Determining Interactivity Enriching Features for Effective Interactive Learning Environments

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under guidance of

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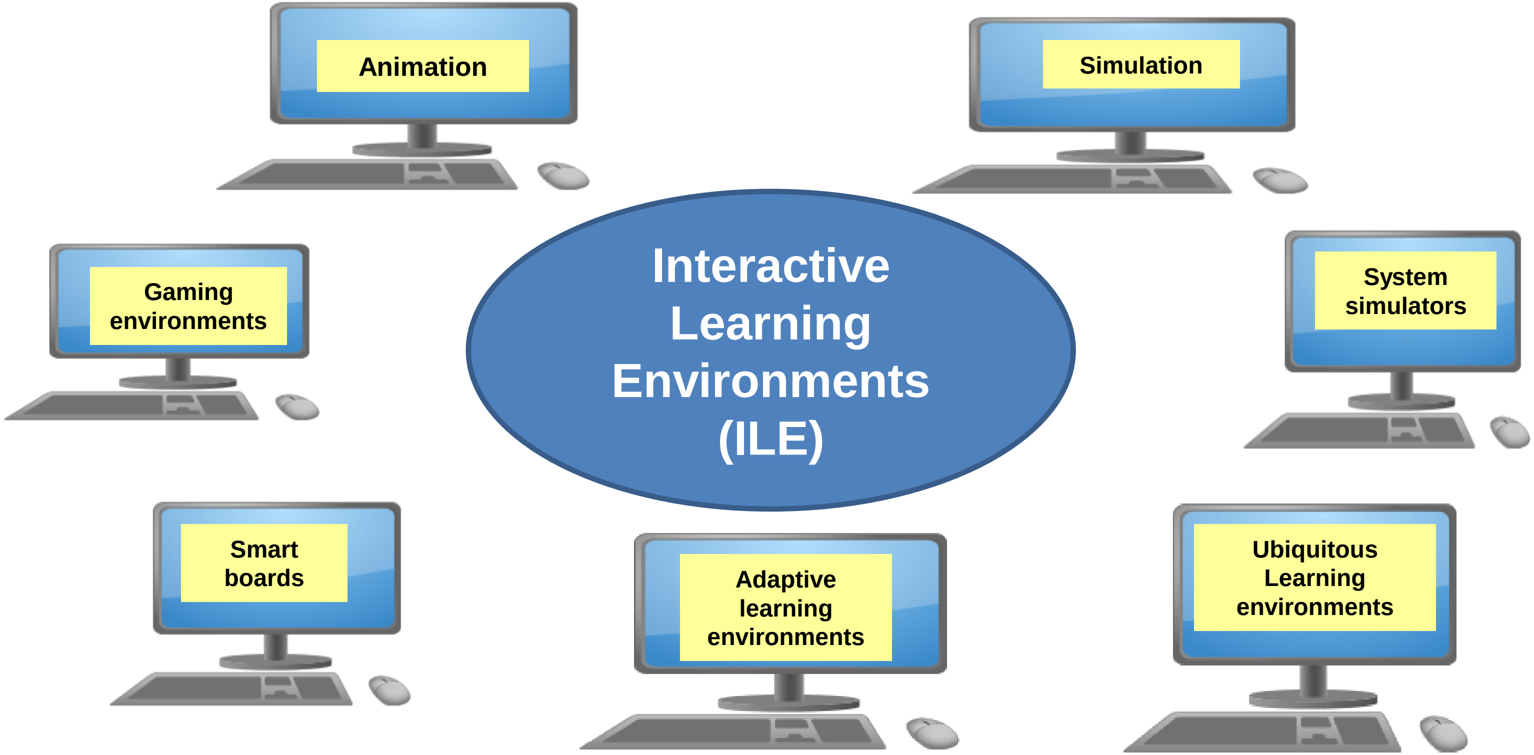
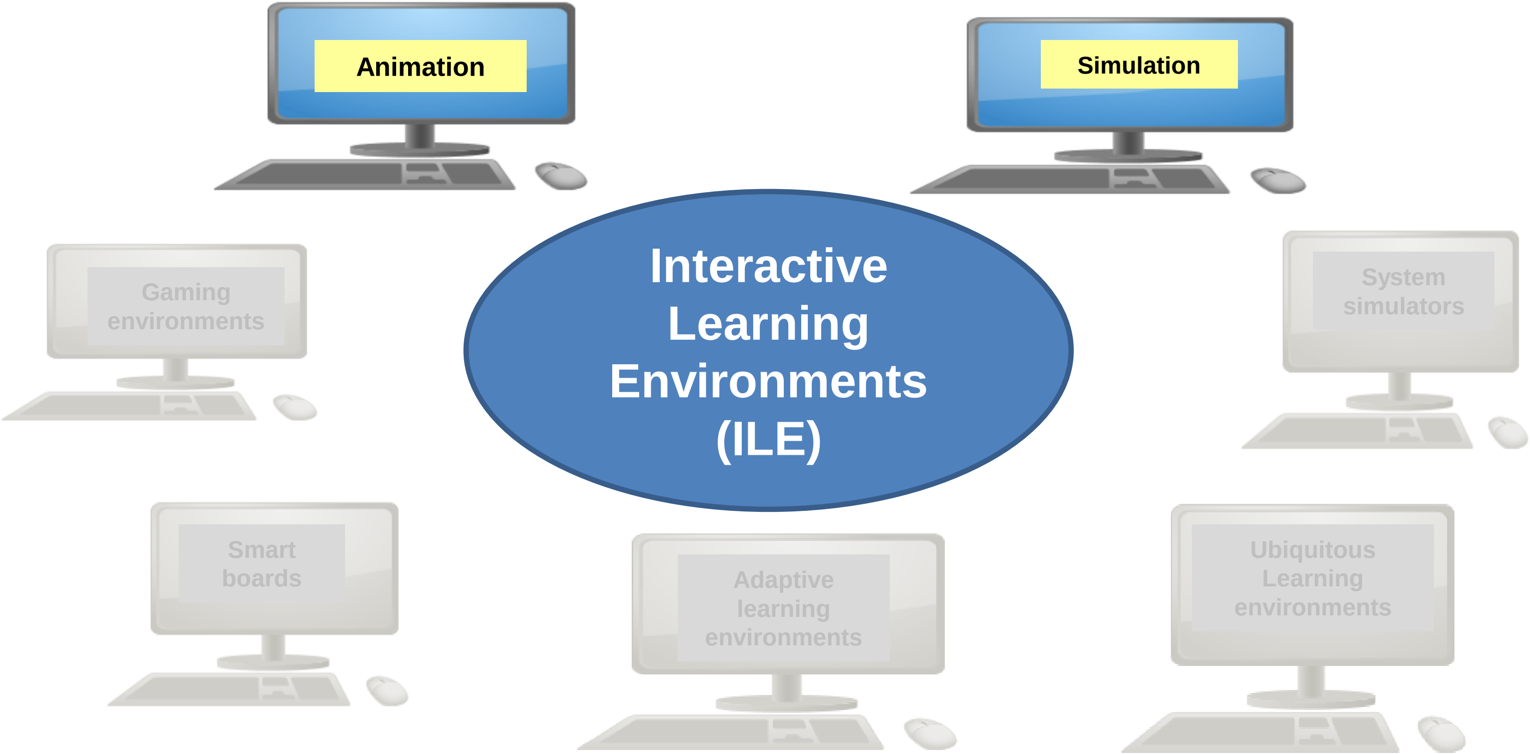
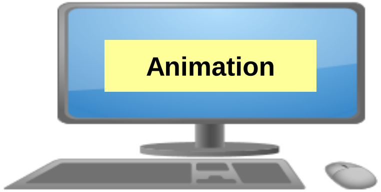
Interactive Learning Environments (ILEs)



