Development of Mental Rotation Skills Using 3D Visualization Tool

Kapil Kadam
10438002
kapilkadam@iitb.ac.in

Under the supervision of
Prof. Sridhar Iyer

IDP in Educational Technology, Indian Institute of Technology Bombay
Background
**Background:** Engineering Drawing (ED) Learning Difficulties

- **Learning Difficulties** in ED subject (analyzing views, conversion of views, etc.)
- Existing teaching methods (conventional to modern)
- Certain difficulties remain
- One of the main reasons is students’ **poor spatial skills** (Medupin, et al 2015).
- Hence it is essential to identify and develop the relevant spatial skills

Multiple Intelligence & Spatial Skills

- Logical - Mathematical
- Bodily - Kinesthetic
- Musical
- Spatial
- Linguistic
- Inter - personal
- Intra - personal

Spatial perception
Spatial visualization
Mental rotation
Spatial relation
Spatial orientation
Background: Multiple Intelligence & Spatial Skills

Multiple Intelligence

- Logical - Mathematical
- Bodily - Kinesthetic
- Musical
- Linguistic
- Inter - personal
- Intra - personal

Spatial Skills

- Spatial perception
- Spatial visualization
- Spatial relation
- Spatial orientation

Mental rotation
Background: MR & ED association

Multiple Intelligence
- Logical - Mathematical
- Bodily - Kinesthetic
- Musical
- Linguistic
- Inter - personal
- Intra - personal

Spatial
- Spatial perception
- Spatial visualization
- Spatial relation
- Spatial orientation

Mental rotation

is associated with ED problems
• Consider an ED problem: Conversion of an isometric view to its orthographic views and vice versa

  • Identifying surfaces (top, front, side, & hidden)
  • Identifying the shape of the surfaces
  • Visualizing shapes at the right angle by rotating
• Consider an ED problem: Conversion of an isometric view to its orthographic views and vice versa

• Some common ED problem-solving steps
  • Identifying surfaces (top, front, side, & hidden)
  • Identifying the shape of the surfaces
  • Visualizing shapes at a right angle by rotating

Involves rotation and requires mental rotation
Mental Rotation (MR) Skills
“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).
“The ability to rapidly and accurately rotate a 2D or 3D figure”,
(Maier, 1998).
Measurement of MR

- Test item from Vandenberg’s Mental Rotation Test instrument

VMRT Sample Item (reproduced from Vandenberg & Kuse, 1978)
Measurement of MR

• Test Item from Vandenberg’s Mental Rotation Test Instrument
Cognitive steps of MR

- Test Item from Vandenberg’s Mental Rotation Test Instrument

- For solving such MR problems, it requires to perform certain Cognitive Steps (Johnson 1990).
The Cognitive Steps of MR (Johnson 1990)

1. Form a mental representation of an object,
2. Rotate the object mentally until its axial orientation allows the comparison to the standard,
3. Make the comparison,
4. Make a judgment, and
5. Report a decision.
The Cognitive Steps of MR (Johnson 1990)

1. Form a mental representation of an object,
2. Rotate the object mentally until its axial orientation allows the comparison to the standard,
3. Make the comparison,
4. Make a judgment, and
5. Report a decision.

The 3D object is represented as 2D drawing, and to perform cognitive steps of MR it may require doing following steps:

- Imagining all aspect of 3D forms, structures, various views (front-side-top-3D), faces, shapes, and orientations of that object.
- Imagining the various axes of rotation

The visual information also needs to be stored mentally while doing the comparison of various possible orientations along with the problem figures.
The Cognitive Steps of MR (Johnson 1990)

1. Form a mental representation of an object,
2. Rotate the object mentally until its axial orientation allows the comparison to the standard,
3. Make the comparison,
4. Make a judgment, and
5. Report a decision.

The 3D object is represented as 2D drawing, and to perform cognitive steps of MR it may require doing following steps:

- Imagining all aspect of 3D forms, structures, various views (front-side-top-3D), faces, shapes, and orientations of that object.
- Imagining the various axes of rotation
- The visual information also needs to be stored mentally while doing the comparison of various possible orientations along with the problem figures.
The mental rotation training methods involve:

• Physical training,
• Computer-based training,
• Computer-aided design (CAD) training,
• Video games,
• Animations,
• Engineering drawing activities and many.
Improvement of MR Skills

- Studies from the literature focus on the development and assessment of multiple spatial skills at a time.
- It may affect the development of an individual skill.
- Training sessions had longer durations (spread over weeks), with only a few exceptions.
- Most of the studies have used computer-based training methods based on 3D visualization tools (such as CAD) and utilized interactivity as an important instructional element.
- Most of the work was carried out in an engineering drawing domain.

