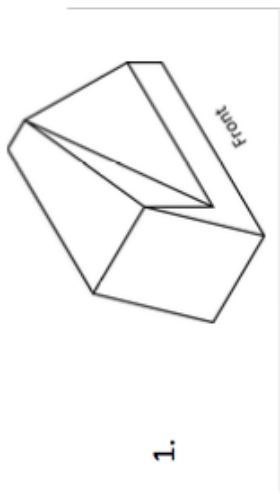
EXERCISE 1B: ORTHOGRAPHIC TO ISOMETRIC.

Instructions : For the objects in orthographic projection below, construct an isometric view in the space provided

Class: Div:	Roll No.

2.

Isometric

Top

Front   Right

Use this space for rough work:

Write Difficulties you faced in solving question 1B

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Appendix V

CG Test Set (CG1)

GOAU /28-03-2015 / **CG Pretest**

Roll No.

Q 1. 2D Transformations
The object in fig 1-a is transformed as shown in fig 1-b,
Identify the required transformations with correct order.
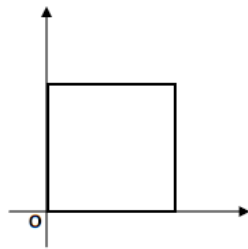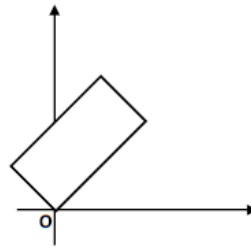
Fig 1-a

Fig 1-b

208

Roll No.

Q 2. 3D Transformations
The object in fig 2-a is transformed as shown in fig 2-b,
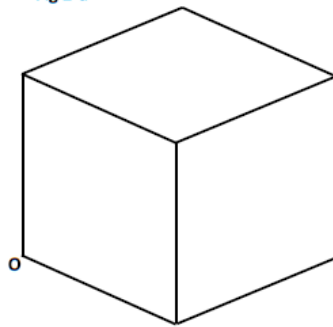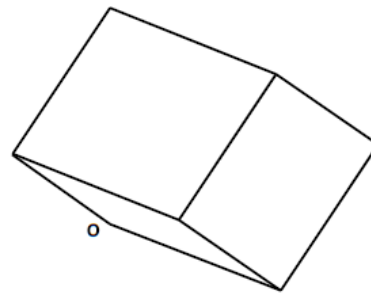Identify the required transformations with correct order.

Fig 2-a

Fig 2-b

O

O

209

GOAU /28-03-2015 / **CG Posttest**

Roll No.

Q 1. 2D Transformations
The object in fig 1-a is transformed as shown in fig 1-b,
Identify the required transformations with correct order.
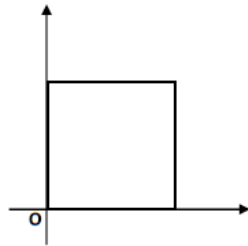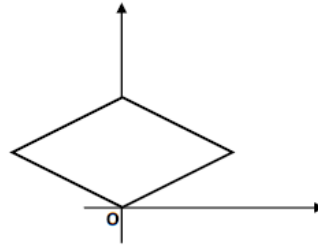
Fig 1-a

Fig 1-b

210

Roll No.

Q 2. 3D Transformations
The object in fig 2-a is transformed as shown in fig 2-b,
Identify the required transformations with correct order.
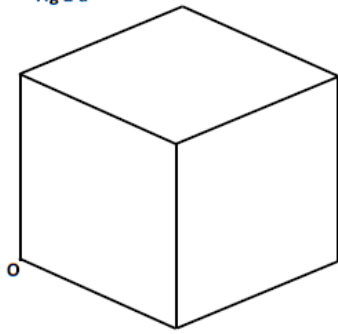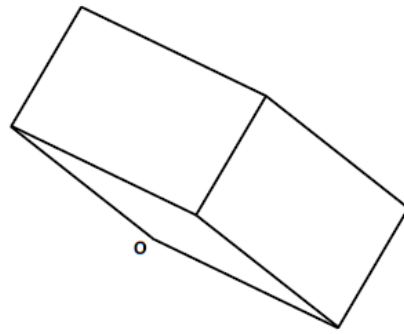
Fig 2-a

Fig 2-b

O

O

211

Appendix VI
Participant Consent Form

STUDY TITLE: TO EVALUATE THE EFFECTIVENESS OF TIMeR IN VISUALIZING AND SOLVING PROBLEMS IN MENTAL ROTATION / ENGINEERING GRAPHICS / COMPUTER GRAPHICS COURSE.

