# A framework for enabling instructors to create effective, customized learning designs with visualization (CuVIS)

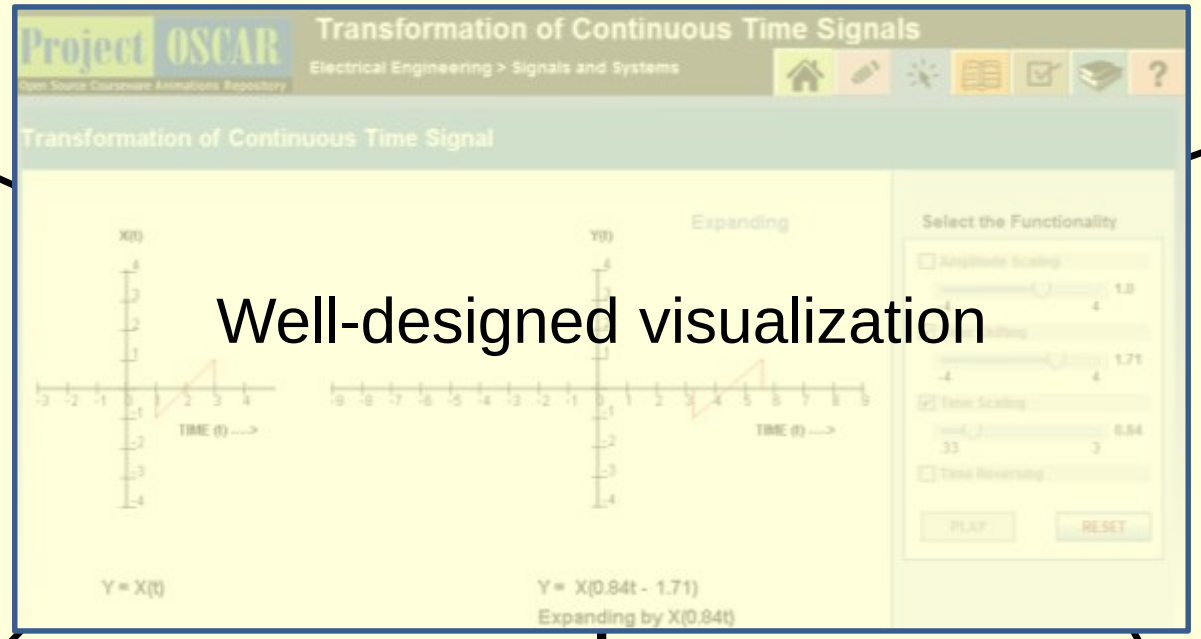
**Thesis Defence Seminar**

**Presented by**
**Gargi BANERJEE**

**Supervisor**
**Prof. Sahana MURTHY**

**Indian Institute of Technology Bombay, INDIA**

# Well-designed visualizations (animation/simulation/video) : Effective teaching-learning resource




Well-designed visualization

**Improved prediction + reasoning**
[Reiss & Mischo,2010]

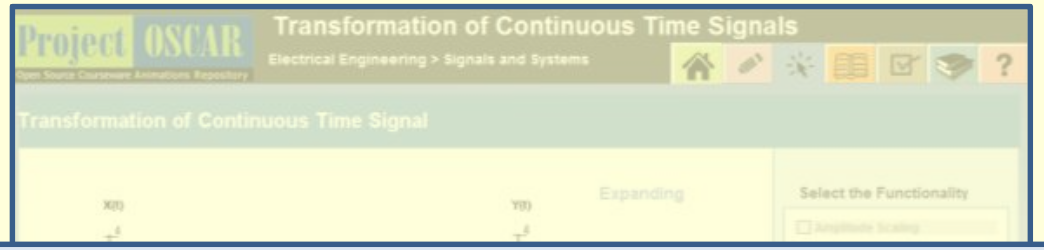
**Invisible to Visible**
[Rutten et.al.,2012]

**Improved conceptual & procedural understanding**
[Byrne et.al.,1999; Laasko et.al., 2009]

**Improved verbalization of programming terms**
[Ben-Basset Levy et.al, 2003]

**Mental model formation**
[Buckley, 2005]

# How should instructors teach with visualization to achieve these objectives?




**<u>Problem</u>: Instructors unable to create effective student-centred learning designs with ICT** (Agneli & Valanides, 2009; Tsai & Chai, 2012; Ertmer et.al, 2012; Bennett et.al, 2015)

- Need to design student-centred learning designs (LDs) that incorporate:
  - = Constructive Alignment [Biggs, 1996]
  - = 5 dimensions of Meaningful Learning with ICT [Howland et.al, 2012]
  - [Active Learning, Constructivist, Intentional, Authentic & Cooperative]

# What help exists to enable instructors to create effective LDs?

| EXISTING SOLUTIONS | GAPS |
| --- | --- |
| Teacher training programs | • Mostly school level [Bennett et.al, 2015]<br>• Short in-service workshops at tertiary level<br>• Insufficient to develop design expertise [Conole & Alevizou,2010] |
| Learning Taxonomies & Teaching Principles | • Difficult for instructors to translate to practice [Laurillard, 2012]<br>• Not customizable |
| Online Portals – Sharing of best practices | • Difficult for instructors to adapt to their context [Shaffer et.al., 2011] |
| Learning Design (LD) Tools | • No guidance on how to achieve constructive alignment & customization in LDs<br>• Do not cater to instructor-mediated classrooms |

# The Research Objective of This Thesis

Develop a framework that will enable instructors to create

effective, customized LDs

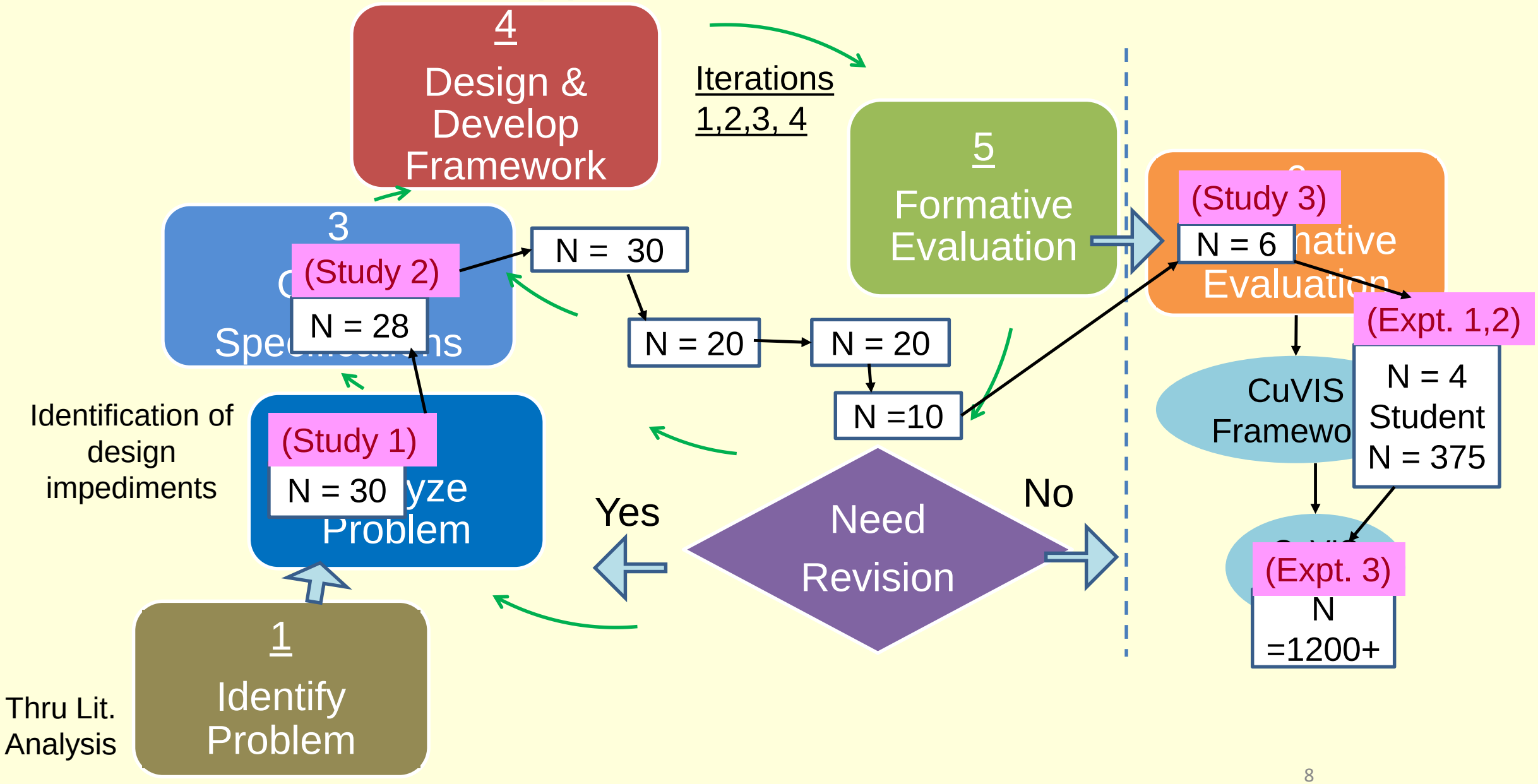
for teaching using visualizations

in instructor-mediated classroom setting

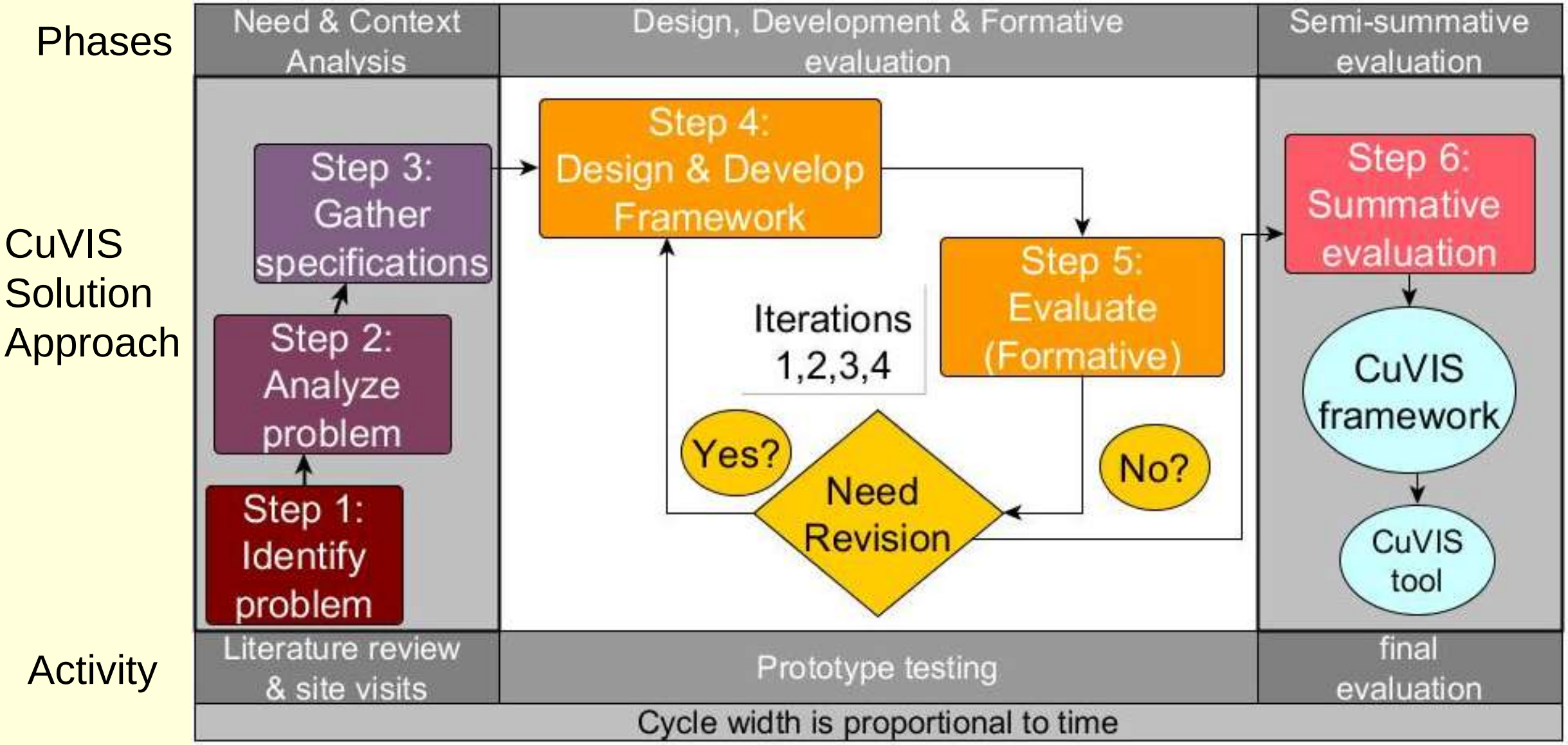
# What is the scope of the research?