This emphasizes the importance of spatial skills, especially mental rotation in the ED.
<table>
<thead>
<tr>
<th>Study</th>
<th>Treatment duration</th>
<th>Outcome measure</th>
<th>Training Description</th>
<th>Sample</th>
<th>Brief Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contero, et al. (2005)</td>
<td>3 sessions of 2 hours</td>
<td>Paper Pencil, Web-based</td>
<td>6-hour course, web-based</td>
<td>78 low scorers from 461, engg. students</td>
<td>Improvement in MR and spatial skills</td>
</tr>
<tr>
<td>Flusberg (2011)</td>
<td>8 min tasks</td>
<td>MRT</td>
<td>Physical rotation of Shepard &amp; Metzler objects</td>
<td>64 participants</td>
<td>MR is connected to the real-world motor experiences</td>
</tr>
<tr>
<td>Froese (2013)</td>
<td>1.5-hour session</td>
<td>MRT, PFT, OPT</td>
<td>CAD, static vs. dynamic visualization</td>
<td>117 participants</td>
<td>Improvement in the performance</td>
</tr>
<tr>
<td>Gillespie (1995)</td>
<td>10 weeks</td>
<td>PFT, MRT, Rotated Blocks</td>
<td>CAD, solid modeling tutorials</td>
<td>41 Engg. Graphics students</td>
<td>Improvement of visualization skills</td>
</tr>
<tr>
<td>Godfrey (1999)</td>
<td>16 weeks</td>
<td>PSVT</td>
<td>CAD</td>
<td>76 Engg Graphics students</td>
<td>Training is beneficial</td>
</tr>
<tr>
<td>Lohman (1990)</td>
<td>3 sessions</td>
<td>Rotation and visualization test</td>
<td>Rotation problems</td>
<td>83, 50, 385</td>
<td>Improvement in performance</td>
</tr>
</tbody>
</table>

*Table continued...*
<table>
<thead>
<tr>
<th>Study</th>
<th>Treatment duration</th>
<th>Outcome measure</th>
<th>Training Description</th>
<th>Sample</th>
<th>Brief Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Onyancha, et al. (2009)</td>
<td>4 weeks</td>
<td>PSVT (web-based)</td>
<td>CAD course</td>
<td>81, 59, 23, 27</td>
<td>Improvement in performance score.</td>
</tr>
<tr>
<td>Samsudin &amp; Ismail (2004)</td>
<td>5 weeks, 1.5 hours per week</td>
<td>CB</td>
<td>CAD</td>
<td>58 Undergraduates, Info. Tech. &amp; Communication.</td>
<td>Treatment was effective in terms of accuracy</td>
</tr>
<tr>
<td>Samsudin, et al. (2011)</td>
<td>8 weeks, 2 hours per week</td>
<td>CB and Online CBMT (free)</td>
<td>98 secondary school students</td>
<td></td>
<td>Statistically significant</td>
</tr>
<tr>
<td>Sorby (2009)</td>
<td>14 weeks in a semester</td>
<td>PSVT:R</td>
<td>Multimedia software course</td>
<td>157, 186 Engg. students</td>
<td>Development in spatial skills</td>
</tr>
<tr>
<td>Thomas (1996)</td>
<td>13 weeks</td>
<td>Cube Rotation</td>
<td>3D CAD vs 2D CAD</td>
<td>50 Technology Students</td>
<td>3D CAD is more effective than 2D CAD</td>
</tr>
<tr>
<td>Turner (1997)</td>
<td>12 weeks</td>
<td>MRT</td>
<td>CAD</td>
<td>556 Engg. Students</td>
<td>CAD shows more improvement than non-CAD</td>
</tr>
<tr>
<td>Wiedenbauer, et al. (2008)</td>
<td>Study 1: 37 minutes, Study 2: 60 minutes</td>
<td>CB</td>
<td>Game Studio</td>
<td>Study 1: 107 Study 2: 67</td>
<td>Effective for limited trained objects</td>
</tr>
<tr>
<td>Zaiyouna (1995)</td>
<td>4-5 weeks</td>
<td>MRT</td>
<td>CBT</td>
<td>19</td>
<td>Gender study, no difference</td>
</tr>
</tbody>
</table>
Research Questions
Two categories of questions: Design Question and Research Question

**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.
“Investigating the effect of 3D visualization tool-based mental rotation training on students’ mental rotation skill, and learning of ED problem-solving.”

We have developed a “TIMeR: Training to Improve Mental Rotation Skills using Blender”
Our solution

“Investigating the effect of 3D visualization tool-based mental rotation training on students’ mental rotation skill.”

We have developed a “TIMeR: Training to Improve Mental Rotation Skills using Blender”
• **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?
Research Methodology
We employ the mixed method as the overall research design.

