Development of Mental Rotation Skills Using 3D Visualization Tool

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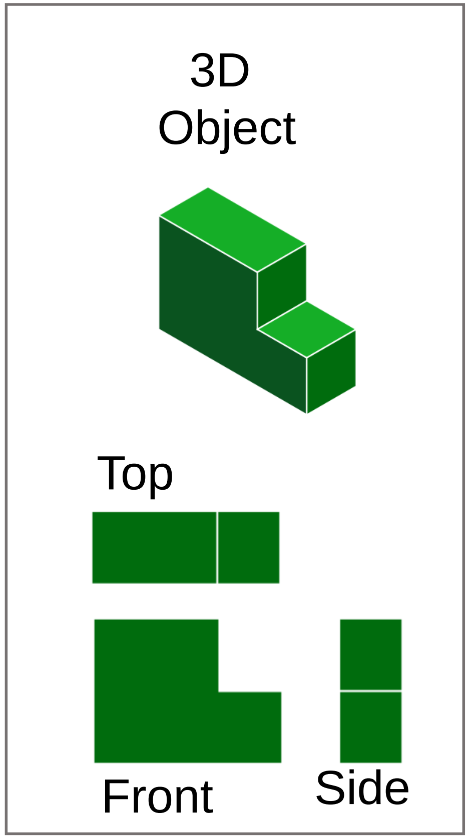
Background

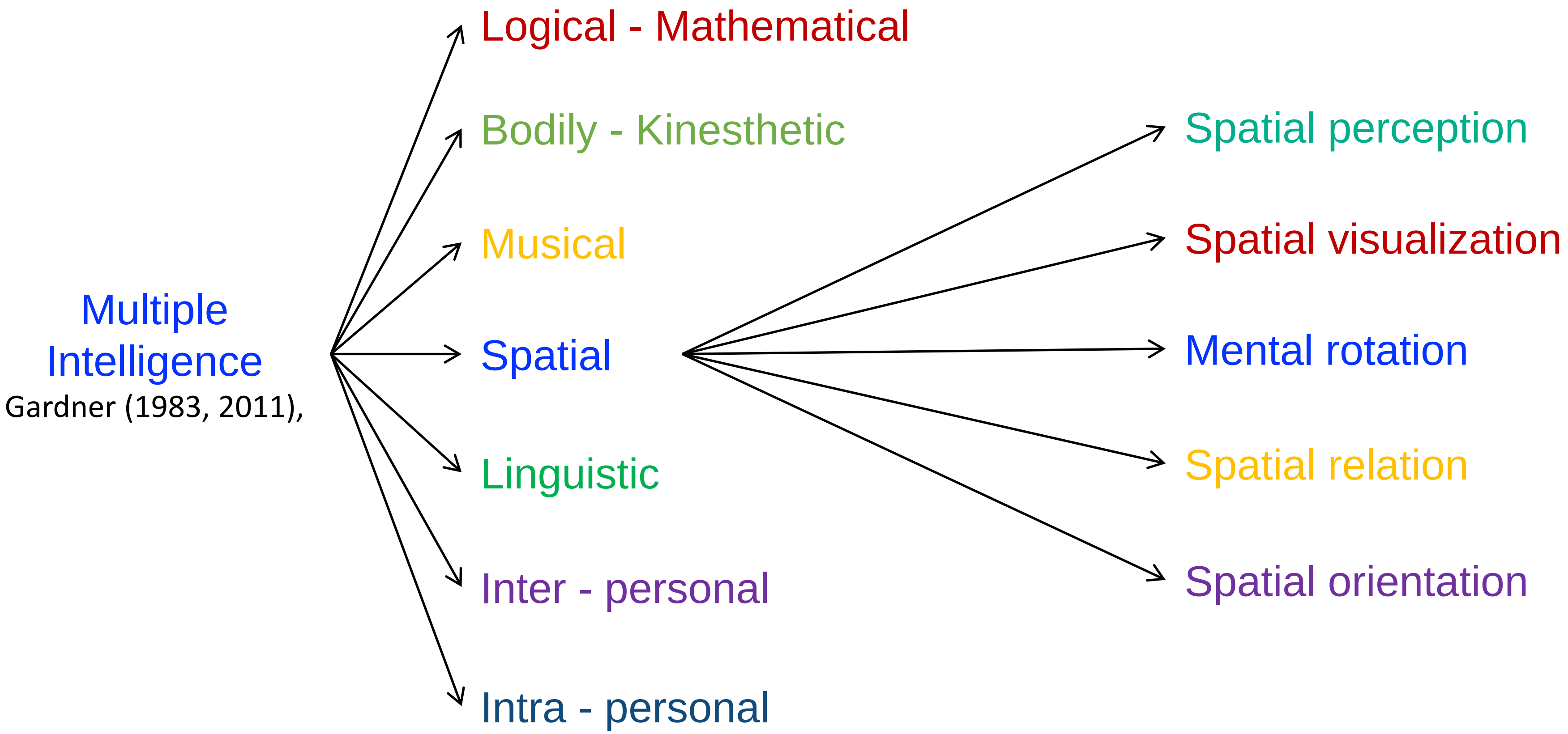
Background: Engineering Drawing (ED) Learning Difficulties

- 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



(Garmendia, Guisasola, & Sierra, 2007; Nagy-Kondoor, 2007; Upadhye, Shaikh, & Yalsingikar, 2013). (Akasah & Alias, 2010; Jiannan, 1998; Kosse, 2005; Nagy-Kondoor 2007).

Background: Multiple Intelligence & Spatial Skills



Background: Multiple Intelligence & Spatial Skills

- Multiple Intelligence
  - Logical - Mathematical
  - Bodily - Kinesthetic
  - Musical
  - Spatial
    - Spatial perception
    - Spatial visualization
    - **Mental rotation**
    - Spatial relation
    - Spatial orientation
  - Linguistic
  - Inter - personal
  - Intra - personal

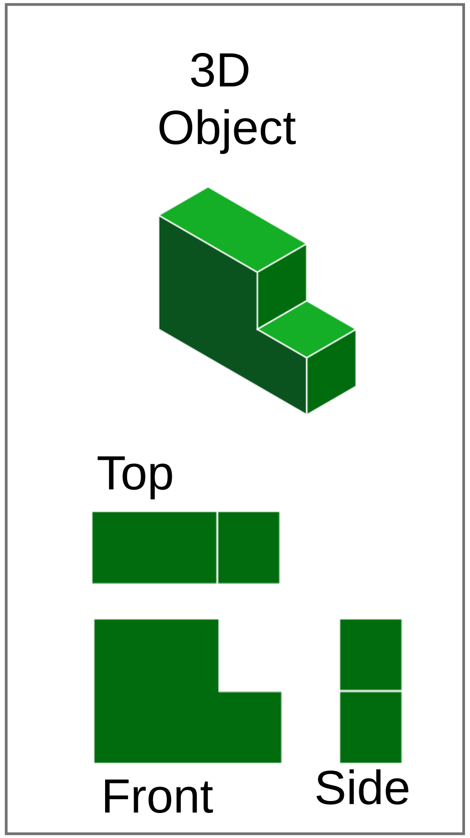
Background: MR & ED association

Multiple Intelligence

- Logical - Mathematical
- Bodily - Kinesthetic
- Musical
- Spatial
  - Spatial perception
  - Spatial visualization
  - **Mental rotation** → is associated with ED problems
  - Spatial relation
  - Spatial orientation
- Linguistic
- Inter - personal
- Intra - personal