- Setting = Instructor-mediated classrooms
- ICT tool = Visualizations (experiment videos, animations, simulations)
- Target user population = Tertiary level science & engineering instructors
- Learning Design = Focused on teaching-learning activities using visualization

# Solution approach to build the framework



# Design and Development Research (DDR) Methodology



# Research questions in each phase of DDR

**RQ1**
What are the points in the LD creation process where instructors need support to design LDs for teaching using visualization?

(Study 1)

Gathering specifications for building blocks of the CuVIS framework

Design CuVIS framework

Develop CuVIS framework

Testing of CuVIS framework

Iterative cycle of framework development

**RQ2:**
What is effectiveness of CuVIS framework in developing instructors' design expertise?

**RQ2.1:**
What is the effectiveness of CuVIS framework in improving instructors' TPACK to create effective & customized LDs with visualization?

**RQ2.2:**
What is the impact of CuVIS framework on instructors' pedagogical practice exhibited through LD?

**RQ2.3:**
What features of CuVIS framework scaffolds do instructors find effective in developing their design expertise for effective and meaningful LDs with visualization?

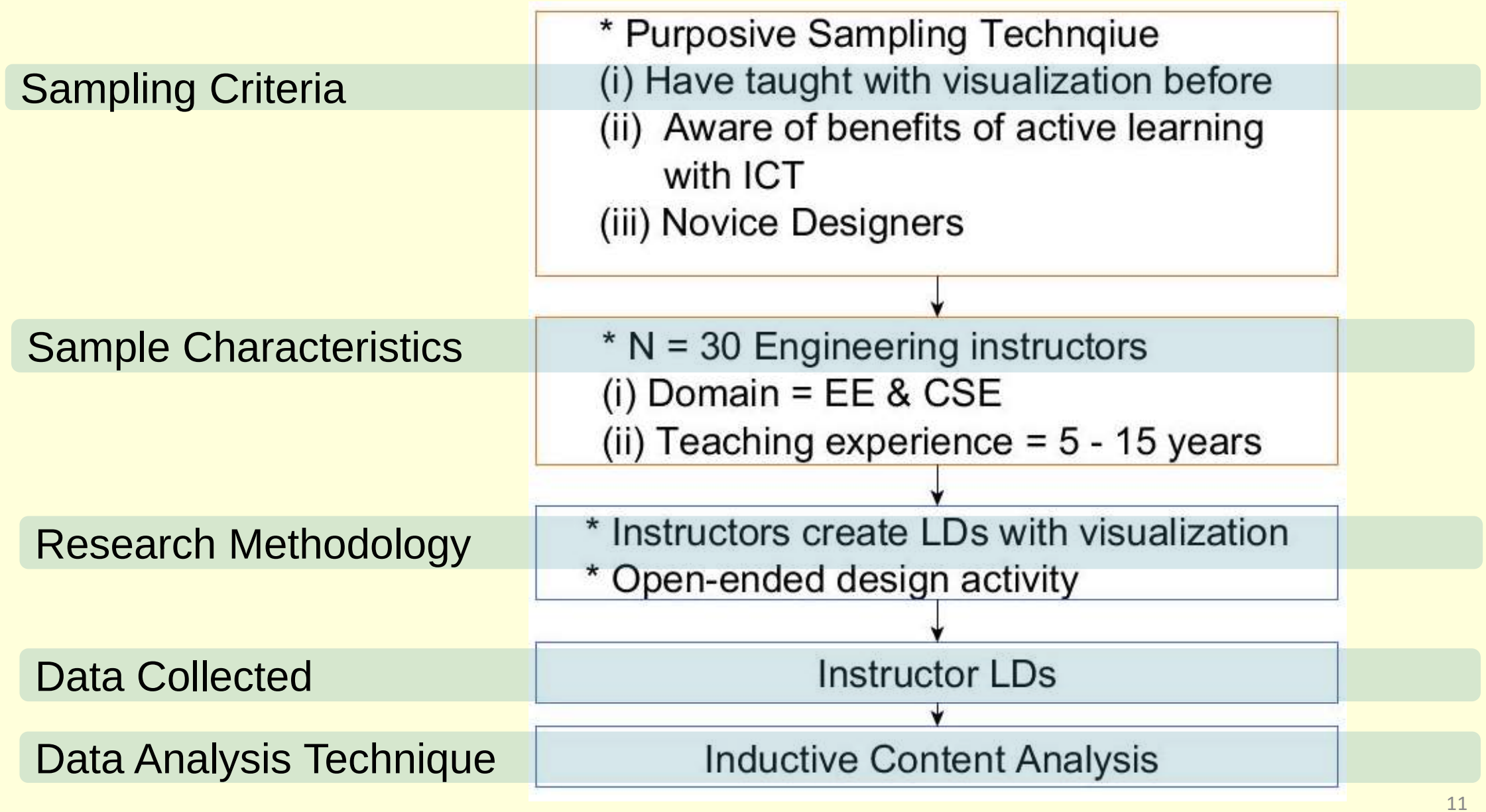
**RQ3:**
What is the effectiveness of CuVIS framework LDs in student learning with visualization?

**RQ4:**
What is the instructor perception on usefulness & usability of CuVIS tool?

Problem Analysis Step → Specification Gathering Step → Design and Development phase → Summative Evaluation Phase

Need & Context Analysis Phase

# Answering RQ1: Qualitative Study to identify design impediments



# Answering RQ1: What design impediments faced by instructors?

| *Design impediment identified:*<br><br>*Instructors unable to –* | *At the level of :* |
|---|---|
| (i) Operationalize Constructive alignment | a) Activity question not mapped to objective<br><br>b) Teaching – Learning activity not mapped to objective |
| (ii) Operationalize Meaningful Learning with ICT | All 5 dimensions |
| (iii) Frame group activity questions based on visualization | Not exploiting visualization:<br>a) Content to design group activity<br>b) Affordances to design group activity |
| (iv) Design implementation of active learning strategies | a)Framing activity question as per strategy protocol<br>b)'What students should do' not adequately specified |

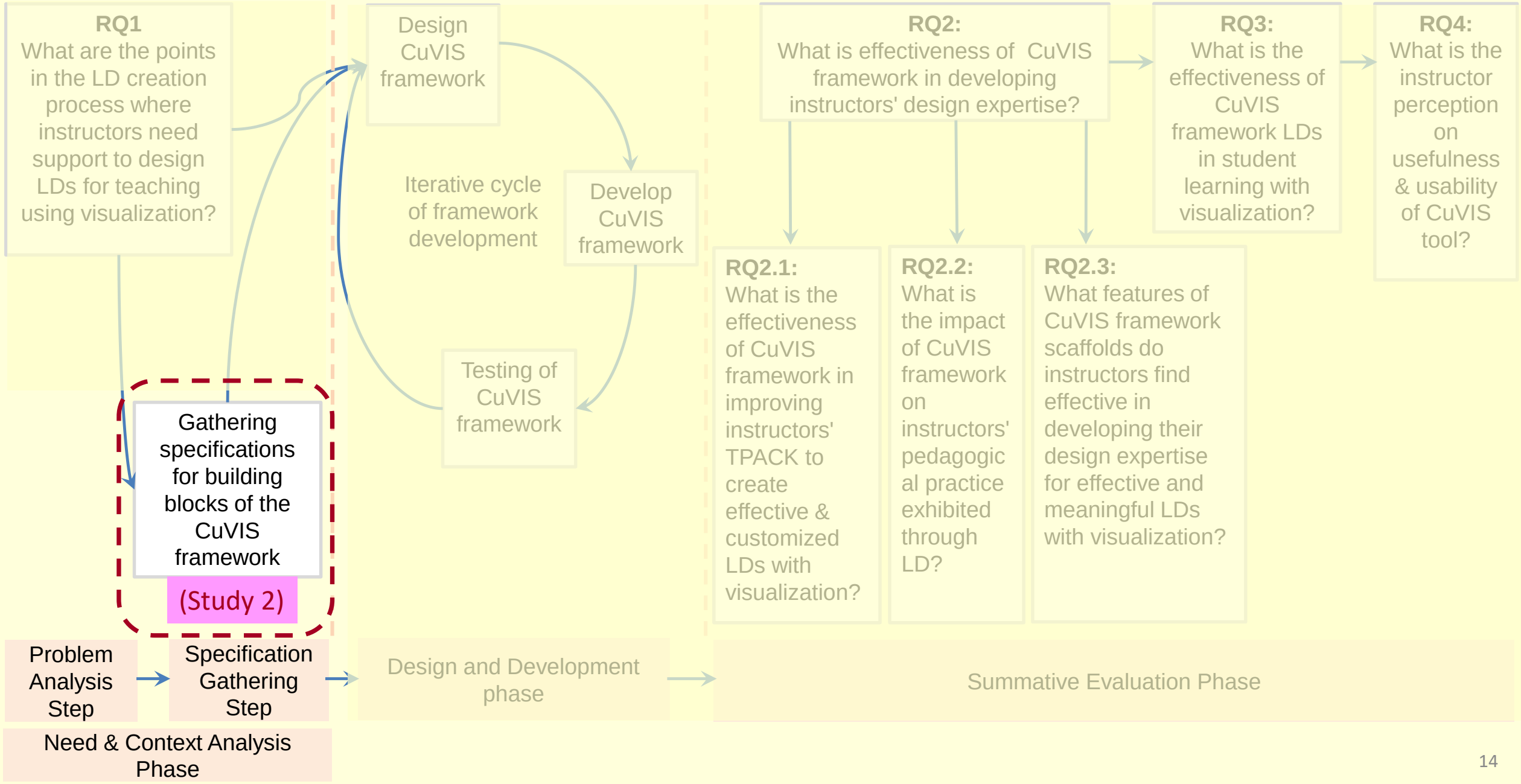
# The building blocks of the framework

Objectives

Customization parameters

Learning Designs

# Research questions in each phase of DDR



# What should be the specifications of the building blocks of the framework? (Study 2) (Banerjee et.al, 2012)

| | |
|---|---|
| Sampling Criteria | * Purposive Sampling<br>(i) Aware of benefits of active learning<br>(ii) Have taught with visualization before<br>(iii) Novice Designers |
| Sample Characteristics | * N = 28 Sc. & Engineering instructors<br>(i) Teaching experience = 5 - 20 years<br>(ii) Domain = Multi-domain |
| Research Methodology: QUAL | > Semi-structured instructor interviews<br>> Instructors show visualizations they used<br>> Gave verbal description of their LDs<br>> Different instructional settings covered<br>> Interview time duration = 45 mins. |
| Data Collected | Instructor interview transcripts |
| Data Analysis Technique | Thematic Analysis of Instructor interviews |