**Mixed method:** It 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).
<table>
<thead>
<tr>
<th>Study Designs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Single group pretest-posttest design</td>
</tr>
<tr>
<td></td>
<td>• Two groups posttest only design</td>
</tr>
<tr>
<td>Sample</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Type1 - Students without prior knowledge of ED</td>
</tr>
<tr>
<td></td>
<td>• Type2 - Students with prior knowledge of ED</td>
</tr>
<tr>
<td></td>
<td>• Type3 - Students learning CG course</td>
</tr>
<tr>
<td>Instruments &amp;</td>
<td>Quantitative</td>
</tr>
<tr>
<td>Data Collection</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Performance scores</td>
</tr>
<tr>
<td></td>
<td>• Mental Rotation Assessment (VMRT)</td>
</tr>
<tr>
<td></td>
<td>• ED Assessment (SVATI)</td>
</tr>
<tr>
<td></td>
<td>• ED Assessment (Textbook Questions)</td>
</tr>
<tr>
<td></td>
<td>• CG Assessment</td>
</tr>
<tr>
<td></td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td>• Reflective Journals</td>
</tr>
<tr>
<td></td>
<td>• Focus-Group Interview</td>
</tr>
<tr>
<td></td>
<td>• Semi-structured Interview</td>
</tr>
<tr>
<td>Data Analysis Procedure</td>
<td>Quantitative</td>
</tr>
<tr>
<td></td>
<td>• Shapiro-Wilk’s test of normality</td>
</tr>
<tr>
<td></td>
<td>• t-test or Mann-Whitney test or Wilcoxon test</td>
</tr>
<tr>
<td></td>
<td>• Means, standard deviations, effect size, and learning gain</td>
</tr>
<tr>
<td></td>
<td>Qualitative</td>
</tr>
<tr>
<td></td>
<td>Transcription, Categorizing and coding, Interpreting, Reporting</td>
</tr>
</tbody>
</table>
| Study Designs | • Single group pretest-posttest design  
|              | • Two groups posttest only design |
| Sample       | • Type1 - Students without prior knowledge of ED  
|              | • Type2 - Students with prior knowledge of ED  
|              | • Type3 - Students learning CG course |
| Instruments & Data Collection | Quantitative | • Performance scores  
|                             |              | • Mental Rotation Assessment (VMRT)  
|                             |              | • ED Assessment (SVATI)  
|                             |              | • ED Assessment (Textbook Questions)  
|                             |              | • CG Assessment  
|                             | Qualitative  | • Reflective Journals  
|                             |              | • Focus-Group Interview  
|                             |              | • Semi-structured Interview  
| Data Analysis Procedure | Quantitative | • Shapiro-Wilk’s test of normality  
|                        |              | • t-test or Mann-Whitney test or Wilcoxon test  
|                        |              | • Means, standard deviations, effect size, and learning gain  
|                        | Qualitative  | Transcription, Categorizing and coding, Interpreting, Reporting |
| Study Designs | • Single group pretest-posttest design  
• Two groups posttest only design |
| Sample | • Type 1 - Students without prior knowledge of ED  
• Type 2 - Students with prior knowledge of ED  
• Type 3 - Students learning CG course |
| Instruments & Data Collection | **Quantitative** | • Performance scores  
• Mental Rotation Assessment (VMRT)  
• ED Assessment (SVATI)  
• ED Assessment (Textbook Questions)  
• CG Assessment |
| | **Qualitative** | • Reflective Journals  
• Focus-Group Interview  
• Semi-structured Interview |
| Data Analysis Procedure | **Quantitative** | • Shapiro-Wilk’s test of normality  
• t-test or Mann-Whitney test or Wilcoxon test  
• Means, standard deviations, effect size, and learning gain |
| | **Qualitative** | Transcription, Categorizing and coding, Interpreting, Reporting |
| Study Designs                  | • Single group pretest-posttest design  
|                              | • Two groups posttest only design      |
| Sample                       | • Type1 - Students without prior knowledge of ED  
|                              | • Type2 - Students with prior knowledge of ED  
|                              | • Type3 - Students learning CG course     |
| Instruments & Data Collection | Quantitative                          
|                              | • Performance scores                  
|                              | • Mental Rotation Assessment (VMRT)    
|                              | • ED Assessment (SVATI)                
|                              | • ED Assessment (Textbook Questions)   
|                              | • CG Assessment                       
|                              | Qualitative                           
|                              | • Reflective Journals                 
|                              | • Focus-Group Interview               
|                              | • Semi-structured Interview           |
| Data Analysis Procedure      | Quantitative                          
|                              | • Shapiro-Wilk’s test of normality     
|                              | • t-test or Mann-Whitney test or Wilcoxon test |
|                              | • Means, standard deviations, effect size, and learning gain |
|                              | Qualitative                           
|                              | Transcription, Categorizing and coding, Interpreting, Reporting |
| Study Designs                      | • Single group pretest-posttest design  
|                                  | • Two groups posttest only design      |
| Sample                           | • Type1 – Novice (Students without prior knowledge of ED)  
|                                  | • Type2 – Advanced learners (Students with prior knowledge of ED)  
<p>|                                  | • Type3 - Students learning CG course |
| Instruments &amp; Data Collection    | Quantitative                         |
|                                  | • Performance scores                 |
|                                  | • Mental Rotation Assessment (VMRT)   |
|                                  | • ED Assessment (SVATI)               |
|                                  | • ED Assessment (Textbook Questions)  |
|                                  | • CG Assessment                      |
|                                  | Qualitative                          |
|                                  | • Reflective Journals                |
|                                  | • Focus-Group Interview              |
|                                  | • Semi-structured Interview          |
| Data Analysis Procedure         | Quantitative                         |
|                                  | • Shapiro-Wilk’s test of normality    |
|                                  | • t-test or Mann-Whitney test or Wilcoxon test |
|                                  | • Means, standard deviations, effect size, and learning gain |
|                                  | Qualitative                          |
|                                  | Transcription, Categorizing and coding, Interpreting, Reporting |</p>
<table>
<thead>
<tr>
<th>RQ</th>
<th>RQ1</th>
<th>RQ2, RQ3</th>
<th>RQ4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study Type</strong></td>
<td>MR</td>
<td>ED</td>
<td>CG</td>
</tr>
<tr>
<td><strong>Study</strong></td>
<td>MR1</td>
<td>MR2</td>
<td>ED1</td>
</tr>
<tr>
<td><strong>Method</strong></td>
<td>Quantitative</td>
<td>Quantitative</td>
<td>Quantitative</td>
</tr>
<tr>
<td><strong>Study Design</strong></td>
<td>Single Group Pre-Post</td>
<td>Single Group Pre-Post</td>
<td>Single Group Pre-Post</td>
</tr>
<tr>
<td><strong>Sample</strong></td>
<td>N=42, Type¹</td>
<td>N=55, Type¹</td>
<td>N=114, Type¹</td>
</tr>
<tr>
<td><strong>Intervention</strong></td>
<td>TIMeR</td>
<td>TIMeR</td>
<td>TIMeR for ED</td>
</tr>
<tr>
<td><strong>Data Collection</strong></td>
<td>Scores</td>
<td>Scores</td>
<td>Scores, RJ, FGI</td>
</tr>
<tr>
<td><strong>Assessment Instrument</strong></td>
<td>VMRT</td>
<td>VMRT</td>
<td>SVATI</td>
</tr>
<tr>
<td><strong>Data Analysis</strong></td>
<td>Descriptive, Statistical</td>
<td>Descriptive, Statistical</td>
<td>Descriptive, Statistical, Content</td>
</tr>
</tbody>
</table>