Background: MR & ED association

- Consider an ED problem: Conversion of an isometric view to its orthographic views and vice versa
- Some common ED problem-solving steps *Alias, et al., (2000)*.
  - Identifying surfaces (top, front, side, & hidden)
  - Identifying the shape of the surfaces
  - Visualizing shapes at the right angle by rotating



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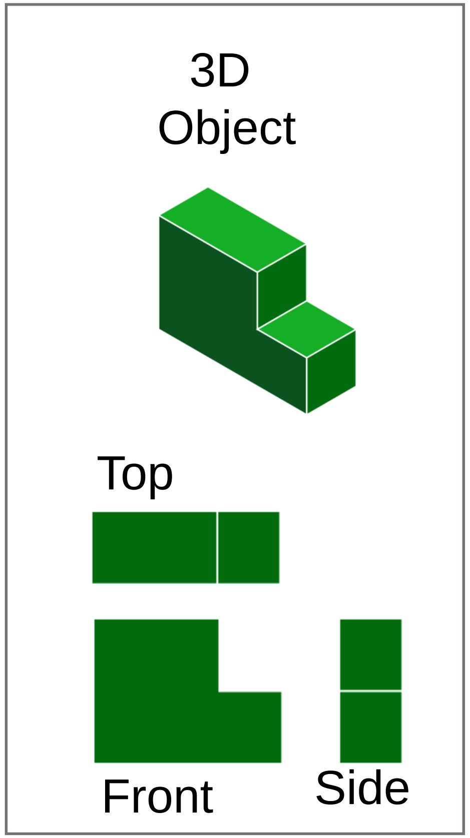
Involves rotation and requires mental rotation



Mental Rotation (MR) Skills

MR definitions

“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).

MR definitions

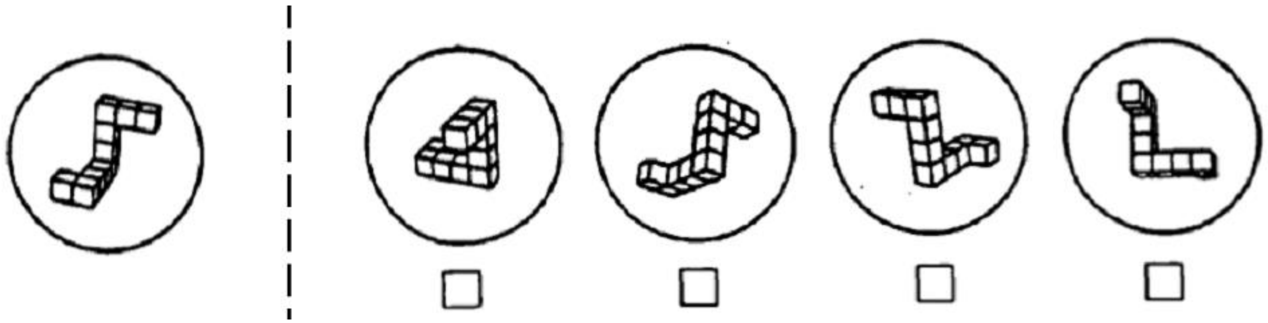
While all these definitions of mental rotation are valid and rather similar, we adopt Maier's (1998) definition of mental rotation as it encapsulates the essence of all the definitions.

"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

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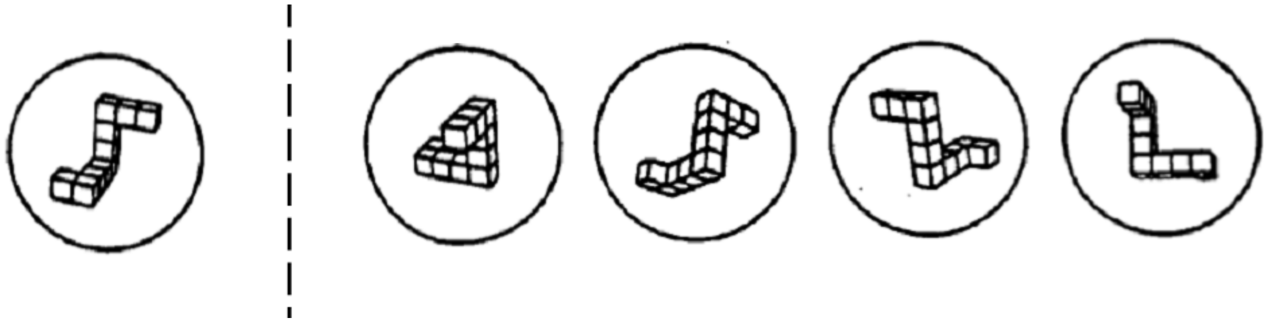
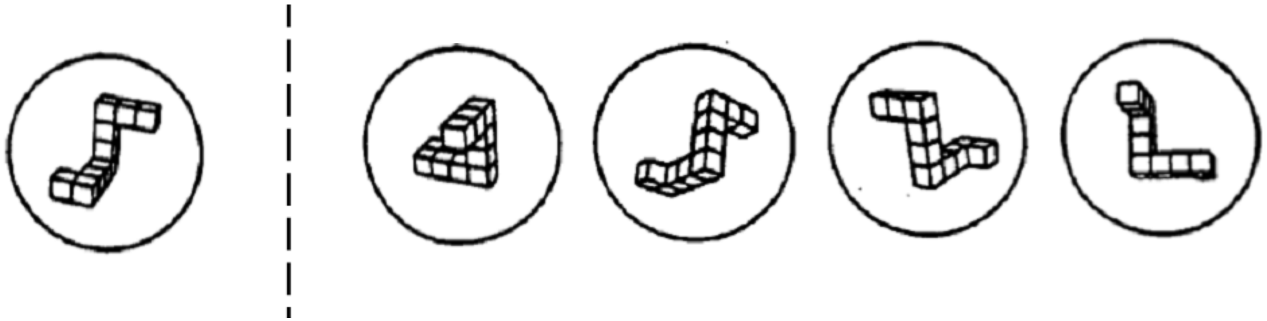


Cognitive steps of MR

- Test Item from Vandenberg’s Mental Rotation Test Instrument



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

Cognitive steps of MR

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.

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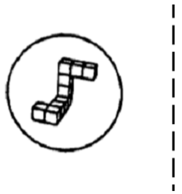
The 3D object is represented as 2D drawing, and to perform cognitive steps of MR it may require doing following steps:

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.



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Improvement of MR Skills

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.

Improvement of MR Skills

Study	Treatment duration	Outcome measure	Training Description	Sample	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

Table continued…

Improvement of MR Skills

Study	Treatment duration	Outcome measure	Training Description	Sample	Brief Outcomes
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

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.