# Gathering Specifications of objectives for CuVIS framework

| Objectives | Example | Bloom's Level |
|---|---|---|
| 1. Visualize to explain a concept with illustration | Explain the theory behind asymmetric key cryptography with illustration | Understand |
| 2. Visualize to explain the working of a process/algorithm or compare multiple processes | What is the difference between 2-stroke and 4-stroke engine? | |
| 3. Write/Draw alternate representations (like graph to equation) from the given visualization or vice-versa. | Given mathematical function, draw the vector field & vice-versa. | Apply |
| 4. Use a given visualization to compute the solution to the given problem involving multiple processes | Given the input signal & output signal equations, write the transformation equations of the intermediate steps. | |
| 5 . Predict output of next step or a set of steps in a multi-step process/ output of a phenomenon | Predict the output of the given program for the given set of input variable values | |
| 6. Devise an explanation for a given process or phenomena from observations made from the visualization, before the topic has been taught | Derive the plot of $I_D$ vs. $V_{GS}$ for junction field effect transistors (JFET) from the visualization | Analyze |

# Gathering Specifications of objectives for CuVIS framework

| Objectives | Bloom's Level | Skill Targeted |
|---|---|---|
| 1. Visualize to explain a concept with illustration | Understand | Conceptual Understanding |
| 2. Visualize to explain the working of a process/algorithm or compare multiple processes | | Procedural Understanding |
| 3. Write/Draw alternate representations (like graph to equation) from the given visualization or vice-versa. | Apply | Multiple Representation |
| 4. Use a given visualization to compute the solution to the given problem involving multiple processes | | Multi-process problem solving |
| 5 . Predict output of next step or a set of steps in a multi-step process/ output of a phenomenon | | Prediction |
| 6. Devise an explanation for a given process or phenomena from observations made from the visualization, before the topic has been taught | Analyze | Inquiry |

# Gathering Specifications for CuVIS framework

## Customization

Instructional Setting = Instructor-mediated classroom

Activity Time duration = (~10mins./~20mins.)

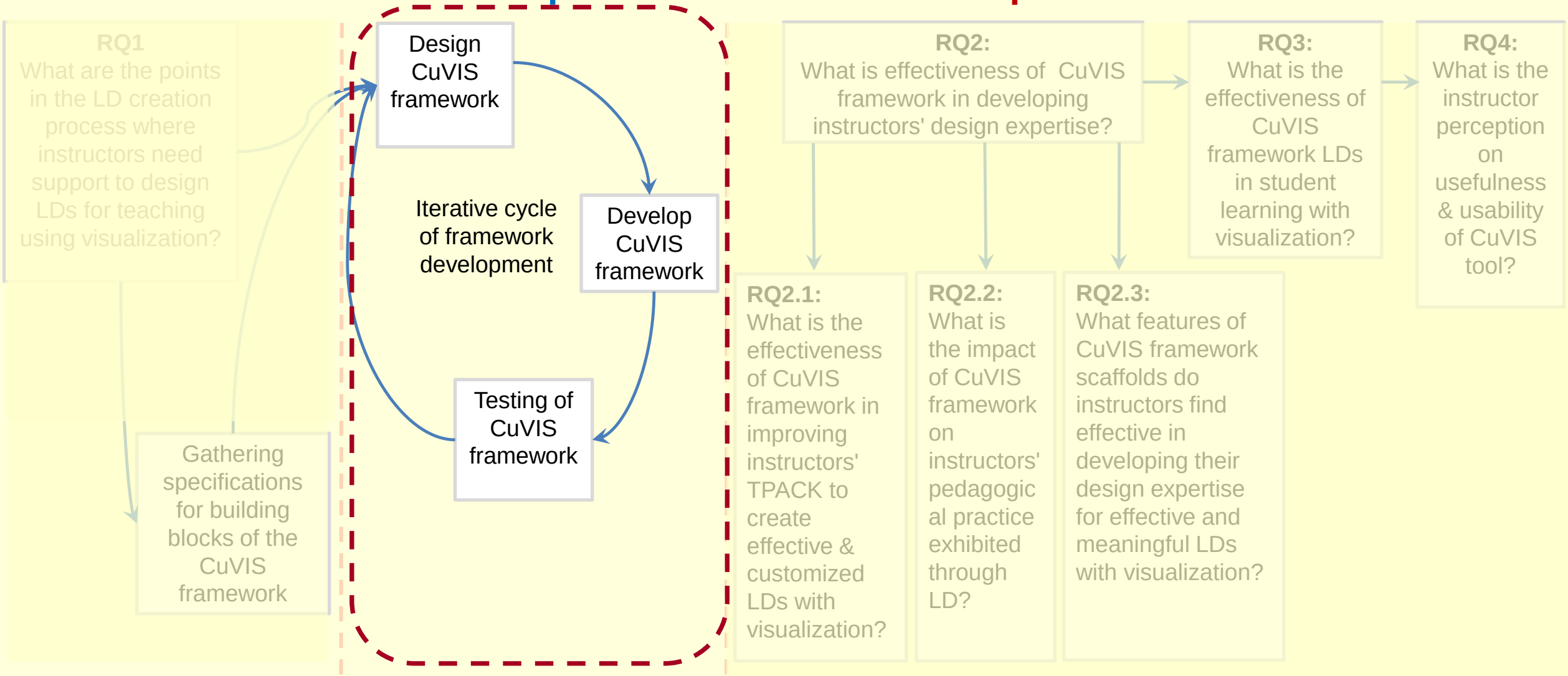
Visualization type = Video/Animation/Simulation

## Learning Design

Design steps of maximum 5 minutes duration

Specify roles of instructor, students & visualization affordance at each step

# Research questions in each phase of DDR

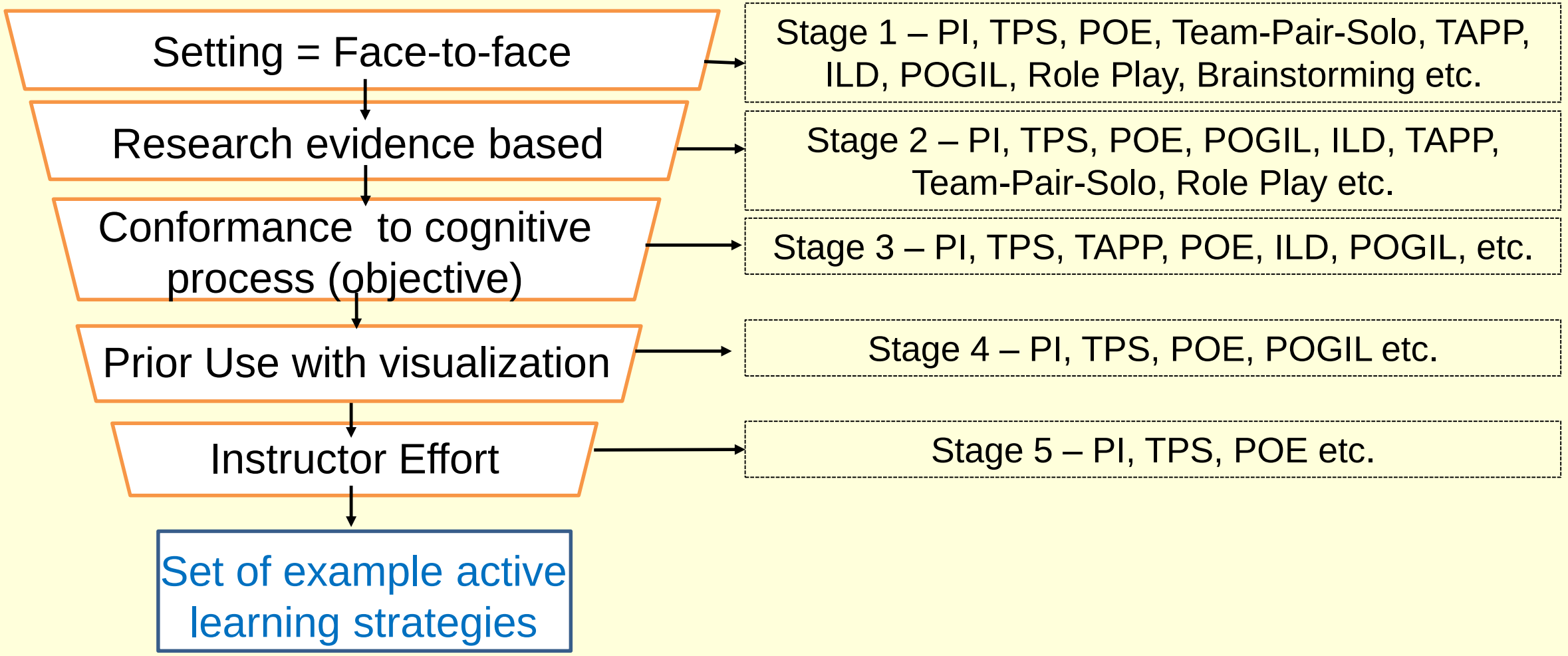


# Design & Development Phase of CuVIS Framework

(Banerjee et.al, 2014)

| *Design impediment identified: Instructors unable to –* | *To explain* |
|---|---|
| (i)Operationalize Constructive alignment | - |
| (ii)Operationalize Meaningful Learning with ICT | - |
| (iii) Frame group activity questions based on visualization | ✓ |
| (iv) Design implementation of active learning strategies | - |

# Addressing Impediment 3 - Framing group activity question based on visualization



# Addressing Impediment 3 - Framing group activity question based on visualization

Aim is to equip instructors to frame student-centered group activity questions using visualization themselves:

- should become adept at the basic building blocks of active learning
- so that they can adapt and build on these strategies for their context

Option 1

Give them a larger set of strategies to pick-n-choose

Option 2 ✓

Train them on a small set of representative strategies, for various customization parameters