*RJ – Reflective Journal, FGI – Focus Group Interview, VMRT – Vandenberg’s Mental Rotation Test Instrument, SVATI – Spatial Visualization Ability Test Instrument*
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.

ED Test Item (reproduced from Earle, 1969)

Orthographic to Isometric Conversion (reproduced from SVATI, Alias, 2000)

Isometric to Orthographic Conversion (reproduced from SVATI, Alias, 2000)

The correct option is ‘d’
Answering RQs and DQs
Answering DQ1

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. We call the training program, “TIMeR: Training to Improve Mental Rotation Skills using Blender.”
Answering DQ1

Cognitive Steps of MR
- Form a mental representation of an object,
- Rotate the object mentally until its axial orientation allows the comparison to the standard
- Make the comparison
- Make a judgment
- Report a decision

Training Tasks associated with MR steps
- Observation of 3D Object
- Rotation Task
- Verification of pretest solutions

Blender Features
- In single view window
- In multiple view
- Rotation of an object about various axes
- Rotation of an object in multiple views
- Rotation of views
Answering DQ1: TIMeR Overview

Phase 1: Preparatory Phase

Phase 2: Training Phase

Phase 3: Transfer Phase
Answering DQ1: TIMeR Overview

Phase 1: Preparatory Phase
- Prerequisite:
- Instructional Goal:
  - Task
  - Rationale
- Expected Outcome
- Tools & materials
- Instructional Strategy
  - Common
  - Different

Phase 2: Training Phase
- Instructional Goal:
  - Task
  - Rationale
- Expected Outcome
- Tools & materials
- Instructional Strategy
  - Common
  - Different

Phase 3: Transfer Phase
- Instructional Goal:
  - Task
  - Rationale
- Expected Outcome
- Tools & materials
- Instructional Strategy
  - Common
  - Different
## Answering DQ1: TIMeR Overview

<table>
<thead>
<tr>
<th>Phase 1: Preparatory Phase</th>
<th>Phase 2: Training Phase</th>
<th>Phase 3: Transfer Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prerequisite</strong></td>
<td>Completion of Pretest.</td>
<td>Completion of Phase 1.</td>
</tr>
<tr>
<td><strong>Instructional Goal</strong></td>
<td>Students should be able to use Blender user interface for getting acquainted with the 3D workspace</td>
<td>Students should develop the cognitive understanding of a 3D object and its rotation.</td>
</tr>
</tbody>
</table>
| **Task** | Getting Acquainted with the Blender User Interface. | A. Observation Task  
B. Rotation Task | Applying phase 2 Learnings to Pretest Objects |
| **Rationale** | Desirable for performing tasks from subsequent phases. | May help to form the mental representations of a 3D object | This phase may allow to concretize MR strategies. |
| **Expected Outcome** | Students will operate basic Blender UI and 3D workspace | Students will be able to form various mental representations of a 3D object | Students will apply the cognitive process of MR to different objects. |
| **Instructional Strategy** | Demo-Drill-Practice | Demo-Drill-Practice | Demo-Drill-Practice |
| **Common** | Instructional Strategy | Instructional Strategy | Instructional Strategy |
| **Different** | Training objects, Training Tasks | Training objects, Training Tasks | Training objects, Training Tasks |
Answering DQ1: TIMeR Overview

Phase 1: Preparatory Phase
Phase 2: Training Phase

Image: Students performing active manipulation of 3D objects during TIMeR
Answering DQ1: TIMeR Overview

Phase 1: Preparatory Phase

Phase 2: Training Phase

Phase 3: Transfer Phase

Students performing Phase 3 tasks (verifying test answers using Phase 2 tasks)
TIMeR procedure

Icebreaker → Pretest → Preparatory Phase → Training Phase → Transfer Phase → Posttest

TIMER Phases
**TIMeR procedure**

- **Icebreaker**
- **Pretest**
- **Preparatory Phase**
- **Training Phase**
- **Transfer Phase**
- **Posttest**

** VMRT Sample Item (reproduced from Vandenberg & Kuse, 1978)**

**Reproduced from Olkun, 2003**
Instructional strategy: Demo-Drill-Practice DDP

- **Demo**
  - Instructor shows demo
  - Student watches demo

- **Drill**
  - Instructor repeats demoed steps
  - Student repeats steps in-tandem with the instructor

- **Practice**
  - Student performs independent practice
  - Instructor provides assistance

Demonstration: (Blatnick, 1996; Kozhevnikov & Thornton, 2006; Mowrer-popiel, 1991; Pulos 1997; Robert and Chaperon 1989; Samsudin & Ismail 2004).
Practice: (Duesbury & O'Neil 1996; Lohman & Nicholas 1990; Martin-Dorta, et al., 2008; Sorby, 2009; Wiedenbauer et al., 2007).
Applying Common Coding
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).