You have been asked to participate in a research study conducted by Kapil Kadam from the Inter-Disciplinary Program in Educational Technology at the Indian Institute of Technology Bombay (IITB). The purpose of the study is 'To evaluate the effectiveness of Blender intervention in visualizing and solving Engineering Graphics problems.' The results of this study will be included in the Ph.D. thesis of Kapil Kadam. You were selected as a possible participant in this study because of your educational background as a first-year engineering student studying Engineering Graphics course.

You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

- In this study you will be asked to view and/or interact with visualization on the topic of 'Isometric drawings and orthographic drawings'.

- This will have no bearing on your university marks. The data will be used for research purposes only, by the investigator of this study.

- Participating in this research study is voluntary. You have the right not to answer any question, and to stop your participation in the study at any time. We expect that the study will take about three to four hours.

- We will not use your name in publications; however, we may need to use your academic performance details if you give us permission.

- You will not be compensated for the participation.

- You will be interviewed after the experiment and interview will be audio/video recorded.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

(*Please check all that apply*)

I give permission for the following information to be included in publications resulting from this study:

[ ] my academic performance details

Your name and signature:

Put your name and signature in the table 'List of Participants'

Signature of Investigator _____Date _____

References

Akasah, Z. A., & Alias, M. (2010). Bridging the Spatial Visualisation Skills Gap Through Engineering Drawing Using the Whole-To-Parts Approach. Australasian Journal of Engineering Education, 16(1), 81-86.

Alias, M. (2000). Spatial Visualisation Ability and Problem Solving in Civil Engineering, Doctoral thesis, University of Surrey.

Alias, M., Gray, D. E., & Black, T. R. (2002). Attitudes Towards Sketching and Drawing and the Relationship with Spatial Visualisation Ability in Engineering Students. International Education Journal, 3(3), 165-175.

Andrei, R. M., Callieri, M., Zini, M. F., Loni, T., Maraziti, G., Pan, M. C., & Zoppè, M. (2012). Intuitive Representation of Surface Properties of Biomolecules Using BioBlender. BMC bioinformatics, 13(Suppl 4), S16.

Ardebili, M., & Sadegh, A. (2004). A New Approach to Teaching Engineering Graphics Using Active Learning and Product Realization. Proceeding of the 2004 American Society for Engineering Education Annual Conference & Exposition Copyright©

Ault, K. H. (2010). Assessing and Enhancing Visualization Skills of Engineering Students in Africa: A Comparative Study. Engineering Design Graphics Journal. Volume 74, Number 2. Print ISSN 0046-2012. Online ISSN 1949-9167.

Baartmans, B. J., & Sorby, S. A. (1996). Introduction to 3-D Spatial Visualization. Englewood Cliffs, NJ: Prentice Hall.

Bhatt, N. D. (2011). Engineering Drawing (Plane and solid geometry).

Blender Tool, Web url: http://www.blender.org/ (20012 - 2017).

Ben-Haim, D., Lappan, G., & Houang, R. T. (1985). Visualizing Rectangular Solids Made of Small Cubes: Analyzing and Effecting Students' Performance. Educational studies in Mathematics, 16(4), 389-409.

Branoff, T. J., & Mapson, K. (2009). Large Course Redesign: Moving an Introductory Engineering Graphics Course from Face-To-Face to Hybrid Instruction. In South-eastern Section Meeting the American Society for Engineering Education, Marietta, Georgia (pp. 5-7).

Chandrasekharan, S., Mazalek, A., Nitsche, M., Chen, Y., & Ranjan, A. (2010). Ideomotor Design - Using Common Coding Theory to Derive Novel Video Game Interactions. Pragmatics & Cognition 18:2 (2010), 313–339. DOI 10.1075 / p&c.18.2.04 chaissn 0929–0907 / e-issn 1569–9943

Cincou, A. (2013). An Innovative and Interactive Approach to Teaching Industrial Drawing to Engineering Students. Proceedings of the Canadian Engineering Education Association.