# Example of Guidelines for Framing Group Activity Questions for objective = 'Prediction' in CuVIS Framework

| Objective | Activity Time (mins.) | Strategy Suggested | Activity Constructor Prompts | Guidelines | Examples |
|---|---|---|---|---|---|
| 4. Predict output of next step or a set of steps in a multi-step process or a phenomenon | 5-10 | Peer | 4. Frame the | c] Frame questions that are | Domain =EE<br>Q. *Two traveling waves 1 and 2 seen in visualization, are described by the equations:*<br><br>*y1(x,t) = 2 sin(2x – t)*<br>*y2(x,t) = 4sin(x – 0.8 t)*<br><br>*All the numbers are in the appropriate SI (mks) units. Predict, with reasoning, which wave has the higher speed?*<br>*A) wave 1 B) wave 2 C) Both have the same speed.* |
| | | | your objective | options should be brief.<br>d] Answer options should prompt students to look for covariation to identify causal variables + causal relationship<br>e] The clear deliverable should be student predictions with reasoning<br>f] You can consult questions from existing question banks like: http://www.cwsei.ubc.ca/resources/clickers.htm#questions | |

Likewise guidelines framed addressing other impediments, in the framework

# The Customized Visualization Integration (CuVIS) framework

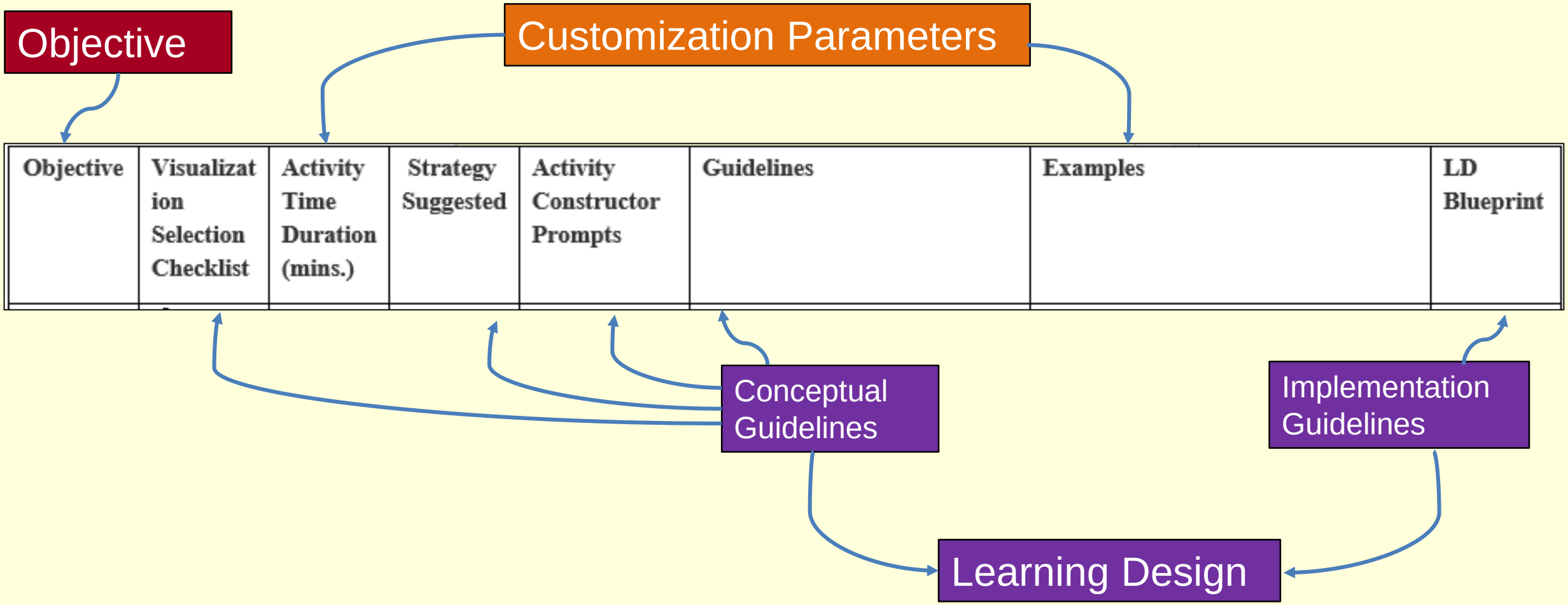
- Provides operationalized guided steps for instructors at the conceptual and implementation levels.

| Objective | Visualization Selection Checklist | Activity Time Duration (mins.) | Strategy Suggested | Activity Constructor Prompts | Guidelines | Examples | LD Blueprint |
|---|---|---|---|---|---|---|---|
| 1. Visualize to explain a concept with illustration | a] Covers difficult to understand/visualize part of the chosen topic or where there is change in the system with motion/ time<br><br>b]Shows (video/ animation) Or, Allows (simulation) change | 5-10 | Peer Instruction (PI) | 1. Decide the difficult part of the topic to target with visualization<br>.....<br>..... | 1. Think of aspects of the topic students generally find difficult to understand/ visualize & which is covered in your selected visualization<br><br>2. Focus the activity with the visualization on this difficult to understand part of the topic you identified. | Domain = EE<br>*If topic = Coding Theory*<br>*Students unable to decide if position of source coding block & channel coding block in a digital communication block diagram can be interchanged.*<br><br>Domain =CS<br>*If topic =Travelling salesman problem*<br>*Students able to construct a tour but unsure whether the chosen tour is the minimum cost tour.* | CU_PI.ppt |
| | | 15-20 | Think-Pair-Share (TPS) | ..... | ..... | ..... | CU_TPS.ppt |
| | | | | 3. Decide what multiple condition sets to show | a] You need to play the visualization to show effect of varying the value (s) of multiple variables on the system. | Domain = EE, Topic = Digital Modulation<br>*Show the simulation output for AM, PM, FM (digital amplitude* | |

Conceptual Guidelines

Implementation Guidelines

# The CuVIS framework

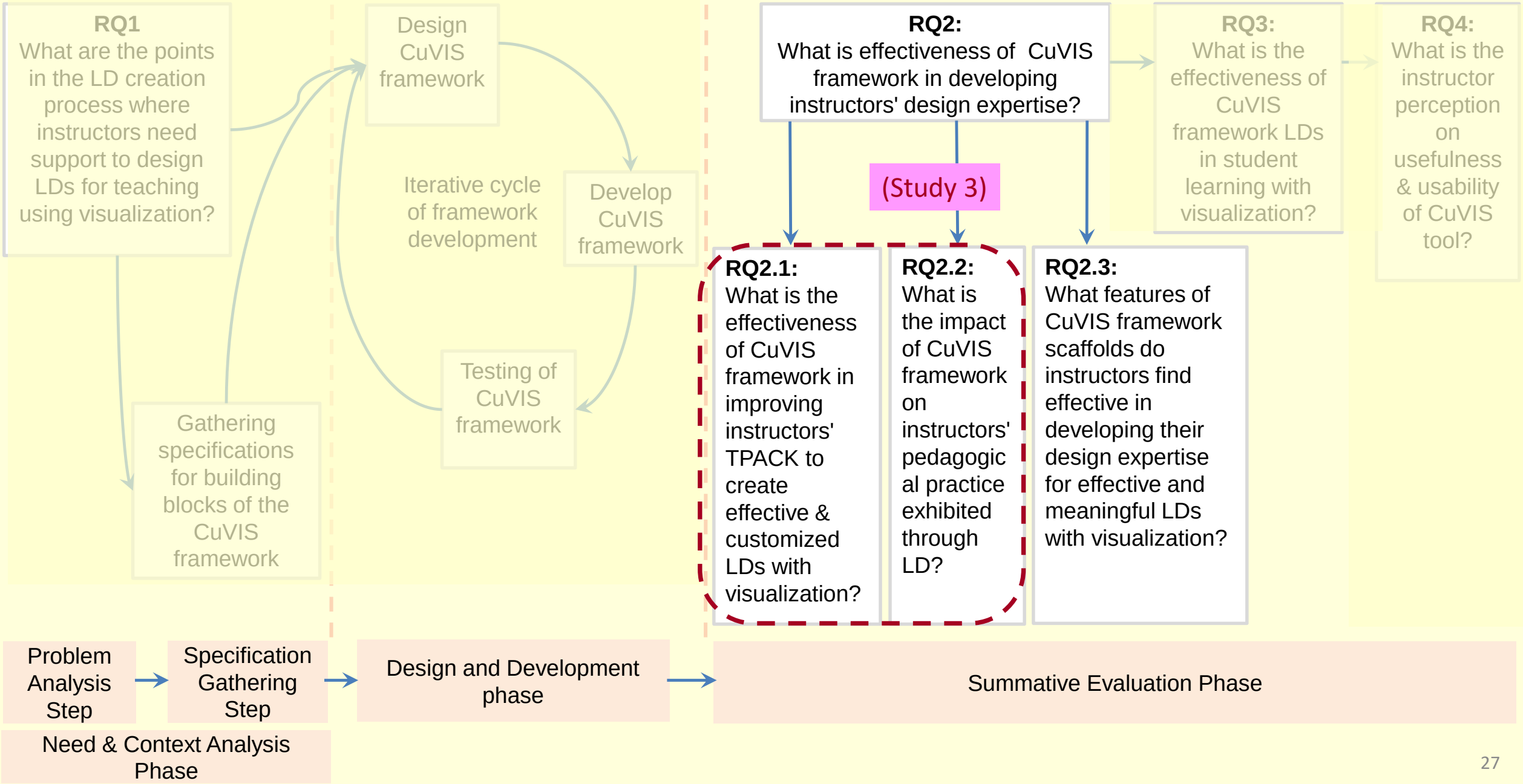


# The Customized Visualization Integration System (CuVIS) tool

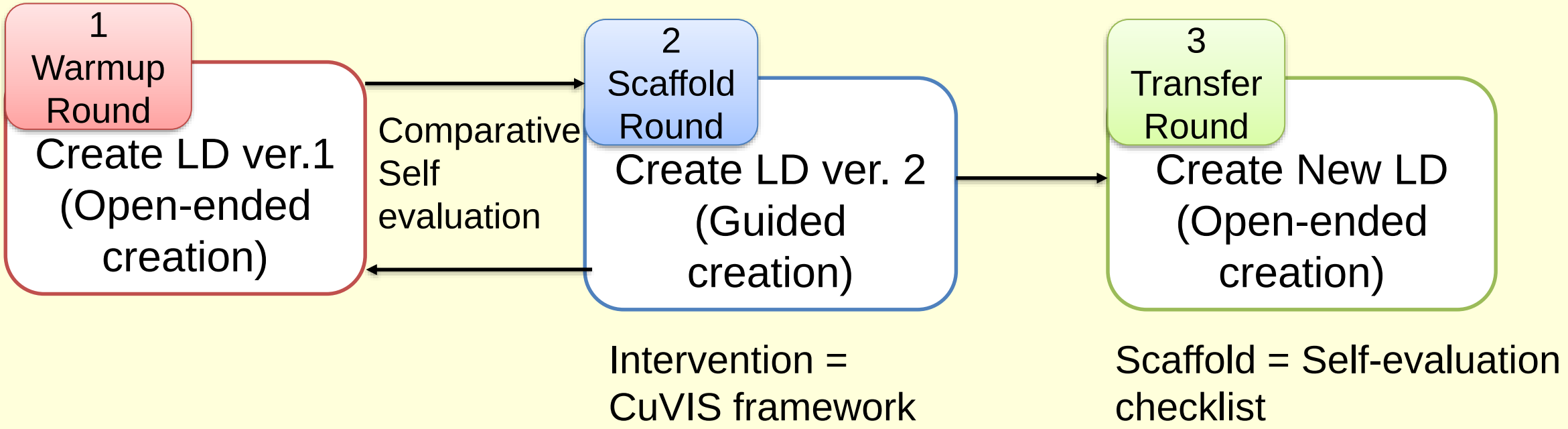
- This is a digital interface for instructors to interact with the CuVIS framework
- A semi-automatic LD authoring tool based on CuVIS framework
- Automaticity = Filling up relevant LD Blueprint template with appropriate activity constructor prompt response of instructor