Mental rotation is an imagination process of visualizing rotations of a three-dimensional object.

### Occurrences of Action-Perception-Imagination in Demo-Drill-Practice (DDP)

<table>
<thead>
<tr>
<th>DDP Stages</th>
<th>Student Action</th>
<th>Corresponding Common Coding Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Perception</td>
</tr>
<tr>
<td>Demo</td>
<td>Watches demo of MR task</td>
<td>X</td>
</tr>
<tr>
<td>Drill</td>
<td>Repeats steps of the task in-tandem with instructor</td>
<td>X</td>
</tr>
<tr>
<td>Practice</td>
<td>Independent practice with multiple objects</td>
<td>X</td>
</tr>
</tbody>
</table>
Answering RQ1
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.
Answering RQ1: Results

- The results from both MR1 and MR2 have shown that the TIMeR session significantly improves the MR skills in the first-year engineering undergraduates, especially for the low-performers.
- Not significant for High-performers, may be due to ceiling effect
- We also found that the TIMeR tasks were perceived to be used by the students while solving the posttest problem.

<table>
<thead>
<tr>
<th></th>
<th>MR1 Overall</th>
<th>MR1 Low</th>
<th>MR1 Medium</th>
<th>MR1 High</th>
<th>MR2 Overall</th>
<th>MR2 Low</th>
<th>MR2 Medium</th>
<th>MR2 High</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>42</td>
<td>20</td>
<td>10</td>
<td>12</td>
<td>55</td>
<td>35</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Pretest mean</td>
<td>4.48</td>
<td>2.20</td>
<td>4.70</td>
<td>8.08</td>
<td>2.92</td>
<td>1.57</td>
<td>4.53</td>
<td>7.60</td>
</tr>
<tr>
<td>Posttest mean</td>
<td>5.86</td>
<td>5.10</td>
<td>5.50</td>
<td>7.41</td>
<td>3.89</td>
<td>3.46</td>
<td>3.76</td>
<td>7.40</td>
</tr>
<tr>
<td>P</td>
<td><strong>0.001</strong></td>
<td><strong>0.000</strong></td>
<td>0.251</td>
<td>0.125</td>
<td><strong>0.006</strong></td>
<td><strong>0.000</strong></td>
<td>0.130</td>
<td>0.785</td>
</tr>
<tr>
<td>Effect size r</td>
<td>0.36</td>
<td>0.54</td>
<td>0.25 (small)</td>
<td>0.31 (med)</td>
<td>0.26 (med)</td>
<td>0.48 (large)</td>
<td>0.27 (med)</td>
<td>0.10 (small)</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.24</td>
<td>0.37</td>
<td>0.15</td>
<td>-0.34</td>
<td>0.14</td>
<td>0.22</td>
<td>-0.10</td>
<td>-0.08</td>
</tr>
</tbody>
</table>
Answering RQ2
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.
Answering RQ2: Results

• Research studies ED1, ED2, ED3 and ED4 answered this RQ.

• **ED1** results have shown that the TIMeR is significantly effective in improving students' ED problem-solving performance, especially low-performers and not for the non-low performers.

• **ED2** results shown that TIMeR is effective for low and medium achievers, and not effective for the high performers (advance learners)

• **ED3** results shown that TIMeR is effective for all students, no student was in high-performers category (advance learners)

• **ED4** had a two-group design and has shown that the TIMeR is significantly more effective 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.

• 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 (MCQ) used in ED1 and ED2 is unable to test the real effects on the non-low-performers in its current form. So these 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.
Answering RQ2: Results

### Novice learners

<table>
<thead>
<tr>
<th></th>
<th>ED1</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>N</td>
<td>114</td>
<td>32</td>
<td>43</td>
<td>39</td>
</tr>
<tr>
<td>Pretest mean</td>
<td>2.07</td>
<td>0.71</td>
<td>2.00</td>
<td>3.28</td>
</tr>
<tr>
<td>Posttest mean</td>
<td>2.49</td>
<td>2.25</td>
<td>2.13</td>
<td>3.07</td>
</tr>
<tr>
<td>P</td>
<td>0.001</td>
<td>0.000</td>
<td>0.420</td>
<td>0.102</td>
</tr>
<tr>
<td>Effect size r</td>
<td>0.21 (med)</td>
<td>0.55 (large)</td>
<td>0.08 (small)</td>
<td>0.18</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.22</td>
<td>0.46</td>
<td>0.06</td>
<td>-0.29</td>
</tr>
</tbody>
</table>

The correct option is 'd' for Novice learners.