Research objective

"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**: **T**raining to **I**mprove **Me**ntal **R**otation Skills using Blender"*

Our solution

"Investigating the effect of 3D visualization tool-based mental rotation training on students' mental rotation skill."

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List of DQ and RQ

- **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

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).

Research Methodology

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

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Research Methodology

<table>
<tr><td>Study Designs</td><td colspan="2">• Single group pretest-posttest design
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<tr><td>Sample</td><td colspan="2">• Type1 – Novice (Students without prior knowledge of ED)
• Type2 – Advanced learners (Students with prior knowledge of ED)
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</table>

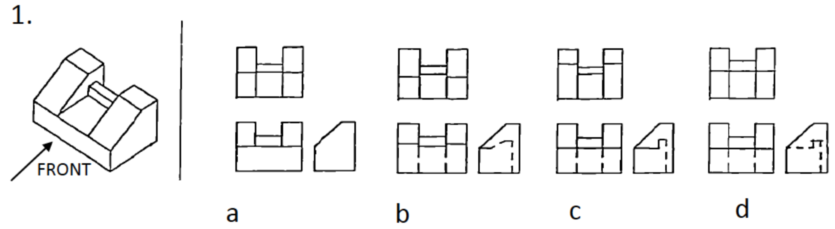
Research Methodology: Summary

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

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

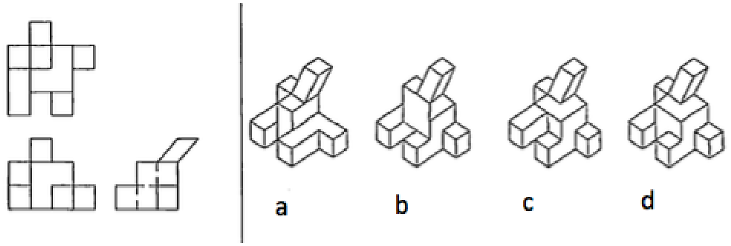
Sample assessment instruments

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



The correct option is ‘d’

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



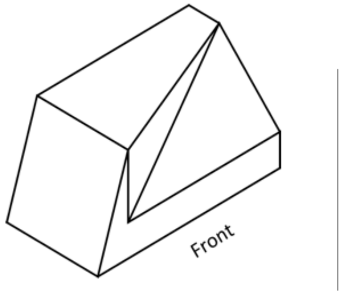
The correct option is ‘d’

ED Test Item (reproduced from Earle, 1969)

Exercise 1A: Orthographic. SIX View Sketching

Instructions : Sketch SIX orthographic views of the object shown below.

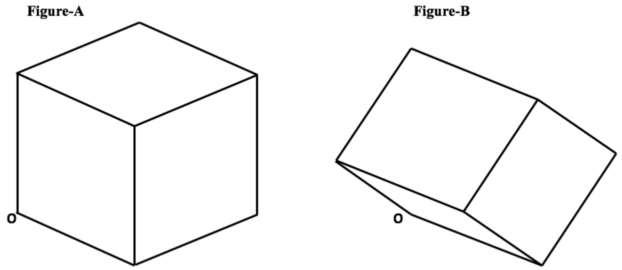
Six views are: TOP, BOTTOM, FRONT, BACK, LEFT, RIGHT.



ED Test Item (reproduced from Earle, 1969)

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.



Answering RQs and DQs

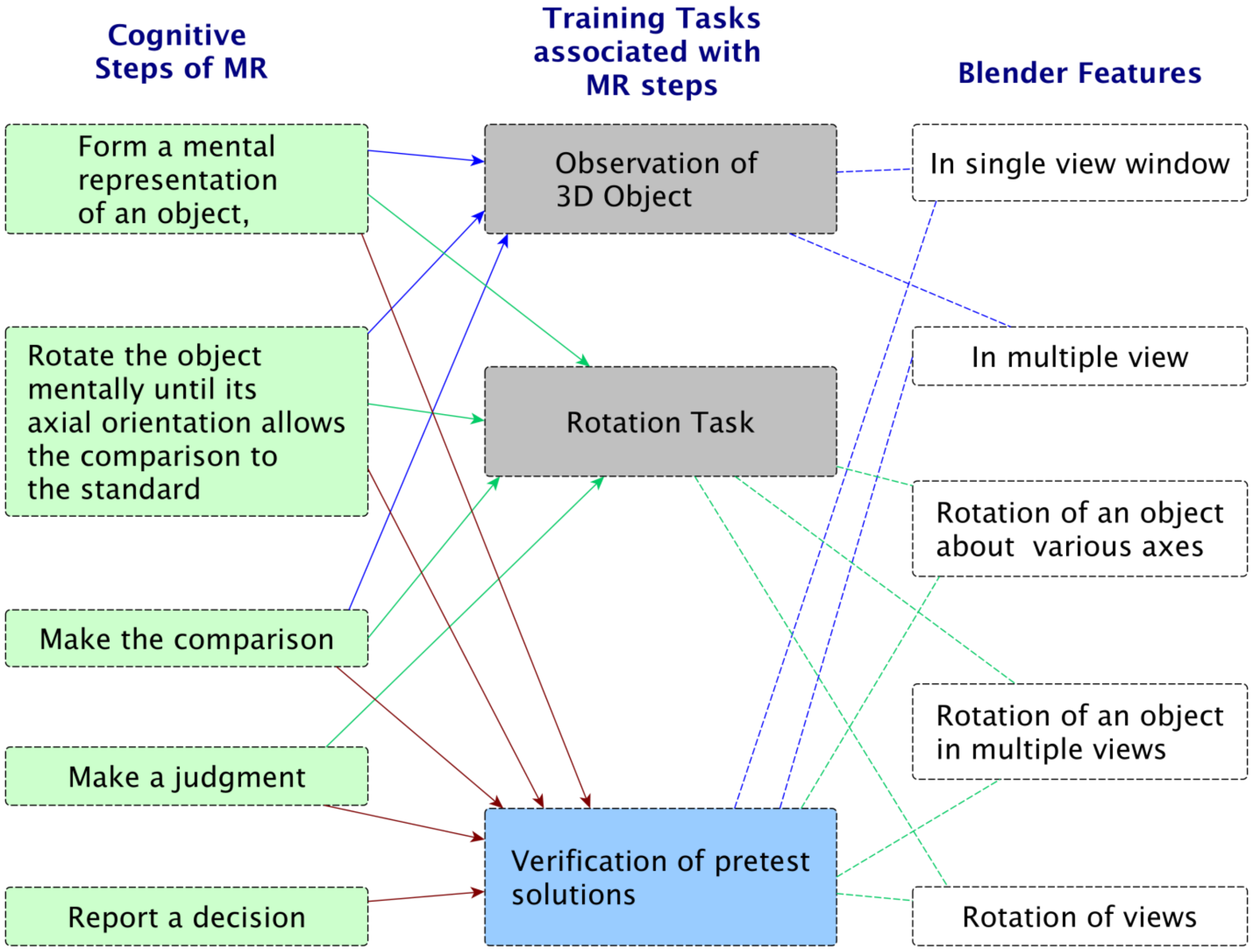
Answering DQ1

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



Answering DQ1: TIMeR Overview

Phase 1:
Preparatory Phase

→

Phase 2:
Training Phase

→

Phase 3:
Transfer Phase

Answering DQ1: TIMeR Overview

	Phase 1: Preparatory Phase	Phase 2: Training Phase	Phase 3: Transfer Phase
Prerequisite			
Instructional Goal			
Task			
Rationale			
Expected Outcome			
Tools & materials			
Instructional Strategy			
Common			
Different			