Cohen, L., Manion, L., Morrison, K. (2007). Research Methods in Education, Book, Sixth edition (2007).

Contero, M., Ferran, N., Company, P., Saorín, J. L., Conesa, J. (2005). "Improving Visualization Skills in Engineering Education", IEEE Computer Graphics and Applications, pp. 24-31.

Cooke-Simpson, A., Voyer, D. (2007). Confidence and Gender Differences on the Mental Rotations Test, Learning and Individual Differences 17, 181–186.

Creswell, J. (2012). Educational Research, Planning, Conducting, and Evaluating Quantitative and Qualitative Research. Fourth Edition. Pearson.

Crown, S. (2001). Improving Visualization Skills of Engineering Graphics Students Using Simple JavaScript Web Based Games, Journal of Engineering Education, July 2001.

Earle, J. H. (1967). Engineering Graphics and Design Problems-1. Addison-Wesley.

Earle, J. H. (1968). Engineering Graphics and Design Problems-2. Addison-Wesley.

Earle, J. H. (1969). Engineering Graphics and Design Problems-3. Addison-Wesley.

Ferguson, C., Ball, A., McDaniel, W., and An- derson, R. (2008). A Comparison of Instructional Methods for Improving the Spatial- Visualization Ability of Freshman Technology Seminar Students, Proceedings, IAJC-IJME International Conference

Flusberg, S. J., & Boroditsky, L. (2011). Are Things that are Hard to Physically Move also Hard to Imagine Moving? Psychonomic bulletin & review, 18(1), 158-164.

Froese, M. E., Tory, M., Evans, G. W., & Shrikhande, K. (2013). Evaluation of Static and Dynamic Visualization Training Approaches for Users with Different Spatial Abilities. Visualization and Computer Graphics, IEEE Transactions on, 19(12), 2810-2817.

Gardner, H. (1983). Frames of Mind. New York: Basic Books Inc.

Gardner, H. (2011). Frames of mind: The theory of multiple intelligences. Basic books.

Garmendia, M., Guisasola, J., & Sierra, E. (2007). First-year Engineering Students' Difficulties in Visualization and Drawing Tasks. European Journal of Engineering Education, 32(3), 315-323.

Gillespie, W. H. (1995). Using Solid Modeling Tutorials to Enhance Visualization Skills (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 9606359)

Godfrey, G. S. (1999). Three-Dimensional Visualization Using Solid-Model Methods: A Comparative Study of Engineering and Technology Students (Doctoral dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 9955758)

Gould, J. (2012). Learning Theory and Classroom Practice in the Lifelong Learning Sector. Learning Matters.

Guay, R. (1977). Purdue Spatial Visualization Tests: Visualization of Rotations. Copyright, Purdue Research Foundation, 1976

Guay, R. B. (1980). Spatial Ability Measurement: A Critique and an Alternative. A paper presented at the 1980 Annual Meeting of the American Education Research Association, April, Boston. (ERIC Document Reproduction Service No. ED189166)

Gumster, J. V. (2003, July). Blender as an Educational Tool. In ACM SIGGRAPH 2003 Educators Program (pp. 1-1). ACM.

Holliday-Darr, K., & Lobaugh, M. (2003). Graphic Claymation–Visualization Through Sight and Touch. *age*, *8*, 1.

Hewner, M., & Mishra, S. (2016, August). When Everyone Knows CS is the Best Major: Decisions about CS in an Indian context. In Proceedings of the 2016 ACM Conference on International Computing Education Research (pp. 3-11). ACM.

Jansen-Osmann, P., & Heil, M. (2007). Suitable Stimuli to Obtain (no) Gender Differences in the Speed of Cognitive Processes Involved in Mental Rotation. Brain and Cognition, 64, 217−227.

Jerz, R. (2002, June). Redesigning Engineering Graphics to Include CAD and Sketching Exercises. In Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.

Jiannan, C. (1998). Kernel Problems of the Modernization of Engineering Graphics Education1. Journal for Geometry and Graphics, 2(1), 65-70.

Johnson, M. (1990). Speed of Mental Rotation as A Function of Problem-Solving Strategies. Perceptual and Motor Skills, 1990, 71, 803-806

Kadam, K., Sahasrabudhe, S., & Iyer, S. (2012, July). Improvement of Mental Rotation Ability using Blender 3-D. In Technology for Education (T4E), 2012 IEEE Fourth International Conference on (pp. 60-66). IEEE.