### Advanced learners

#### ED1

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>59</td>
<td>7</td>
<td>8</td>
<td>44</td>
</tr>
<tr>
<td>Pretest mean</td>
<td>2.983</td>
<td>1.000</td>
<td>2.000</td>
<td>3.477</td>
</tr>
<tr>
<td>Posttest mean</td>
<td>3.288</td>
<td>2.857</td>
<td>3.500</td>
<td>3.318</td>
</tr>
<tr>
<td>P</td>
<td>0.068</td>
<td>0.026</td>
<td>0.014</td>
<td>0.289</td>
</tr>
<tr>
<td>Effect size r</td>
<td>0.167 (small)</td>
<td>0.596 (large)</td>
<td>0.612 (large)</td>
<td>0.113</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.299</td>
<td>0.619</td>
<td>0.75</td>
<td>-0.30</td>
</tr>
</tbody>
</table>

### Advanced learners

#### ED2

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>38</td>
<td>12</td>
<td>26</td>
<td>0</td>
</tr>
<tr>
<td>Pretest mean</td>
<td>2.815</td>
<td>1.25</td>
<td>3.538</td>
<td>-</td>
</tr>
<tr>
<td>Posttest mean</td>
<td>3.706</td>
<td>2.833</td>
<td>4.231</td>
<td>-</td>
</tr>
<tr>
<td>P</td>
<td>0.001</td>
<td>0.002</td>
<td>0.030</td>
<td>-</td>
</tr>
<tr>
<td>Effect size r</td>
<td>0.386 (medium)</td>
<td>0.622 (large)</td>
<td>0.300 (medium)</td>
<td>-</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.182</td>
<td>0.234</td>
<td>0.155</td>
<td>-</td>
</tr>
</tbody>
</table>

### ED3

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>23</td>
<td>18</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Pretest mean</td>
<td>2.000</td>
<td>1.000</td>
<td>2.000</td>
<td>3.477</td>
</tr>
<tr>
<td>Posttest mean</td>
<td>3.288</td>
<td>2.857</td>
<td>3.500</td>
<td>3.318</td>
</tr>
<tr>
<td>P</td>
<td>0.068</td>
<td>0.026</td>
<td>0.014</td>
<td>0.289</td>
</tr>
<tr>
<td>Effect size r</td>
<td>0.167 (small)</td>
<td>0.596 (large)</td>
<td>0.612 (large)</td>
<td>0.113</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.299</td>
<td>0.619</td>
<td>0.75</td>
<td>-0.30</td>
</tr>
</tbody>
</table>

---

**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.

---

The correct option is ‘d’.
Answering RQ2: Results

ED4 Between group results

<table>
<thead>
<tr>
<th>TIMeR Group (Mean)</th>
<th>Test1</th>
<th>Test2</th>
<th>Test3</th>
<th>Test4</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.00</td>
<td>7.44</td>
<td>5.77</td>
<td>7.00</td>
<td></td>
</tr>
<tr>
<td>Conventional Group (Mean)</td>
<td>3.87</td>
<td>6.12</td>
<td>4.75</td>
<td>4.25</td>
</tr>
<tr>
<td>P</td>
<td>0.834</td>
<td>0.036</td>
<td>0.150</td>
<td>0.000</td>
</tr>
<tr>
<td>Effect size $r$</td>
<td>0.038</td>
<td>0.359</td>
<td>0.246</td>
<td>0.673</td>
</tr>
<tr>
<td>Small</td>
<td>Medium</td>
<td>Close to medium</td>
<td>large</td>
<td></td>
</tr>
</tbody>
</table>

ED4 Within group results for separate topics

**Topic 1: Orthographic Projection**

<table>
<thead>
<tr>
<th>Group</th>
<th>TIMeR</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Test1</td>
<td>4.00</td>
<td>3.87</td>
</tr>
<tr>
<td>Test2</td>
<td>7.44</td>
<td>6.12</td>
</tr>
<tr>
<td>P</td>
<td>0.001</td>
<td>0.010</td>
</tr>
<tr>
<td>Effect size $r$</td>
<td>0.575</td>
<td>0.454</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.86</td>
<td>0.55</td>
</tr>
<tr>
<td>Large</td>
<td>Close to large</td>
<td></td>
</tr>
</tbody>
</table>

**Topic 2: Isometric Projection**

<table>
<thead>
<tr>
<th>Group</th>
<th>TIMeR</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>18</td>
<td>16</td>
</tr>
<tr>
<td>Test3</td>
<td>5.77</td>
<td>4.75</td>
</tr>
<tr>
<td>Test4</td>
<td>7.00</td>
<td>4.25</td>
</tr>
<tr>
<td>P</td>
<td>0.022</td>
<td>0.449</td>
</tr>
<tr>
<td>Effect size $r$</td>
<td>0.382</td>
<td>0.133</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.54</td>
<td>-0.15</td>
</tr>
<tr>
<td>Medium</td>
<td>Negative</td>
<td></td>
</tr>
</tbody>
</table>
Answering RQ3, RQ3.1, RQ3.2
Answering RQ3, 3.1, 3.2

RQ3: In what way does TIMeR resolve the learning difficulties that students face while solving the engineering drawing problems?
We answered RQ3 by mapping the learning difficulties (answered in RQ3.1) to the TIMeR features. We confirmed this by the list of benefits reported by the students (answered in RQ3.2).

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.

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

We answered 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.
Answering RQ3.2: Benefits of TIMeR

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

We answered RQ3 by mapping the learning difficulties (answered in RQ3.1) to the TIMeR features. We confirmed this by the list of benefits reported by the students (answered in RQ3.2).