Answering DQ1: TIMeR Overview

	Phase 1: Preparatory Phase	Phase 2: Training Phase	Phase 3: Transfer Phase
Prerequisite	Completion of Pretest.	Completion of Phase 1.	Completion of Phase 2.
Instructional Goal	Students should be able to use Blender user interface for getting acquainted with the 3D workspace	Students should develop the cognitive understanding of a 3D object and its rotation.	Students should apply Phase 2 learnings to verify their pretest solutions.
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.
Tools & materials	Computer, Blender, 3D models, instruction hand-out.	Computer, Blender, 3D models, instruction hand-out.	Computer, Blender, 3D models, instruction hand-out.
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

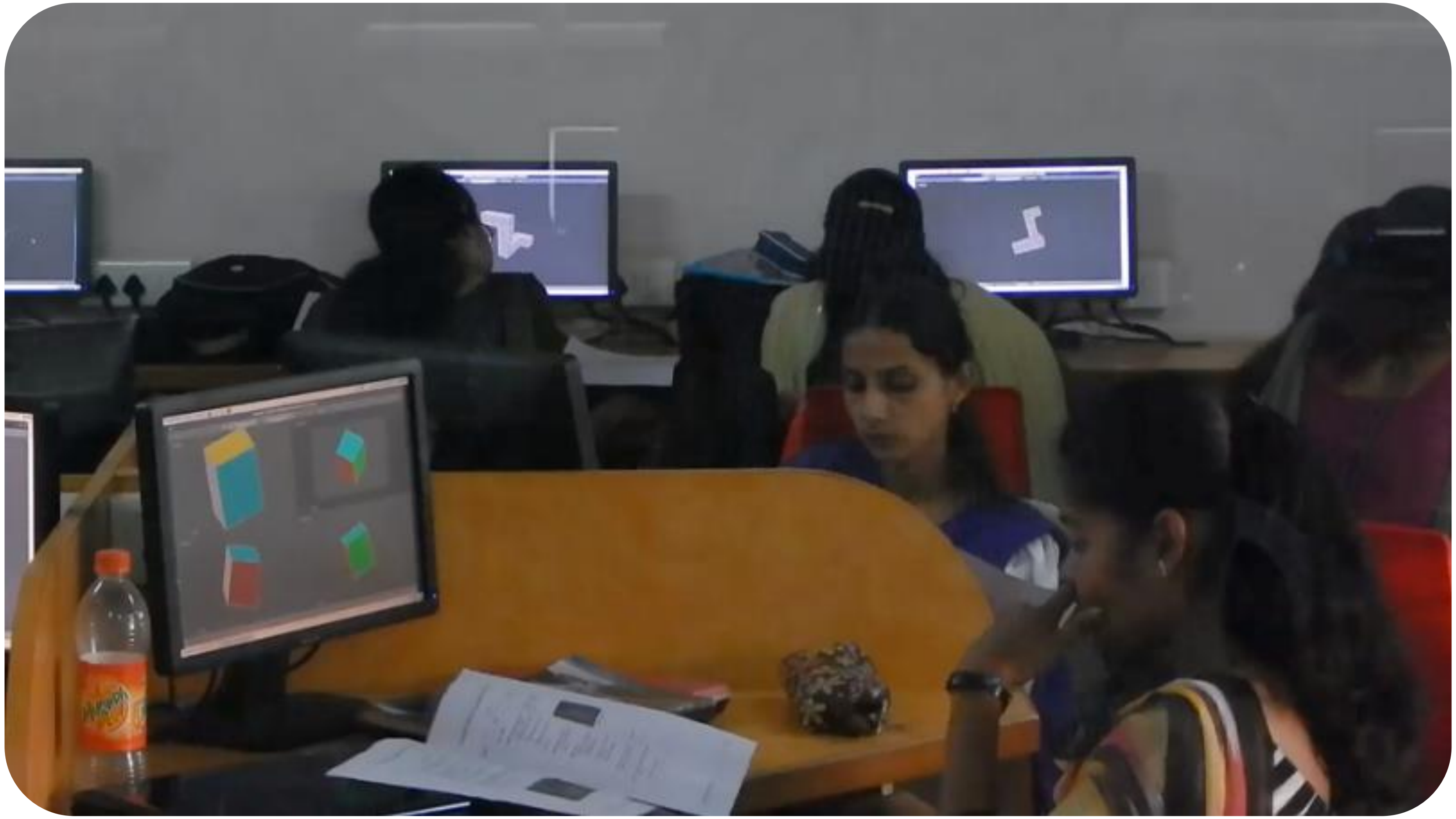


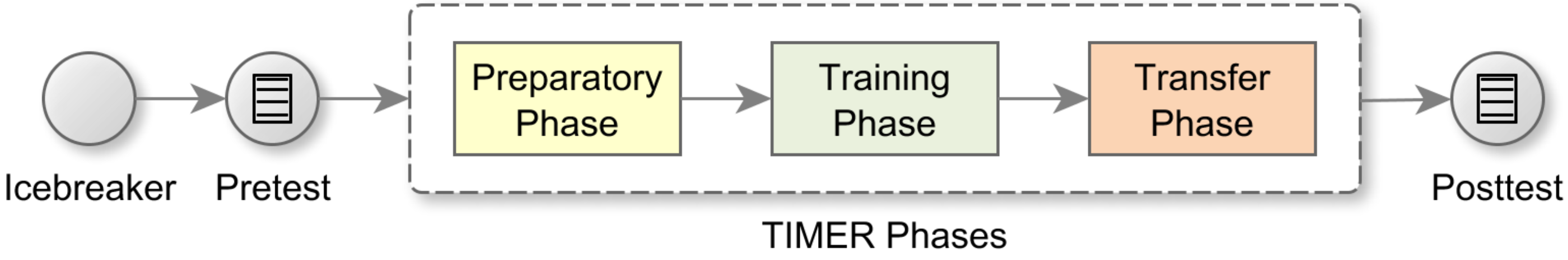
Image: Students performing active manipulation of 3D objects during TIMeR