CuVIS Tool Demo

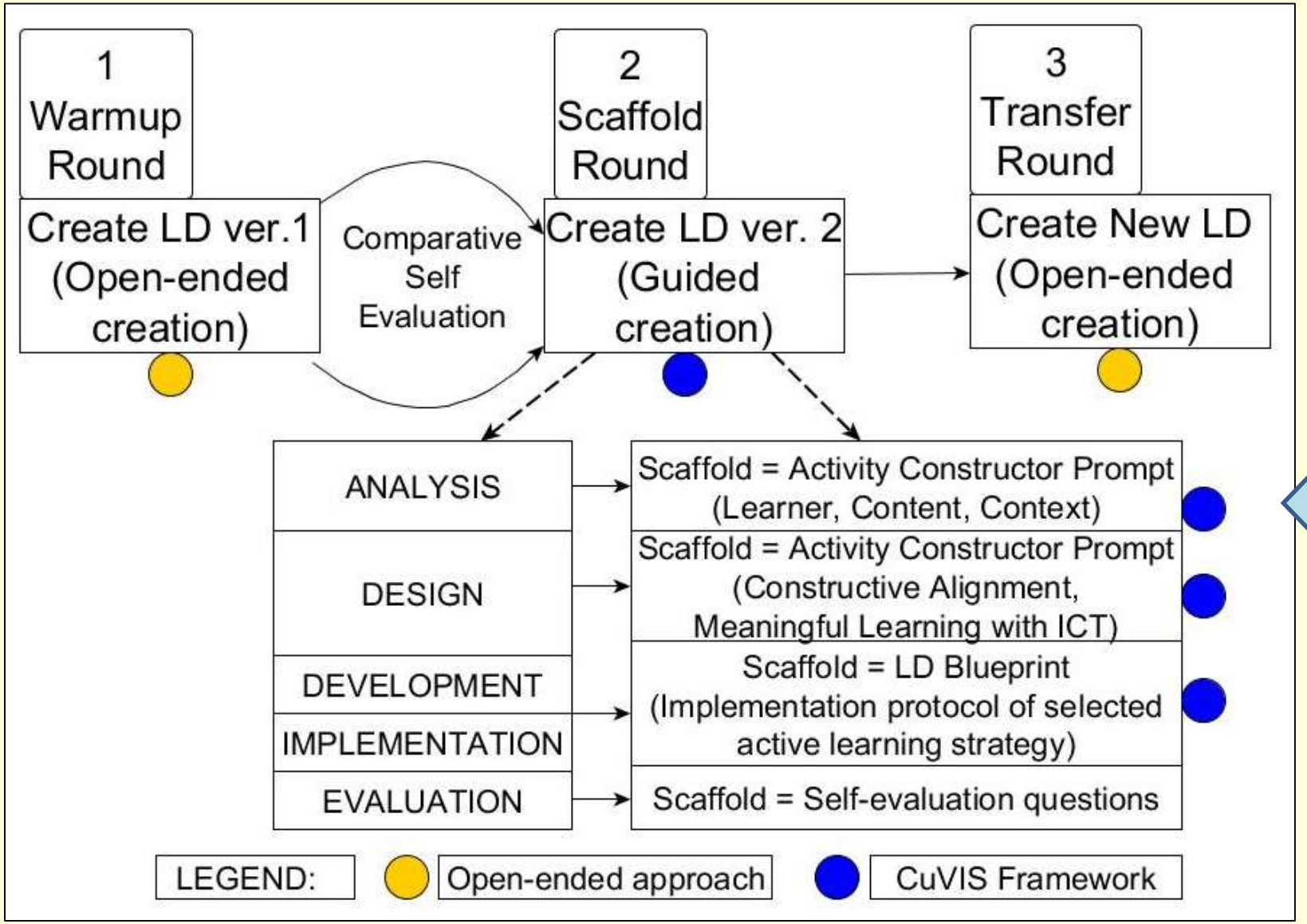
# Research questions in each phase of DDR



# Study 3: Methodology followed to develop instructor's design expertise using CuVIS Framework



# Methodology followed to develop instructor's design expertise using CuVIS Framework




Training workflow
(Adapted from Kali & Ronen-Fuhrmann's model)

3 elements:

i) ADDIE structure

ii) Access to CuVIS framework database

iii) Open-ended design activities (non-collaborative)

# Answering RQ2 : Effectiveness in developing instructor's design expertise (Study 3) (Banerjee & Murthy, 2015)

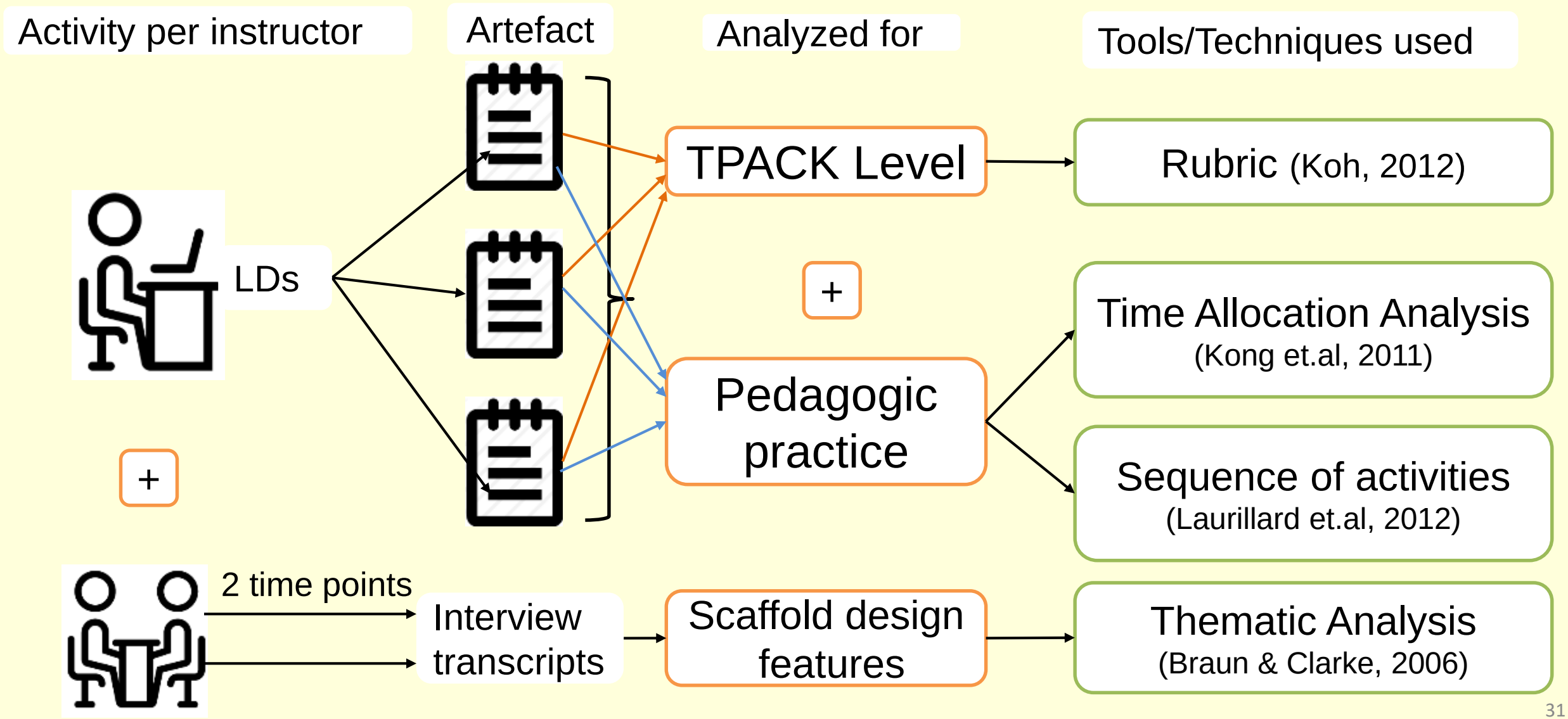
Sampling Criteria

- Have taught with visualization before
- Attended a 2-week blended pedagogy workshop
- Novices in terms of designing active learning activities with visualization

Sample Characteristics

- In-service Electrical and Computer Engineering instructors
- 16 instructors volunteered, 6 instructors (Female = 5, Male = 1) completed this semester-long study
- 1:1 representation of Tier 1 & Tier II cities
- Instructor-mediated classrooms of 70 – 100 students