From Study ED1
- 24 students reported only difficulties but not the benefits.
- 12 students reported only benefits but not the difficulties.
- 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.
### Answering RQ3: Results

<table>
<thead>
<tr>
<th>Learning Difficulties in ED</th>
<th>TIMeR Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>VIEWS:</strong> Difficulties about orthographic views</td>
<td><strong>COGNITIVE COMPONENT:</strong> The training helped students to learn:</td>
</tr>
<tr>
<td>1. Difficulty in identifying and analysing different views (<em>C1</em>)</td>
<td>1. Skill of identifying different views</td>
</tr>
<tr>
<td>2. Difficulty in visualizing different views (<em>C3</em>)</td>
<td>2. Concepts of different views</td>
</tr>
<tr>
<td>3. Difficulty in distinguishing between views (<em>C5</em>)</td>
<td>3. Skill of visualizing different views,</td>
</tr>
<tr>
<td><strong>SHAPES:</strong> Difficulties about the shapes of an object</td>
<td>4. Skill of visualizing 3D Objects by rotation</td>
</tr>
<tr>
<td>1. Difficulty in identifying and interpreting shapes of an object</td>
<td>5. Skill of visualizing different views and Comparing (Evaluate) with options.</td>
</tr>
<tr>
<td><strong>HIDDEN:</strong> Difficulties about hidden surfaces and hidden lines (<em>C6</em>)</td>
<td>6. Skill of identifying and visualizing hidden lines and surfaces</td>
</tr>
<tr>
<td>1. Difficulty in identifying and observing hidden lines</td>
<td>7. <strong>Miscellaneous</strong></td>
</tr>
<tr>
<td>2. Difficulty in visualizing hidden surfaces from various views</td>
<td>Identification of relevance of the visualization to problem-solving process.</td>
</tr>
<tr>
<td><strong>VISUALIZE:</strong> Difficulty about visualizing 3D objects (<em>C3</em>)</td>
<td>1. Learnt visualization skills.</td>
</tr>
<tr>
<td>1. Difficulty in visualizing and constructing a 3D form from a 2D drawing (<em>C4</em>)</td>
<td>2. Learnt about the Environment (Blender) – Training phase 1 successful.</td>
</tr>
<tr>
<td><strong>CONCEPT:</strong> Difficulty about the conceptual understanding</td>
<td>3. Applying training skills for solving tests.</td>
</tr>
<tr>
<td>1. Difficulty in conceptual understanding (<em>C2, C7</em>)</td>
<td>4. Conceptual understanding about &quot;introduction to the domain.&quot;</td>
</tr>
<tr>
<td><strong>OTHER:</strong> Difficulties about the ED problems solving process:</td>
<td>5. How to concentrate (observe).</td>
</tr>
<tr>
<td>1. Difficulty in the process of finding a correct solution to the problem (<em>C7</em>)</td>
<td></td>
</tr>
<tr>
<td>2. Difficulty in identifying the correct solution between the given choices (<em>C7</em>)</td>
<td></td>
</tr>
<tr>
<td>3. Time required to solve the problem</td>
<td></td>
</tr>
</tbody>
</table>
Answering DQ2
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.
Instructions for Conventional Group

Blackboard teaching, demonstration of drawings, sometimes use of PowerPoint presentation, and discussion on the test answers. It requires approximately four classroom hours to teach each of the topics, resulting in the total 8 hours of teaching.
Instructions for Conventional Group

- Test 1 (Intermediate test)
- Reflective Journal

Day 1: (Orthographic, Part 1)

Day 2: (Orthographic, Part 2)

Day 3: (Isometric, Part 1)

Day 4: (Isometric, Part 2)

Instructions for TIMeR Group

- Test 1 (Intermediate test)
- Reflective Journal

Day 1: TIMeR Session 1 (Icebreaker Activity, Orthographic, Part 1)

Day 2: TIMeR Session 2 (Orthographic, Part 2)

Day 3: TIMeR Session 3 (Isometric, Part 1)

Day 4: TIMeR Session 4 (Isometric, Part 2)

Blackboard teaching, demonstration of drawings, sometimes use of PowerPoint presentation, and discussion on the test answers. It requires approximately four classroom hours to teach each of the topics, resulting in the total 8 hours of teaching.

Eight hours were divided into four sessions, with approximately two hours of teaching in each session on separate days.
Blackboard teaching, demonstration of drawings, sometimes use of PowerPoint presentation, and discussion on the test answers. It requires approximately four classroom hours to teach each of the topics, resulting in the total 8 hours of teaching.

Eight hours were divided into four sessions, with approximately two hours of teaching in each session on separate days.
Answering RQ4
RQ4: How effective is TIMeR for problems involving MR in other domain such as Computer Graphics (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.
TIMeR group students performed significantly better than the students who had undergone traditional lecture for the same duration.