Answering DQ1: TIMeR Overview

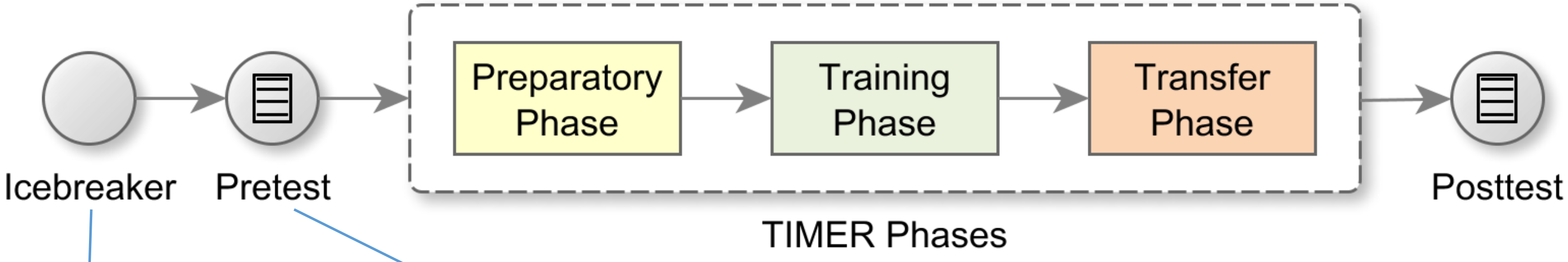
Phase 2: Training Phase → **Phase 3: Transfer Phase**

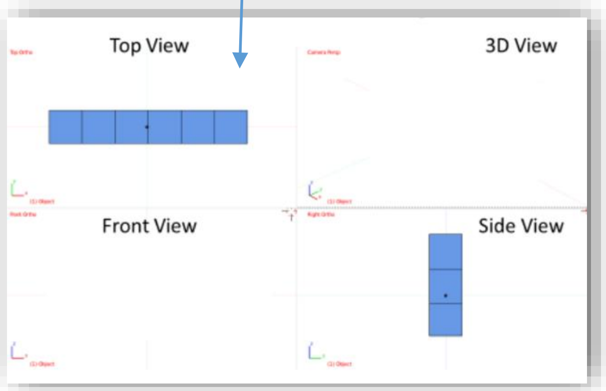
Students performing Phase 3 tasks (verifying test answers using Phase 2 tasks)

TIMeR procedure

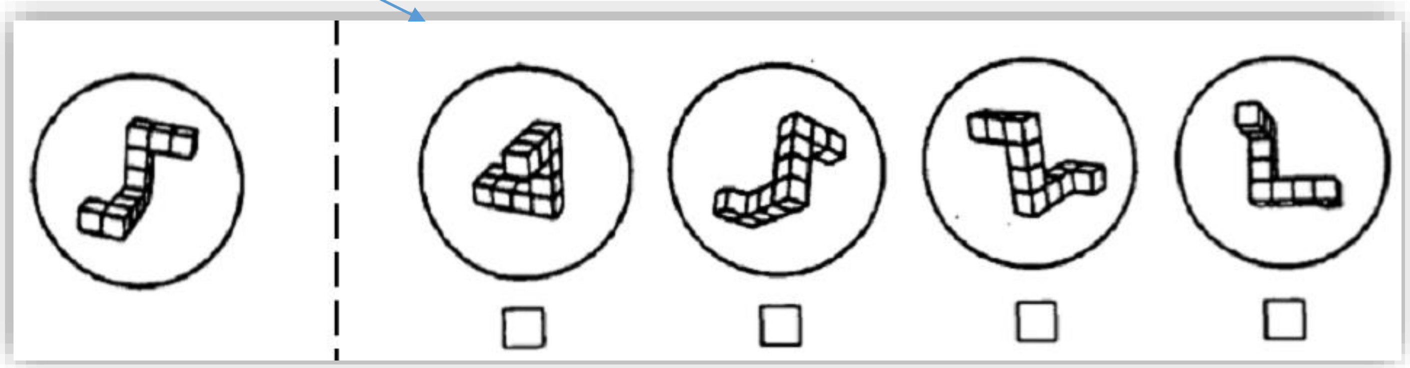


TIMeR procedure





Reproduced from Olkun, 2003



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

Instructional strategy: Demo-Drill-Practice DDP

Demo → **Drill** → **Practice**

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

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)

DDP Stages	**Student Action**	**Corresponding Common Coding Event**		
		Perception	**Execution**	**Imagination**
Demo	Watches demo of MR task	X		
Drill	Repeats steps of the task in-tandem with instructor	X	X	
Practice	Independent practice with multiple objects	X	X	

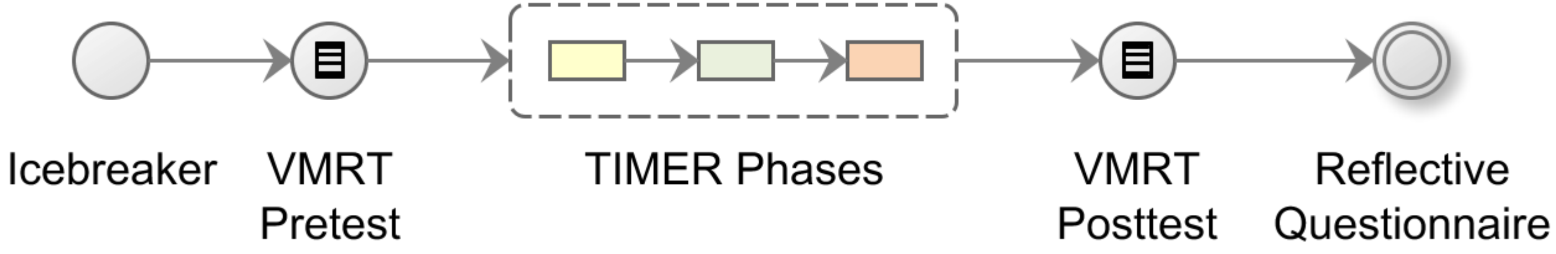
Answering RQ1

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**.**

TIMeR Procedure for MR1



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.

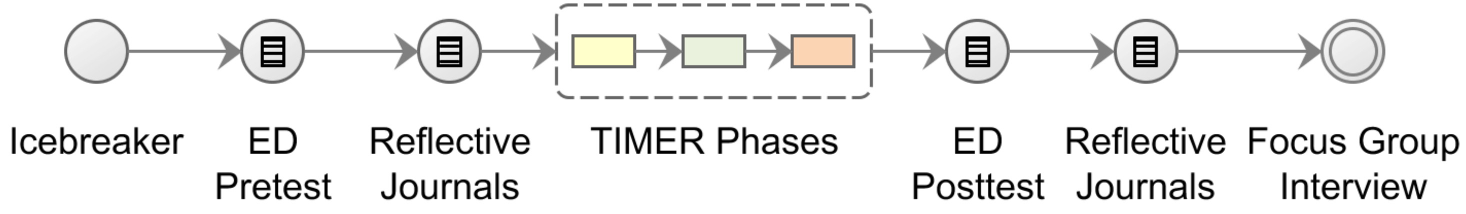
	MR1				MR2			
	Overall	**Low**	**Medium**	**High**	**Overall**	**Low**	**Medium**	**High**
N	42	20	10	12	55	35	15	5
Pretest mean	4.48	2.20	4.70	8.08	2.92	1.57	4.53	7.60
Posttest mean	5.86	5.10	5.50	7.41	3.89	3.46	3.76	7.40
P	**0.001**	**0.000**	0.251	0.125	**0.006**	**0.000**	0.130	0.785
Effect size 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

Answering RQ2

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.