Kadam, K., Sahasrabudhe, S., Iyer, S., & Kamat, V. (2013). Integration of Blender 3D in Basic Computer Graphics Course. International Conference on Computers in Education (ICCE), Bali, Indonesia, Nov 2013

Kadam, K., & Iyer, S. (2014, July). Improvement of Problem Solving Skills in Engineering Drawing Using Blender Based Mental Rotation Training. In Advanced Learning Technologies (ICALT), 2014 IEEE 14th International Conference on (pp. 401-402). IEEE.

Kadam, K., & Iyer, S. (2015, July). Impact of Blender based 3D Mental Rotation Ability Training on Engineering Drawing Skills. In Advanced Learning Technologies (ICALT), 2015 IEEE 15th International Conference on (pp. 370-374). IEEE.

Kaufman S., B. (2007). Sex Differences in Mental Rotation and Spatial Visualization Ability: Can They be Accounted for by Differences in Working Memory Capacity? Intelligence 35, 211–223

Khabia, S., & Khabia, D. (2012, January). Engineering Drawing Teaching Made Easy by Use of Latest Educational Technology. In Technology Enhanced Education (ICTEE), 2012 IEEE International Conference on (pp. 1-8). IEEE.

Kosse, V. (2005). Engineering Drawing as a Global Language for Engineers. In 4th ASEE/AaeE Global Colloquium on Engineering Education (p. 1232). Australasian Association of Engineering Education.

Kuang, J. S., & Hu, Thomas., W. (2004). A Multimedia-based Approach to Teaching Engineering Drawing.

Leopold, C., Gorska, R. A., & Sorby, S. A. (2001). International Experiences in Developing the Spatial Visualization Abilities of Engineering Students. Journal for Geometry and Graphics, 5(1), 81-91.

Linn, M. C., & Petersen, A., C. (1985, December). Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis. In Child Development 56(6), pp. 1479-1498.

Maier, P. H. (1994). Raeumliches vorstellungsvermoegen [Spatial Imagination]. New York: Lang.

Maier, P. H. (1998). Spatial Geometry and Spatial Ability: How to Make Solid Geometry Solid? In E. Cohors-Fresenborg, H. Maier, K. Reiss, G. Toerner, and H.-G. Weigand (eds.), Selected Papers from the Annual Conference of Didactics of Mathematics 1996, Regensberg, pp. 63–75.

Marschner, S., & Shirley, P. (2015). Fundamentals of Computer Graphics. CRC Press.

Martin-Dorta, N., Saorin, J. L., & Contero, M. (2008). Development of a Fast-Remedial Course to Improve the Spatial Abilities of Engineering Students, Journal of Engineering Education (October 2008), pp. 505-513

Martin-Dorta, N., Saorin, J. L., & Contero, M. (2011). Web-based Spatial Training Using Handheld Touch Screen Devices. Journal of Educational Technology & Society, 14(3), 163-177.

Medupin, R. O., Abubakre, O. K., Adebayo, S. A., Enock, O. I., & Sulayman, F. A. (2015). Students' Academic Performance in Engineering Drawing in Nigerian Polytechnics: A Case Study of the Federal Polytechnic Bida, Nigeria. Journal of Multidisciplinary Engineering Science and Technology, 2(2), 99-106.

Miller, C. L. (1992). Enhancing Visual Literacy of Engineering Students through the Use of Real and Computer-Generated Models. Engineering Design Graphics Journal, 56(1), 27-38.

Moè, A. (2009). Are Males Always Better Than Females in Mental Rotation? Exploring a Gender Belief Explanation, Learning and Individual Differences 19, 21–27.

Mohler, J. L. (2006). Computer Graphics Education: Where and How Do We Develop Spatial Ability? EUROGRAPHICS '06 / Judy Brown and Werner Hansmann, Education Papers

Nagy-Kondor, R. (2007). Spatial Ability of Engineering Students. In Annales Mathematicae et Informaticae (Vol. 34, No. 2007).

Norman, K. L. (1994). Spatial Visualization – A Gateway to Computer-Based Technology. Journal of Special Educational Technology, XII (3), 195–206.