# Study 3 :Range of data analysis done to determine development of instructors' design expertise



# Answering RQ 2.1 : Effectiveness of CuVIS Framework on TPACK

## Data Analysis Technique

- Evaluate TPACK for competency in designing LDs
- At each of the 3 time points

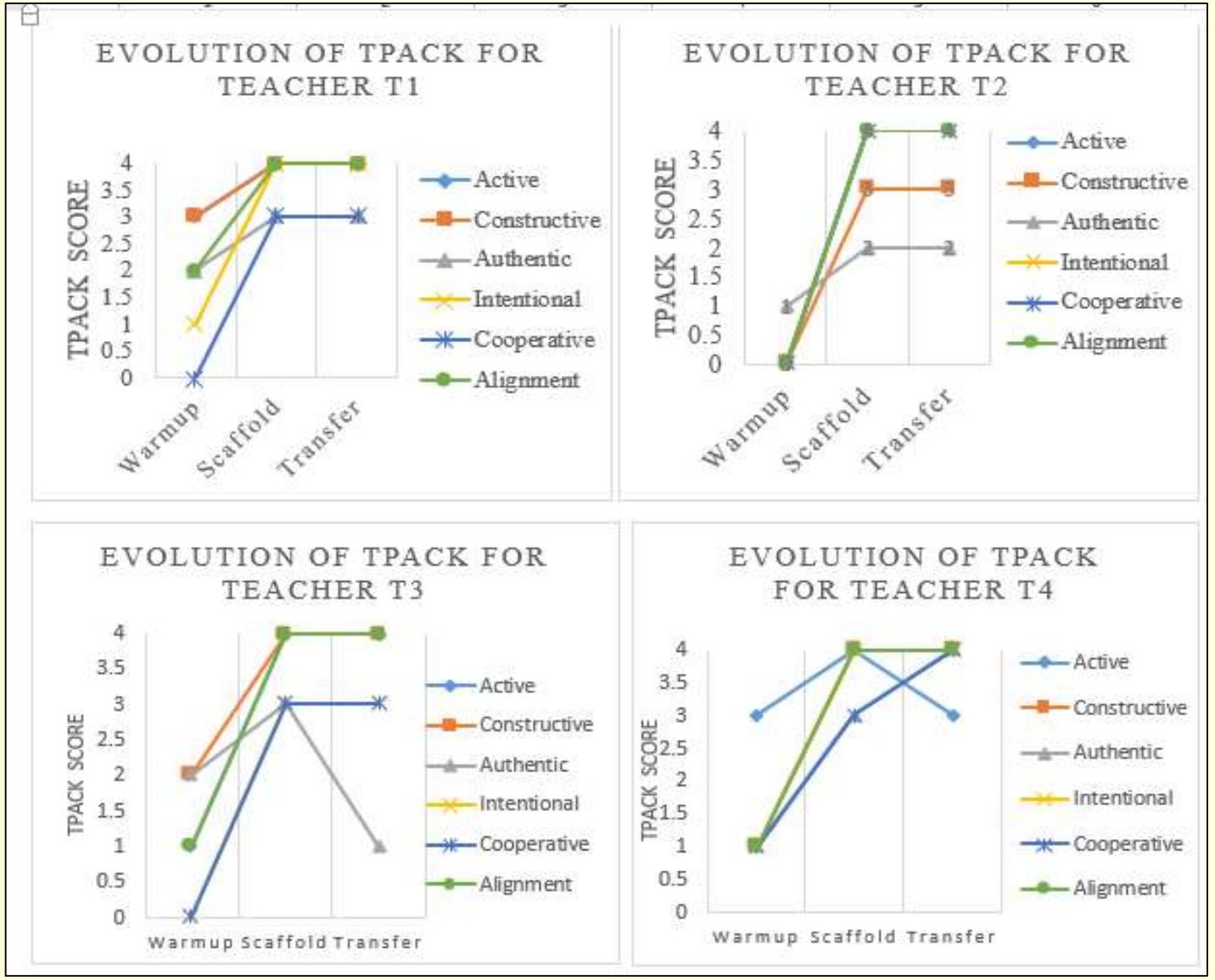
## Rubric Used

- Modified version of TPACK rubric (Koh, 2013)
- Inter-rater reliability = 0.81 (Cohen's kappa)

## Conclusion

- TPACK score (Transfer phase) = 20 – 23 (out of 24)
- Increase along all dimensions for all instructors (except Authentic)

## Results



# Answering RQ 2.2: Impact of CuVIS framework on Pedagogic practice

Change in Pedagogic Practice (Warmup -> Transfer)

Data Analysis Techniques

Time Allocation Analysis
(Kong et. al, 2011)

Sequence of Activities
(Laurillard, 2011)

Phase 1

Category 1: Lecturing without student interaction

Category 2: Guided Interactive Activity with viz.

Category 3: Interactive Activity without viz.

Phase 2

| Category 2 | Sub-category | Instructor | Percentage of time allocated (%) | | | |
|---|---|---|---|---|---|---|
| | | | Warmup | Transfer | Increase | Mean |
| | | T6 | 0 | 33.33 | 33.33 | |
| | Feedback through visualization | T1 | 3.45 | 24 | 20.55 | 16.84 |
| | | T2 | 0 | 22.7 | 22.7 | |
| | | T3 | 20 | 28.57 | 8.57 | |
| | | T4 | 0 | 10 | 10 | |
| | | T5 | 0 | 5.9 | 5.9 | |
| | | T6 | 0 | 33.33 | 33.33 | |

Conclusion:

Mean increase of 32.06% for Category 2 while going from warmup -> transfer round

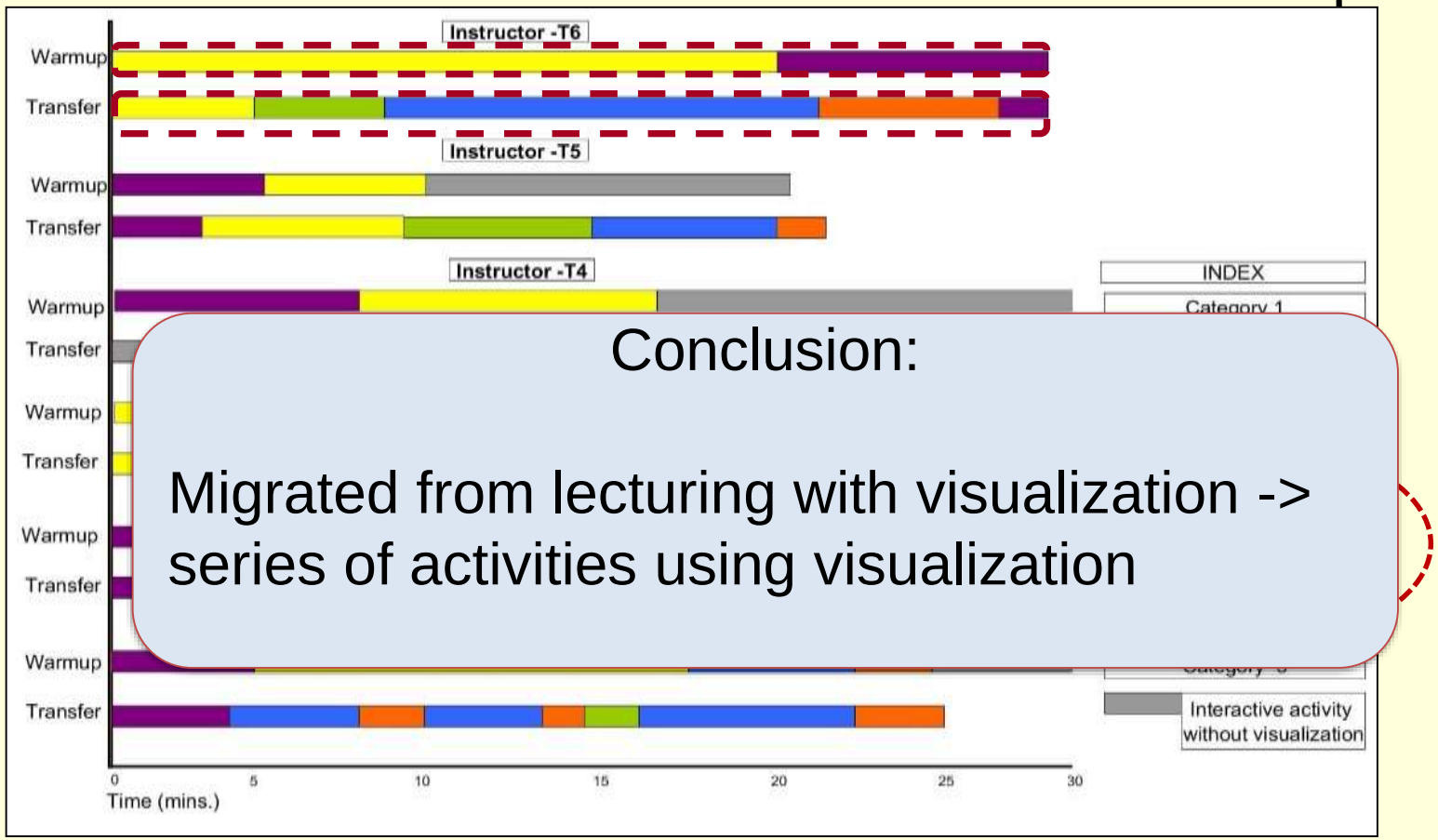
# Answering RQ 2.2: Impact of CuVIS TEL system on Pedagogic practice

Change in Pedagogic practice (Pretest -> Transfer)

Data Analysis Techniques

Time Allocation Analysis
(Kong et. al, 2011)

Sequence of Activities
(Laurillard, 2011)




Conclusion:

Migrated from lecturing with visualization -> series of activities using visualization

# Study 3: Sample LDs generated by same instructor

## Warmup round LD

Topic – Diode Function

LO = Illustrate application of diodes

| Step No. | Time (mins.) | What teacher will do | What student will do | Which visualization feature used, if any |
|---|---|---|---|---|
| 1 | 5 mins.<br>5 mins.<br>7 mins.<br>3 mins. | Explain the basic symbol of diode<br>Explain the p-n junction concept<br>Explain the need of biasing<br>Will take the quiz | The student will be able to understand the working of diode | Animation |
| 2 | 10 mins. | List the applications of diodes | List diode application | |

## Scaffold round LD (CuVIS)

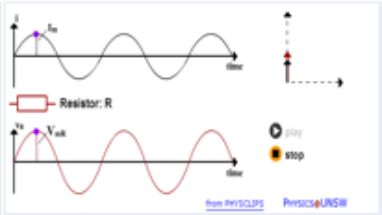
Topic – Diode Function

LO = Illustrate application of diodes

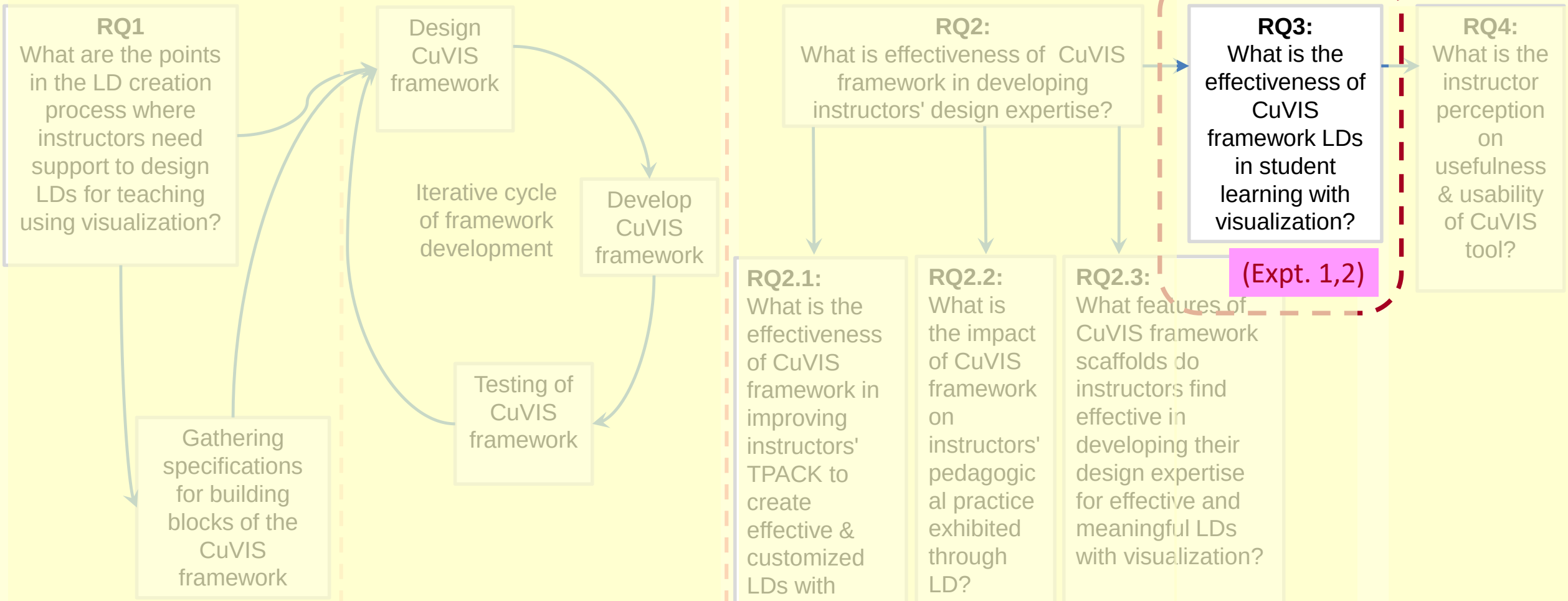
## Transfer round LD

Topic – Resistive Circuit

LO = Define voltage-current relationship

| No. | (mins.) | What teacher will do | student will do | visualization feature used, if any |
|---|---|---|---|---|
| | | What teacher will do | What student will do | n feature used, if any |
| 1 | 3-5 mins. | Play the visualization, Show multiple condition sets like<br>A. *I will explain and show how an alternating quantity can be viewed as in phase with each other.*<br>B. The vector changes and correspondingly the quantity changes so the revolution of alternating current and voltage in phase | Listen & Watch | Pause button |
| 2 | 3-5 mins. |  <br>I will pause the play when the vector reaches to 90 degrees | Listen & Watch | Pause button |
| 3 | | • Show the parent Question : Draw phasor diagram of vector rotation<br>• Think phase: Think (individually) :<br>a) Identify the value of current and voltage at 90 degrees of rotation<br>b) Identify the vertical component of the phasors<br>c) Compare the behavior of current and | Individual Activity<br>'Thinks' about the answer for 2 – 3 mins.<br>Writes | Pause button |