TIMeR Procedure for ED1, ED2, ED3

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.

Answering RQ2: Results

- 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

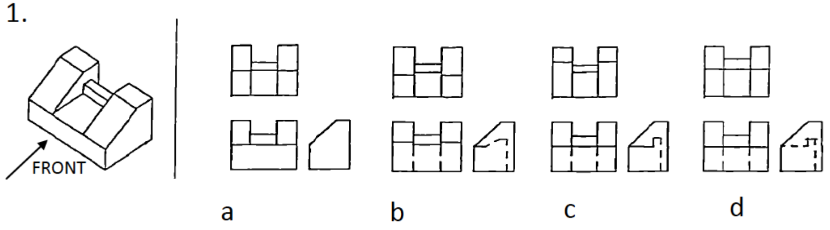
	ED1			
	Overall	**Low**	**Medium**	**High**
N	114	32	43	39
Pretest mean	2.07	0.71	2.00	3.28
Posttest mean	2.49	2.25	2.13	3.07
P	**0.001**	**0.000**	0.420	0.102
Effect size r	0.21 (med)	0.55 (large)	0.08 (small)	0.18
Learning gain	0.22	0.46	0.06	-0.29

Advanced learners

	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

Advanced learners

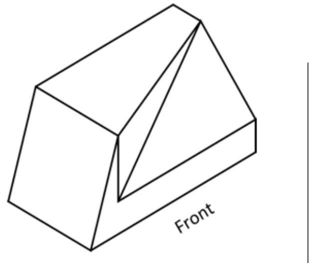
	ED3			
	Overall	**Low**	**Medium**	**High**
N	38	12	26	0
Pretest mean	2.815	1.25	3.538	-
Posttest mean	3.763	2.833	4.231	-
P	**0.001**	**0.002**	**0.030**	-
Effect size r	0.386 (medium)	0.622 (large)	0.300 (medium)	-
Learning gain	0.182	0.234	0.155	-



The correct option is ‘d’

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.



Answering RQ2: Results

ED4 Between group results

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

ED4 Within group results for separate topics

Topic 1: Orthographic Projection		
Group	TIMeR	Conventional
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

Topic 2: Isometric Projection		
Group	TIMeR	Conventional
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

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.

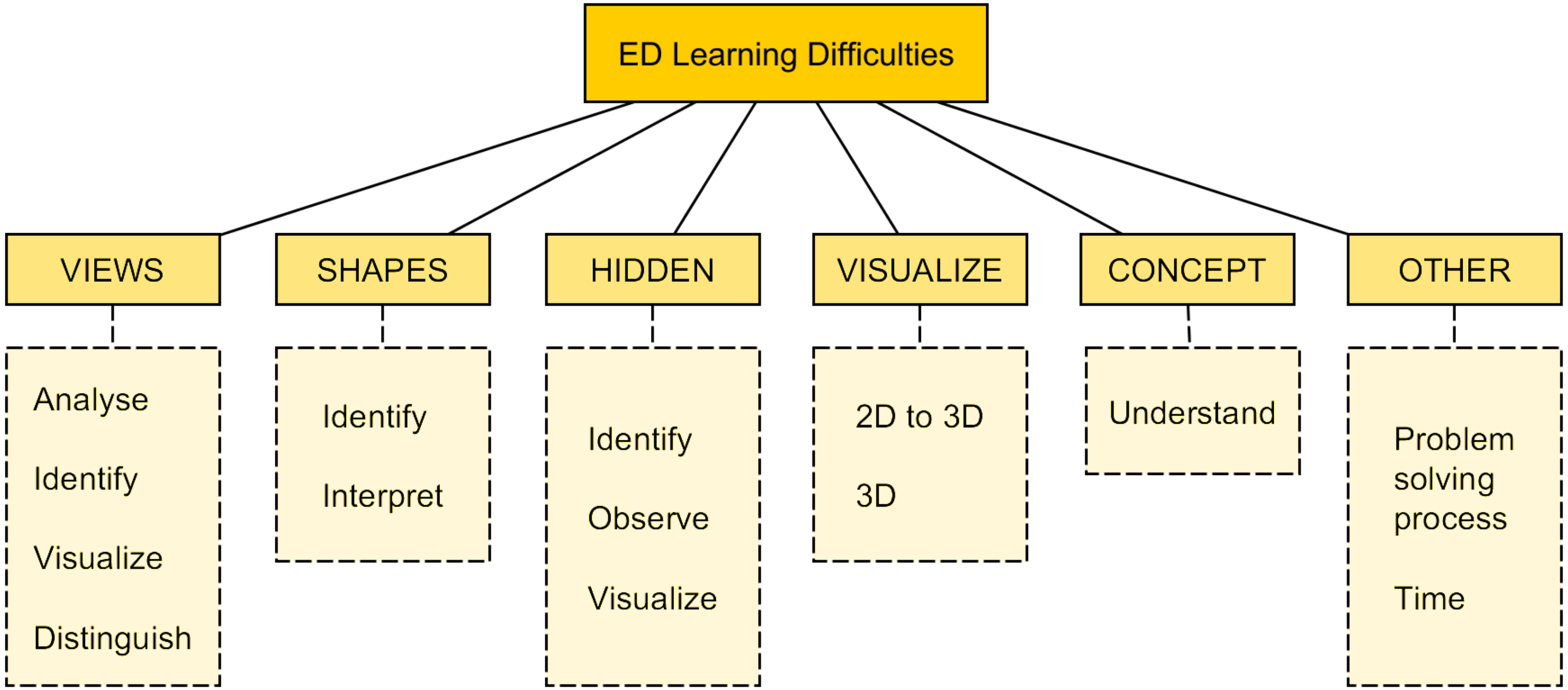
RQ3.2: What are the benefits of TIMeR as perceived by the students?

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.

Answering RQ3.1: Learning Difficulties

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.



Answering RQ3.2

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.

Answering RQ3

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>
<tr><th>Learning Difficulties in ED</th><th>TIMeR Benefits</th></tr>
<tr><td>

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

</td><td>

COGNITIVE COMPONENT:
The training helped students to learn:
1. Skill of identifying different views
2. Concepts of different views
3. Skill of visualizing different views,
4. Skill of visualizing 3D Objects by rotation
5. Skill of visualizing different views and Comparing (Evaluate) with options.
6. Skill of identifying and visualizing hidden lines and surfaces
7. Miscellaneous
Identification of relevance of the visualization to problem-solving process.
1. Learnt visualization skills.
2. Learnt about the Environment (Blender) – Training phase 1 successful.
3. Applying training skills for solving tests.
4. Conceptual understanding about "introduction to the domain."
5. How to concentrate (observe).