Olkun, S. (2003). Making Connections: Improving Spatial Abilities with Engineering Drawing Activities. International Journal of Mathematics Teaching and Learning, 3(1), 1-10.

Onyancha, R., Towle, E., & Kinsey, B. (2007). Improvement of Spatial Ability Using Innovative Tools: Alternative View Screen and Physical Model Rotator. Proceedings of the 114th ASEE Conference and Exposition.

Onyancha, R. M., Derov, M., and Kinsey, B. L. (2009). Improvements in Spatial Ability as a Result of Targeted Training and Computer Aided Design Software Use: Analyses of Object Geometries and Rotation Types. J. Eng. Educ., 98(2), 157–167.

Ortlipp, M. (2008). Keeping and Using Reflective Journals in the Qualitative Research Process. The qualitative report, 13(4), 695-705.

Pallant, J. (2005). SPSS Survival Manual. McGraw-Hill Education (UK).

Pillay, H. K. (1994). Cognitive Load and Mental Rotation: Structuring Orthographic Projection for Learning and Problem Solving. Instructional Science, 22(2), 91-113.

Plomp, T., & Nieveen, N. (2013). Educational Design Research: illustrative cases.

Rabiee, F. (2004). Focus-Group Interview and Data Analysis. Proceedings of the Nutrition Society (2004), 63, 655–660, DOI:10.1079/PNS2004399.

Rifkin, B. (2005). A Ceiling Effect in Traditional Classroom Foreign Language Instruction: Data from Russian. The Modern Language Journal, 89(1), 3-18.

Sahasrabudhe, S., & Iyer, S. (2009). Creating 3D Animations of Laboratory Experiments Using Open Source Tools, Proceedings of ICEL 2009, Toronto, Canada

Samsudin, K. A., & Ismail, A. (2004). The Improvement of Mental Rotation Through Computer Based Multimedia Tutor. Malaysian Online Journal of Instructional Technology (MOJIT), 1(2), 24-34.

Samsudin, K. A., Rafi, A., & Hanif, A. S. (2011). Training in Mental Rotation and Spatial Visualization and Its Impact on Orthographic Drawing Performance. Educational Technology & Society, 14(1), 179-186.

Shepard, R., N. & Metzler, J. (1971). Mental Rotation of Three-Dimensional Objects, science, New Series, Vol. 171, No. 3972 (Feb 1971), pp. 701-703, Published by: American Association for the Advancement of Science.

Smail, B. (1983). Spatial Visualization Skills and Technical Drafts Education. Educational Research, 25 (November 1983): 230-1.

Sorby, S. A., & Wysocki, A. F. (2003). Introduction to 3D Spatial Visualization: an active approach. Cengage Learning.

Sorby, S. (2009). Educational Research in Developing 3-D Spatial Skills for Engineering Students, International Journal of Science Education, Vol.31, No. 3, pp. 459-480, 2009-02-00

Sutton, K., Heathcote, A., & Bore, M. (2005). Implementing a Web-based Measurement of 3D Understanding. In Proceedings of the 17th Australia conference on Computer-Human Interaction: Citizens Online: Considerations for Today and the Future (OZCHI '05). Computer-Human Interaction Special Interest Group (CHISIG) of Australia, Narrabundah, Australia, Australia, 1-4.

Sutton, K. J., & Williams, A. P. (2007). Spatial Cognition and its Implications for Design. International Association of Societies of Design Research, Hong Kong, China.

Thomas, D. A. (1996). Enhancing Spatial Three-Dimensional Visualization and Rotational Ability with Three-Dimensional Computer Graphics (Doctoral Dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 9702192)

Turner, G. F. W. (1997). The Effects of Stimulus Complexity, Training, and Gender on Mental Rotation Performance: A Model-Based Approach (Doctoral Dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 9817592)

Upadhye, S. N., Shaikh, S. M., & Yalsangikar, T. B. (2013). New Teaching Method to Teach Projection & Development of Solids. International Journal of Engineering, 2(2).

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2012, June 4). The Malleability of Spatial Skills: A Meta-Analysis of Training Studies. Psychological Bulletin. Advance online publication. doi: 10.1037/a0028446

Vandenberg, S. G., & Kuse, A. R. (1978). Mental rotations: A Group Test of Three-Dimensional Spatial Visualization. Perceptual and Motor Skills, 47, 599-604.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of Gender Differences in Spatial Abilities: A Meta-Analysis and Consideration of Critical Variables. Psychological Bulletin, 117, 250–271.