# Research questions in each phase of DDR




Problem Analysis Step → Specification Gathering Step → Design and Development phase → Summative Evaluation Phase

Need & Context Analysis Stage

# CuVIS Framework

## Answering RQ3: What is the effectiveness of CuVIS framework LDs on student learning with visualization?

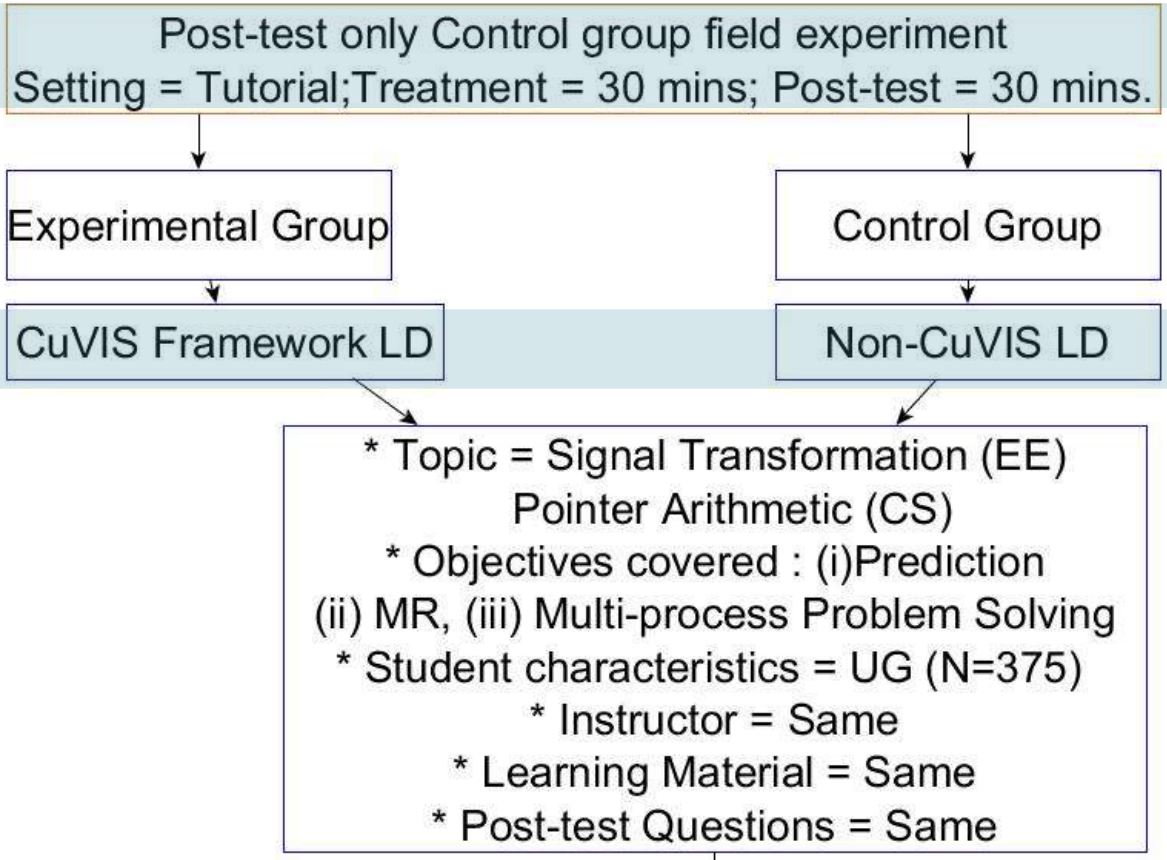
(Banerjee et.al, 2015; Banerjee et.al, 2014, Banerjee et.al, 2013)

# Answering RQ3: Effect of CuVIS LDs on student learning (Expts. 1 & 2)

Methodology

Intervention

Metrics measured



# Results: Effect of CuVIS LDs on student learning

Mann-Whitney U test for 'Pointer Arithmetic'

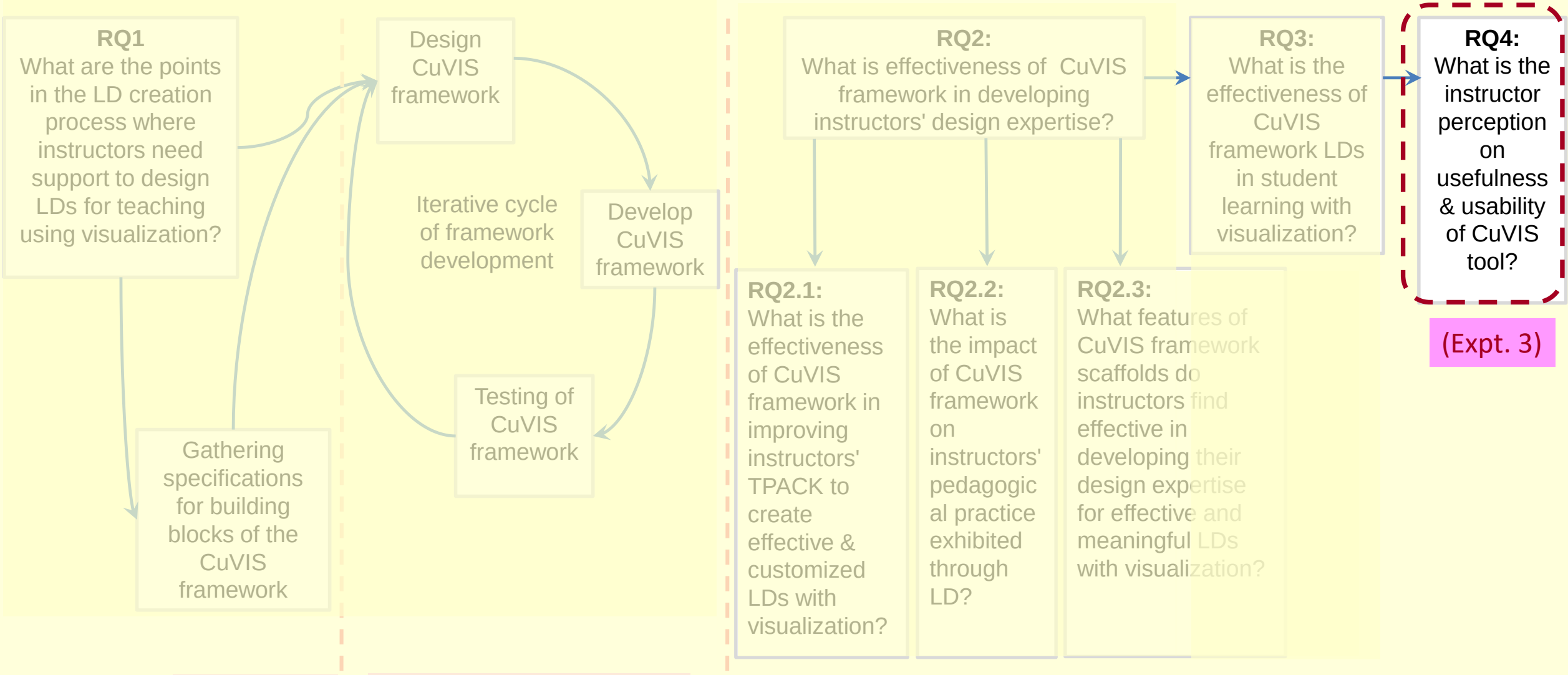
| Dimension | Group | Standard Deviation | Mean | Effect Size (Cohen's d) | U-value | p-value |
|---|---|---|---|---|---|---|
| Rate of problem solving | Prediction (N= 136) | 0.26 | 0.62 | 1.45 | 966.5 | 0.00 |
| | Viewing (N=95) | 0.13 | 0.32 | | | |
| Average post-test score | Prediction | 2.55 | 6.18 | 0.06 | 6435 | 0.96 |
| | Viewing | 2.52 | 6.35 | | | |

Mann-Whitney U test for 'Signal Transformation'

| Learning Objective | Experiment Mean (SD) [Total Marks] | Control Mean (SD) | Effect Size (Cohen's d) | Is difference significant ? |
|---|---|---|---|---|
| Visualize to explain a specified concept | 2.86 (0.43) [3 marks] | 2.42 (0.84) | 0.66 | U=1853 ; p= 0.00 |
| Use a given visualization to compute the solution to the given problem by executing multiple processes | 4.36 (1.18) [5 marks] | 3.47 (1.71) | 0.605 | U=1883; p=0.001 |
| Write/Draw alternate representations from the given visualization or vice-versa. | 2.56 (0.77) [3 marks] | 1.86 (1.15) | 0.72 | U= 1744; p= 0.00 |

**Conclusion: Experimental group taught with CuVIS framework LDs had significantly higher post-test scores/rate of problem solving than students in Control group**

# Research questions in each phase of DDR



# CuVIS Tool

## Answering RQ 4: What is the instructor perception on usefulness & usability of CuVIS tool? (Expt.3)

# Answering RQ4: Usefulness & Usability of CuVIS Tool

## Sample Characteristics

- Sc. & Engineering instructors from multiple domains
- Teaching experience = 1 – 30 yrs.
- A
  u