<table>
<thead>
<tr>
<th>Group</th>
<th>TIMeR</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Pretest</td>
<td>3.62</td>
<td>3.88</td>
</tr>
<tr>
<td>Posttest</td>
<td>7.00</td>
<td>3.88</td>
</tr>
<tr>
<td>( P )</td>
<td>( 0.011 )</td>
<td>1.000</td>
</tr>
<tr>
<td>Effect size ( r )</td>
<td>0.634</td>
<td>-</td>
</tr>
<tr>
<td>Learning gain</td>
<td>0.7716</td>
<td>0.00</td>
</tr>
</tbody>
</table>

CG1 Within group results
Generalizability
Across different domains
- TIMeR improves students' performance of MR, ED, and CG
- Variations of problem difficulty and complexity.
  - MCQs,
  - Drawing problems.
  - CG problems: students expected to visualize and identify the processes of 3D transformations when the initial and final states of a 3D object are given.
- Our results are generalizable across various types of problems that involve MR.
- The possible domains are chemistry (molecular structures, morphemes), Architecture, 3D Modelling, Sculpting, Animation, etc.

Across different population
- TIMeR is effective for the range of the learners, including high and low-performers, and advanced and novice learners.
- CG1 study extends this further and shows that the TIMeR is even effective for the students from disciplines which are not exactly engineering but are equivalent.

Across different durations of implementation
- The normal duration of a complete TIMeR pedagogy is around three hours.
- We demonstrated (in ED4) how to split the TIMeR phases into two sessions (90 minutes each) and still yield similar effectiveness.
- The pedagogy is implementable for the classroom sessions equivalent to the typical lab durations which are equal to or more than two hours.
Contribution
Contribution

To the field of spatial skills research and its application domains such as in ED and CG

**Pedagogy:**
3D visualization tool based pedagogy that develops students’ MR skills and the learning of relevant concepts such as ED and CG.
- TIMeR and results are supporting the common-coding theory.
- This pedagogy has shown an instance of how to operationalize the cognitive steps of MR.
- also demonstrates an integration of a technology tool (Blender, which is traditionally not an educational tool) to achieve an educational goal.

**Workshop Models:**
- Three-hour TIMeR model
- Recommendation for incorporating TIMeR in a regular 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 MR 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:** seven TIMeR workshops, within the different engineering institutes from India, trained 360+ students.
Limitations
Limitations

Limitations related to learner characteristics:
- This thesis does not provide insights into how learner characteristics (motivation, interest, self-efficacy) play a role into students’ achievements.
- Population: scoped to engineering undergraduates, not explored for the postgraduate level or school level, and learners familiar with the 3D graphing environments.

Limitations related to topics and domains
- Spatial skills: scoped MR. Not tested on other spatial skills.
- Scoped to problems in ED and some problems in CG.

Limitations related to research method
- Mixed method design – primary: quantitative, secondary: qualitative
- No in-depth qualitative analysis
- Study designs: single group pre-post design for most of the studies. (Study ED4 addressed this by having two-group posttest design.)
- The duration between treatment and posttest: we administered posttest immediately after the treatment, we did not administer the posttest after a longer duration
- No longitudinal studies.

Limitations related to the test instruments
- Studies ED1 & ED2: has four test items for the pretest and the posttest each. This limitation was addressed in the study ED4, by having total sixteen test items.
- Multiple choices questions - one of the four represents chance. This was addressed in the study ED3 by having more difficult assessment items – drawing task.

Limitations related to instructor and instructional strategies
- A semi-computer based pedagogy design.
- Instructor based.
- We do not comment anything about how to convert the training model into a self-learning environment.

Limitations related to the tools and technology
- Tool: we have used only Blender, not other tools e.g. CAD were tested.
- Tool UI: needs customization
- Tool Expertise required
Future scope
Learner characteristics

- Role of motivation, interest, self-efficacy, etc. into students’ achievements in the TIMeR session can be further investigated.
- A different population such as at the school level.

Topics and domains

- Other types of ED (e.g. projection of solids) and CG problems (programming)
- Other possible domains: chemistry (molecular structures, morphemes), Architecture, 3D Modelling, Sculpture Artists, Animators, etc.

Research method

- A further in-depth qualitative examination of the cognitive processes triggered while a student interacts with the learning environment and the pedagogy which lead to the enhancement of MR skill. e.g. which individual TIMeR task lead to what individual effect(s)?
- Eye tracking: 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.

Future scope

- Currently, the involvement of the instructor is essential. A self-learning MR training module can be developed. The instructor’s role can be replaced by self-explanatory videos or other appropriate instruction medium.
- Standalone or a web application for PCs, tablets, etc.
- Self-learning mobile application for smartphones.
- Developing a self-learning environment could be a plausible future educational design problem.
- Interactivity: Mouse and keyboard controllers can be replaced by e.g., Touch-screens, Joystick, Gesture-Based, etc.

Scaling

- A large-scale spatial skill development program for first-year engineering students.
- A part of first-year ED curriculum.
  - A short-term training program for the teachers,
  - An online MR training program for students/teachers.
Conclusion
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.
Thesis Related Publications


Other Publications

Acknowledgements

• Prof. Sridhar Iyer
• Prof. Sahana Murthy
• Prof. Anirudha Joshi
• Prof. Deepak B. Phatak
• Prof. Kannan Moudgalya
• Prof. Vikram Gadre
• Thesis reviewers
• IIT Bombay, Project OSCAR Team, Project TEQIP, IITBombayX Team, IDPET & CDEEP family,
• Study Participants and Instructors.
• Dr. Sameer Sahasrabudhe, Dr. Yogendra Pal, Ms. Aditi Kothiyal, Dr. Shitanshu Mishra,
• Dr. Jayakrishnan M. Dr. Rwitajit Majumdar, Mr. Anurag Deep, RS.ET, All my friends, and family.
Thank You!