</td></tr>
</table>

Answering DQ2

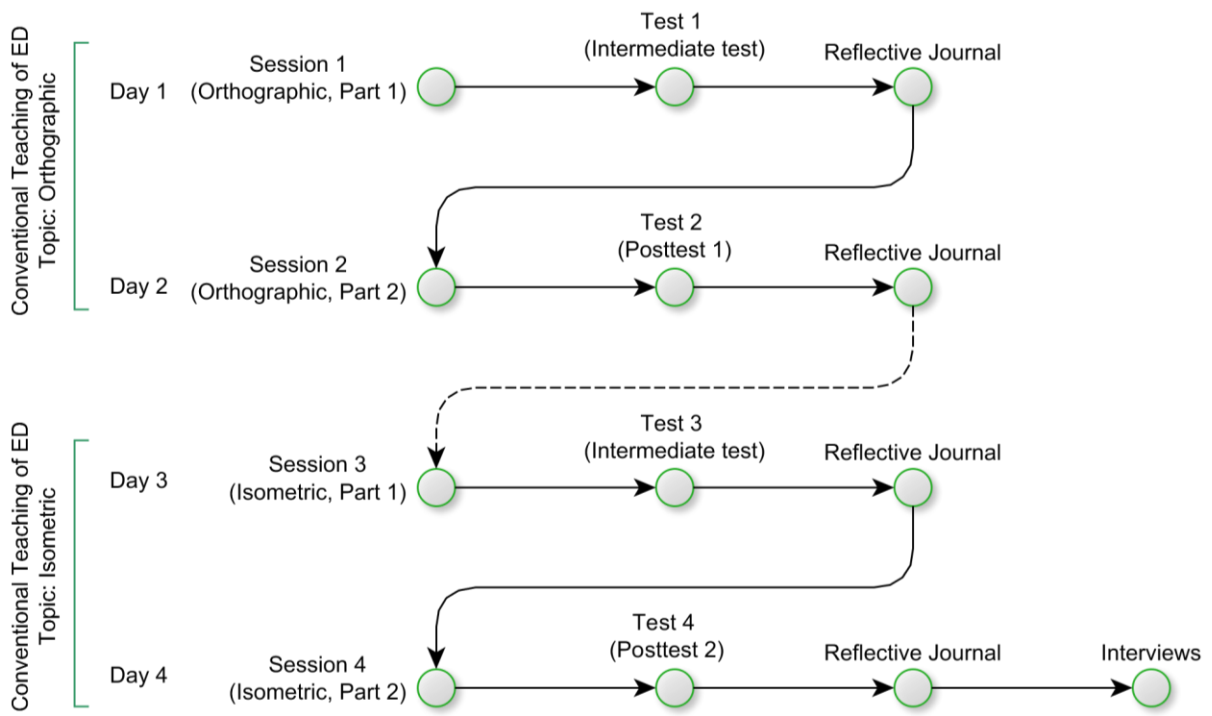
Answering DQ2

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..

Answering DQ2: Incorporation of TIMeR in ED course

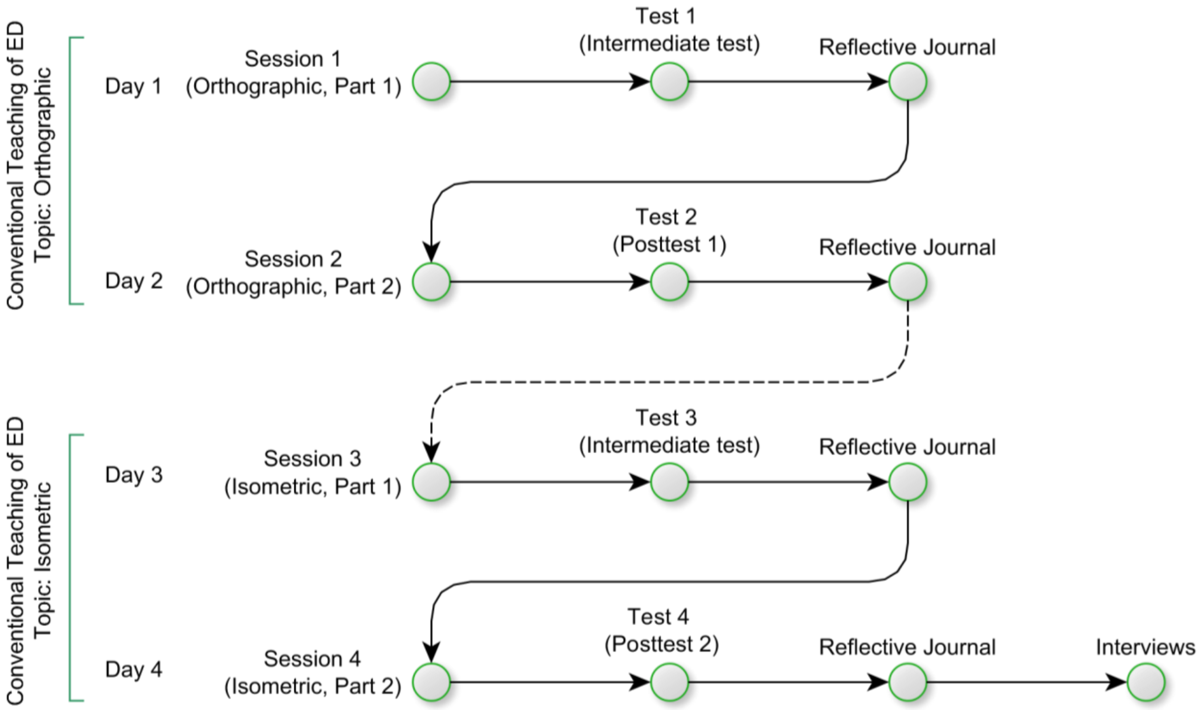
Instructions for Conventional Group



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.