## Usefulness

- Highly useful (90%)
- N = 1422 Sc. & Engg. Instructors

**Conclusion: Instructors perceive CuVIS tool to be useful and usable.**

## Methodology

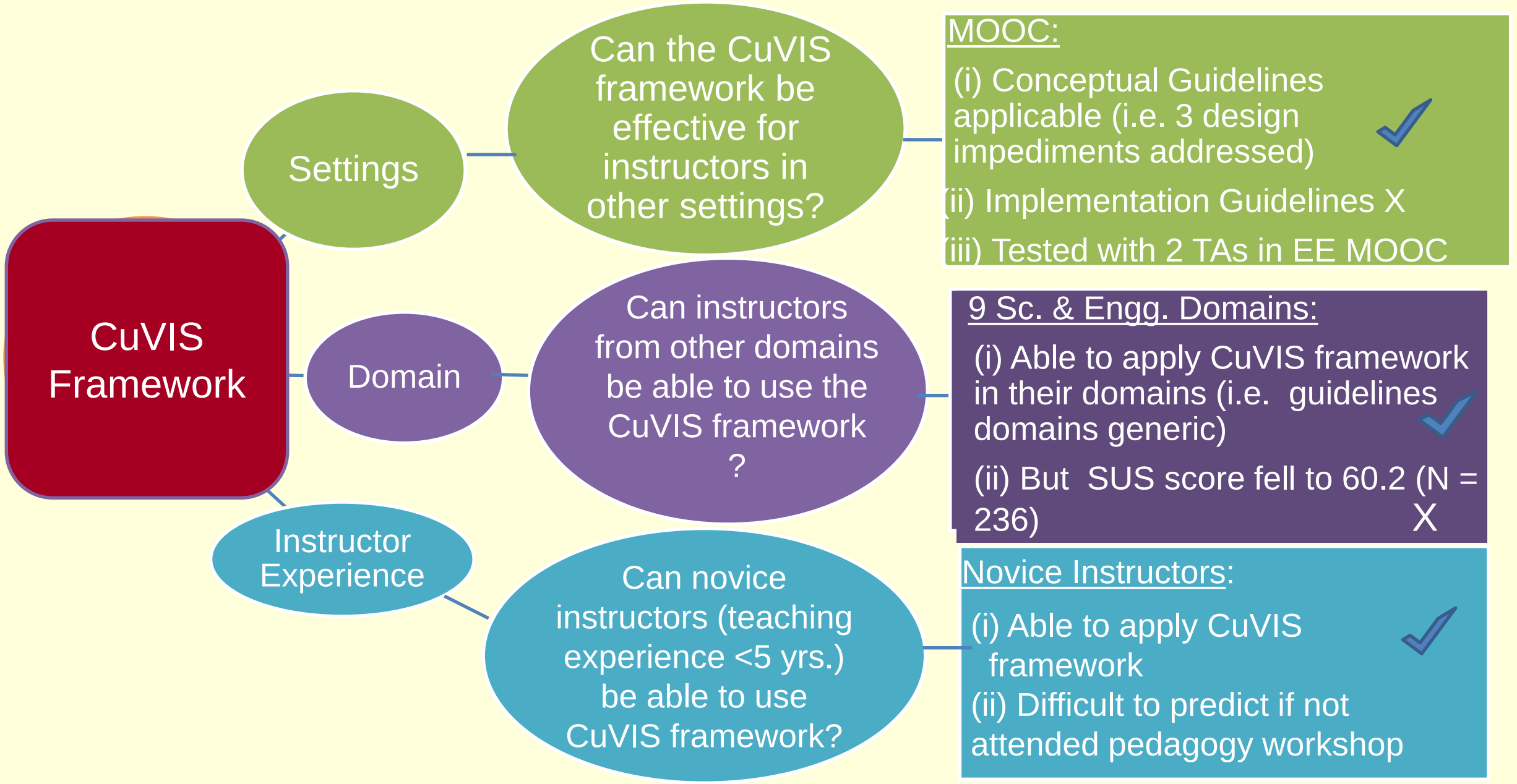
- Instructors used CuVIS tool to create LDs
- Uploaded LDs as Moodle assignment
- Then responded to the surveys in Moodle
- Optional activity (Submitted LDs = 1780)
- Researcher did random check on 10% of submissions to ensure responses valid

## Usability

- SUS score = 78.86
- N= 1290 Sc. & Engg. instructors
- SUS Survey (Brooke, 1996)

# Generalizability & Limitations of CuVIS framework

# Generalizability of CuVIS Framework



# Limitations of CuVIS Framework

- Prescriptive:

  - to a certain degree like choosing from a given set of objectives or suggesting a strategy to design the LD

- Completeness of objective list:

  - Includes 6 objective types. Does not cover design type objectives like ‘visualize a banking scenario and design an appropriate solution.’

- Strategy choice:

  - set of 3 active learning strategies (PI, TPS, POE) included after filtration through 5 filters mapped to our research context.

- Effectiveness assessment:

  - Control group experiments with 375 students but involves 1 topic in each domain
  - Design expertise study with 6 instructors involving 12 topics from EE & CSE

- IMS-LD specification:

  - Technical aspects were not the focus areas of CuVIS framework. The focus is more on the pedagogy of teaching using visualization.

# Contributions of the Thesis

- Major Contributions:
  - CuVIS Framework

  - Identifying 4 design impediments to LD creation

  - Scaffolds helpful in developing design expertise
  (Activity Constructor prompts, LD Blueprint, Self-evaluation checklist)

  - Framework evaluation along multiple axes
  (impact on design expertise –TPACK, Pedagogic Practice & impact on student learning, Usefulness & Usability)
- Minor Contributions:
  - CuVIS tool
  - Design recommendations for scaffolds targeting instructor design expertise

# Future Work from CuVIS Framework

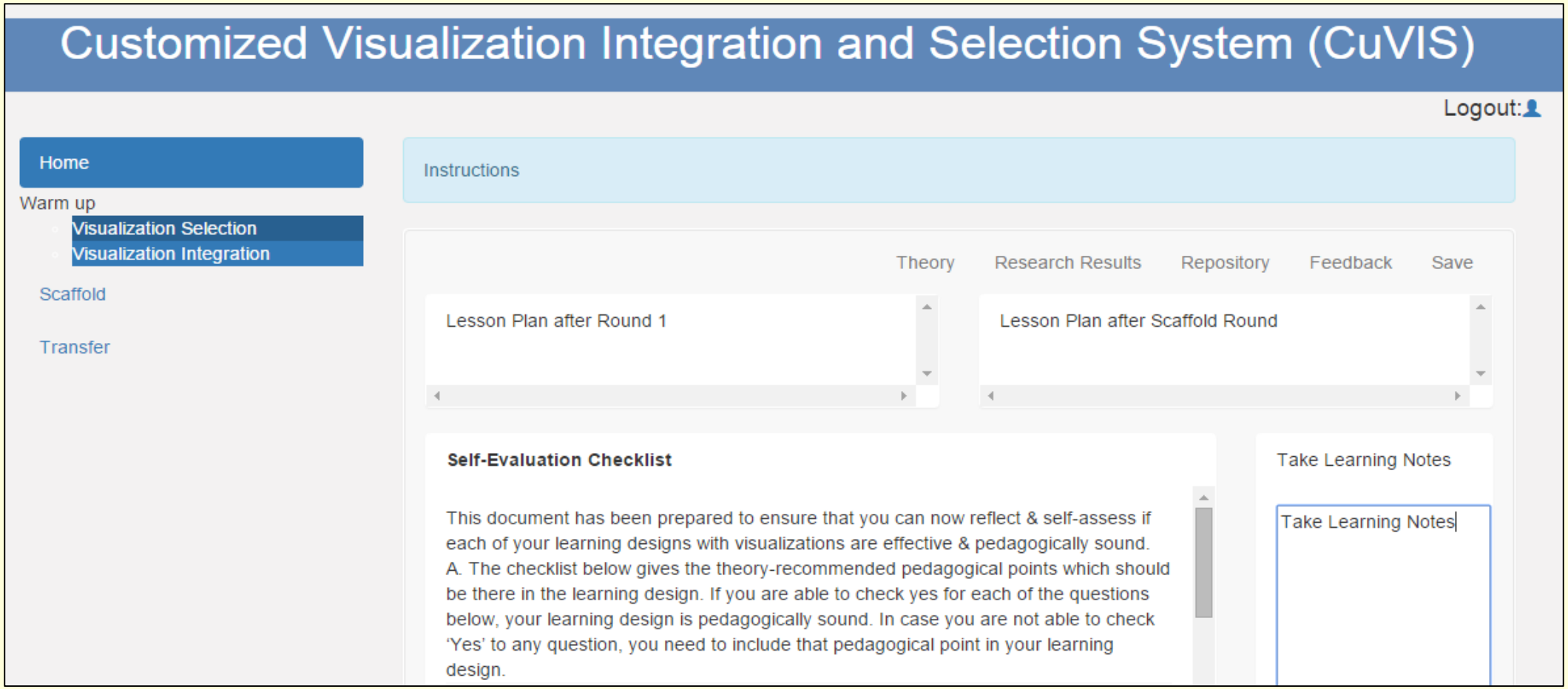
- Extending to other instructional settings like MOOC :
  - Conceptual guidelines adaptable to other settings
  - But researchers need to design a new set of implementation level guidelines specific to the setting, specially for the cooperative dimension

- Create a framework of design scaffolds for instructors of different TPACK levels :
  - Guidelines can be customized to different TPACK levels of instructors
  - Thus create an adaptive training framework for instructors based on TPACK

# Future Work from CuVIS Framework

- Extending CuVIS tool to a collaborative TEL system :

  - Incorporate features like automatic group formation, peer feedback mechanism, discussion forums for collaborative activity etc.



# List of publications from Thesis

Journal Paper

1. Banerjee, G., Murthy, S., & Iyer, S. (2015). Effect of active learning using program visualization in technology-constrained college classrooms. *Research and Practice in Technology Enhanced Learning*, *10*(1), 1-25.

Conference Papers

2. Banerjee G. & Murthy S. (2015). "CuVIS Tool to Develop Instructors' Competency in Creating Meaningful Learning Designs", 23rd International Conference on Computers in Education (ICCE).
3. Banerjee G., Patwardhan M. & Murthy S. (2014). "Learning Design Framework for Constructive Strategic Alignment with Visualizations", 22nd International Conference on Computers in Education (ICCE).
4. Banerjee, G., Kenkre, A., Mavinkurve, M., & Murthy, S. (2014, July). "Customized Selection and Integration of Visualization (CVIS) Tool for Instructors", In *Advanced Learning Technologies (ICALT), 2014 IEEE 14th International Conference on* (pp. 399-400).
5. Banerjee, G., Patwardhan, M., & Mavinkurve, M. (2013, December). Teaching with visualizations in classroom setting: Mapping Instructional Strategies to Instructional Objectives. In *Technology for Education (T4E), 2013 IEEE Fifth International Conference on* (pp. 176-183).
6. Banerjee G., Murthy S. & Iyer S. (2013), **"**Program Visualization: Effect of viewing vs. responding on student learning**"**, 21st International Conference on Computers in Education (ICCE).
7. Banerjee G., Murthy S. (2012), **"**Effect of Instructors' Pedagogy and TPACK on integration of computer based visualizations", Workshop Proceedings of 20th International Conference on Computers in Education (ICCE), Singapore. Available at:http://www.lsl.nie.edu.sg/icce2012/wp-content/uploads/2012/11/WORKSHOP-E-BOOK.pdf
8. Kenkre, A., Banerjee, G., Mavinkurve, M., & Murthy, S. (2012, July). Identifying Learning Object pedagogical features to decide instructional setting. In *Technology for Education (T4E), 2012 IEEE Fourth International Conference on* (pp. 46-53).

# Thank You!


17 July 2015

et@iitb