Voyer, D., & Saunders, K. A. (2004). Gender Differences on the Mental Rotations Test: a Factor Analysis, Acta Psychologica 117, 79–94.

Wiedenbauer, G., & Jansen-Osmann, P. (2008). Manual Training of Mental Rotation in Children, Learning and Instruction 18 (2008).

Wu, C. F., & Chiang, M. C. (2013). Effectiveness of Applying 2D Static Depictions and 3D Animations to Orthographic Views Learning in Graphical Course. Computers & Education, 63(Complete), 28-42.

Yates, B. C. (1988). The Computer as an Instructional Aid and Problem-Solving Tool: An Experimental Analysis of Two Instructional Methods for Teaching Spatial Skills to Junior High School Students (Doctoral Dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. 8903857)

Yue, J. (2009). Spatial Visualization by Realistic 3D Views. Engineering Design Graphics Journal, 72(1).

Zaiyouna, R. (1995). Sex Differences in Spatial Ability: The Effect of Training in Mental Rotation (Doctoral Dissertation). Available from ProQuest Dissertations and Theses database. (UMI No. MM04165)

List of Publications

Thesis Related Publications

Kapil Kadam, Sameer Sahasrabudhe and Sridhar Iyer. Improvement of Mental Rotation Ability Using Blender 3-D. In Technology for Education (T4E) Fourth International Conference (IEEE 2012), 2012.

Kapil Kadam and Sridhar Iyer. Improvement of Problem Solving Skills in Engineering Drawing Using Blender Based Mental Rotation Training. In IEEE 14th International Conference on Advanced Learning Technologies (ICALT), 401-402, Athens, Greece, July 2014.

Kapil Kadam, Sridhar Iyer. Impact of Blender Based 3-D Mental Rotation Ability Training on Engineering Drawing Skills. In IEEE 15th International Conference on Advanced Learning Technologies (ICALT), Hualien, Taiwan, July 2015.

Kapil Kadam, Sameer Sahasrabudhe, Sridhar Iyer and Venkatesh Kamat. Integration of Blender 3D in a basic computer graphics course. In IEEE 21st International Conference on Computers in Education (ICCE 2013), Bali, Indonesia, 2013.

Other Publications

A. Anand, A. Kothiyal, A. Diwakar, A. Kenkre, A. Deep, D. Reddy, J. Warriem, **Kapil Kadam**, Neena Thota. Designing Engineering Curricula Based on Phenomenographic Results: Relating Theory to Practice. In Sixth international conference on Technology for Education (T4E), (pp. 80-87). IEEE, December 2014

Acknowledgement

I wish to express my utmost gratitude and heartfelt appreciation to my research advisor **Prof. Sridhar Iyer**, for his guidance, continuous support, and motivation throughout the course of my research work. Without my supervisor's advice this thesis would not have been possible. I thank **Prof. Sahana Murthy** for valuable guidance for improving my thesis work as my Research Progress Committee member. Her comments helped me to explore the possibilities of a wider research domain and at the same time details to the finest granularity. I also take this opportunity to thank my other Research Progress Committee member **Prof. Anirudha Joshi** for his valuable comments that helped to improve my research work.

I am grateful to all the instructors and students who agreed to participate in my studies. I take the privilege to acknowledge my fellow researchers Sameer Sahasrabudhe, Shitanshu Mishra, and Jayakrishnan M. for their help in experiment conduction and their support during my work. I would also like to thank IIT Bombay and projects (OSCAR, TEQIP) for financial support.

I thank all the members of Interdisciplinary Programme in Educational Technology, IIT Bombay and who provided a friendly environment for research. My special thanks to the staff of IDP in Educational Technology, IIT Bombay. I thank all ET research scholars who encouraged me through constructive feedback throughout my research work. I dedicate this thesis to my family, friends, and my research advisor who encouraged me to continue my education and constant support at every stage of my thesis work. I take privilege to thank all the people who helped and supported me directly or indirectly throughout my academic career.

Date: Kapil Kadam

IIT Bombay, India   10438002