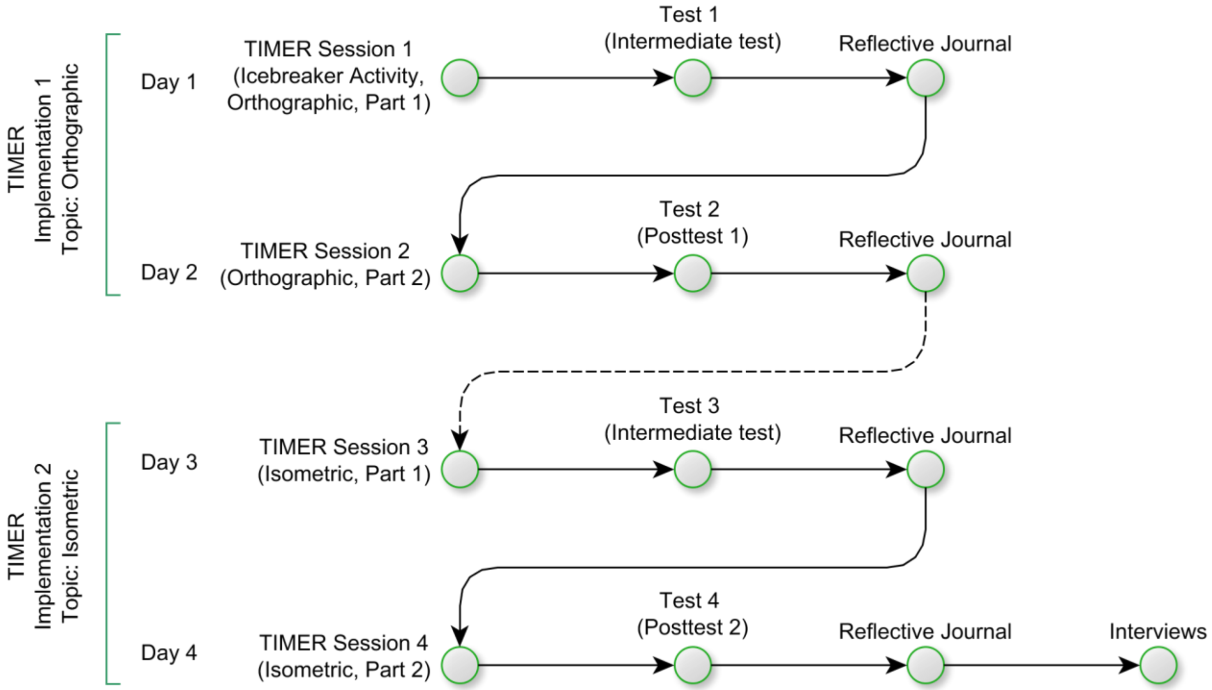
Answering DQ2: Incorporation of TIMeR in ED course

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.

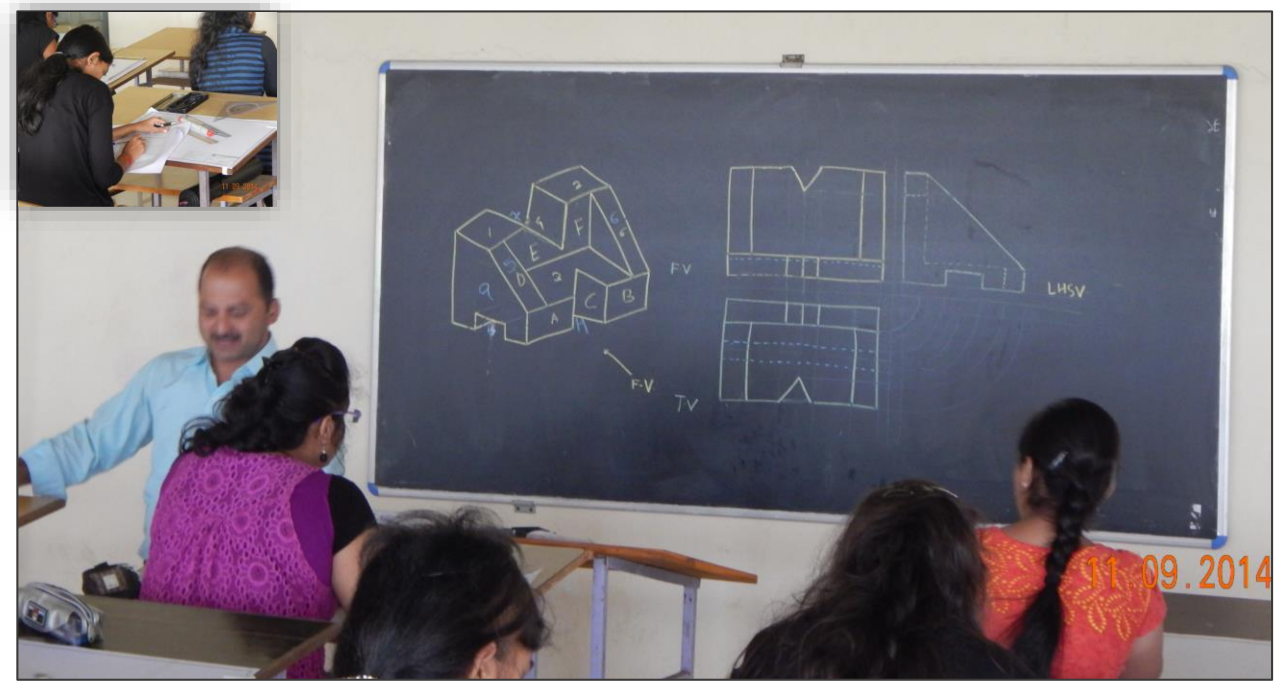
Instructions for TIMeR Group



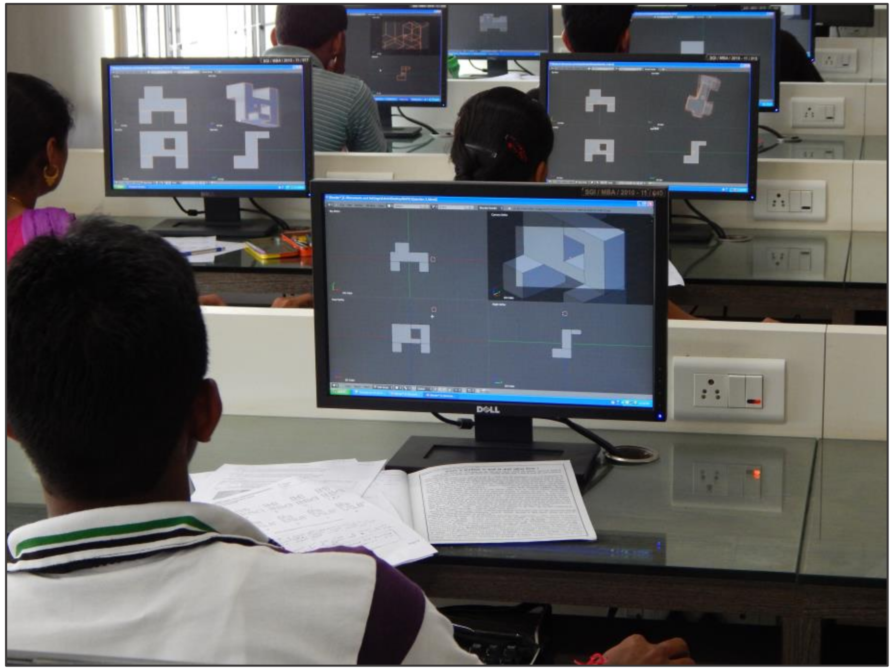
Eight hours were divided into four sessions, with approximately two hours of teaching in each session on separate days.

Answering DQ2: Incorporation of TIMeR in ED course

Instructions for Conventional Group



Instructions for TIMeR 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.

Eight hours were divided into four sessions, with approximately two hours of teaching in each session on separate days.

Answering RQ4

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.

Answering RQ4: Results

TIMeR group students performed significantly better than the students who had undergone traditional lecture for the same duration.

CG1 Between Group Statistics Summary	
	Posttest
Experimental Group	7.00
Control Group	3.88
P	**0.001**
Effect size *r*	0.8275
	large

Group	TIMeR	Control
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

CG1 Within group results

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

Generalizability

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 the how the 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

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.

- 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

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.

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

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