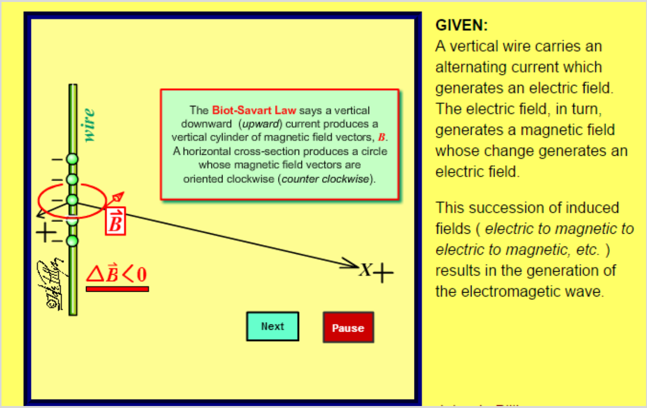
Interactive Learning Environments (ILEs)



Interactive Learning Environments (ILEs)



Interactive Animation



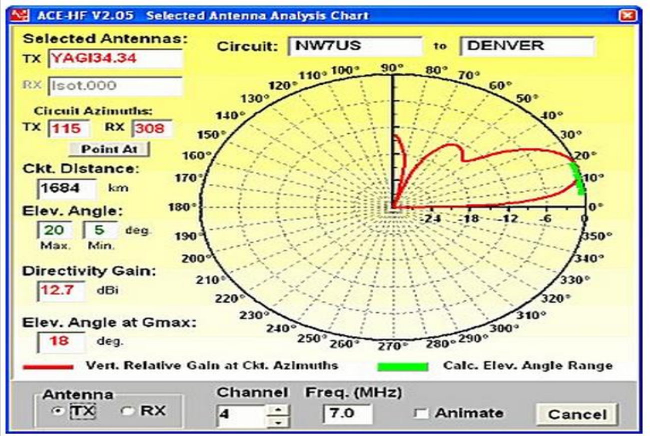
http://math.ucr.edu/~jdp/Relativity/EM_Propagation.html

Interactive Learning Environments (ILE)

Two important and very widely used ILEs especially in science and engineering

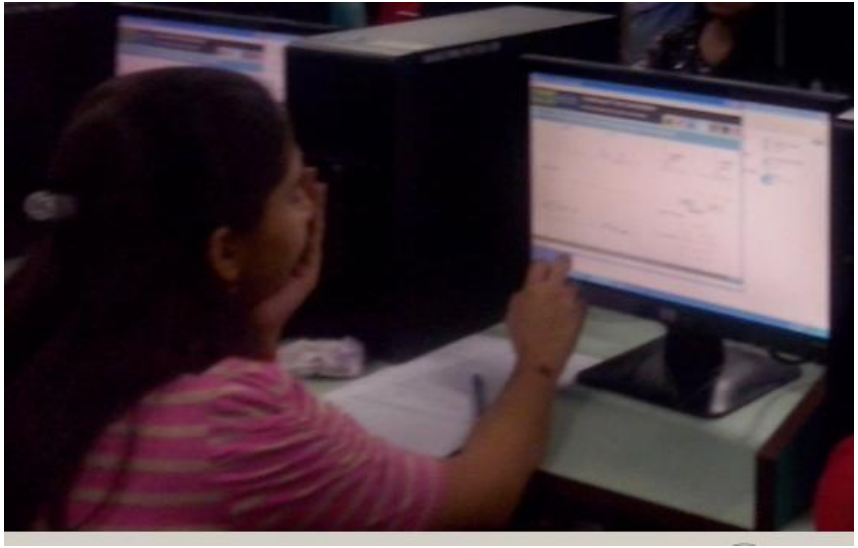
(Yaman, Nerdel, & Bayrhuber, 2008)

Interactive Simulation



http://hfradio.org/ace-hf/ace-hf-antenna_is_key.html

Do learners learn from ILEs?

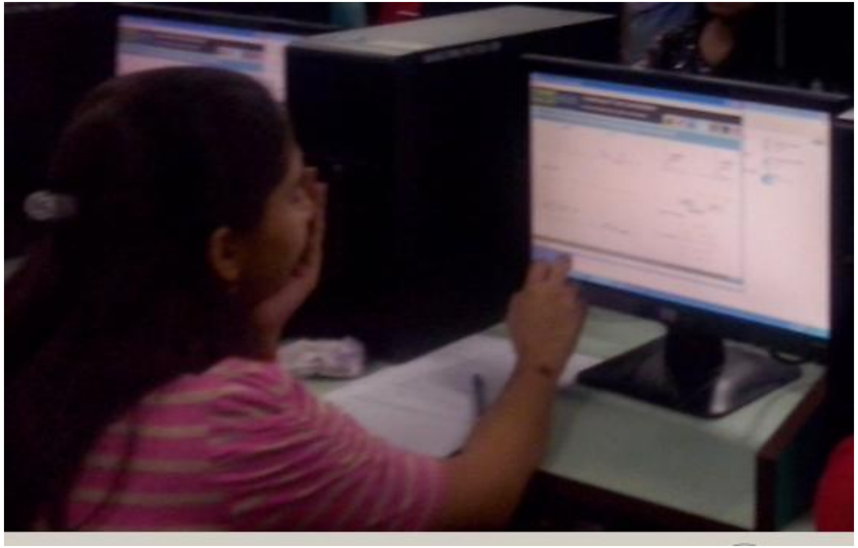


Especially beneficial for learning scientific concepts, processes, principles (Hansen, 2005; Rutten et al., 2011, Cook, 2006)

Promote deeper and clear understanding of the domain knowledge (Lengler and Eppler,2007)

Foster students' analytical skills, challenges their creativity, abstract thinking and reasoning abilities (Chaturvedi, 2006; Vidal, 2006, Part et al., 2008)

Do learners learn from ILEs?



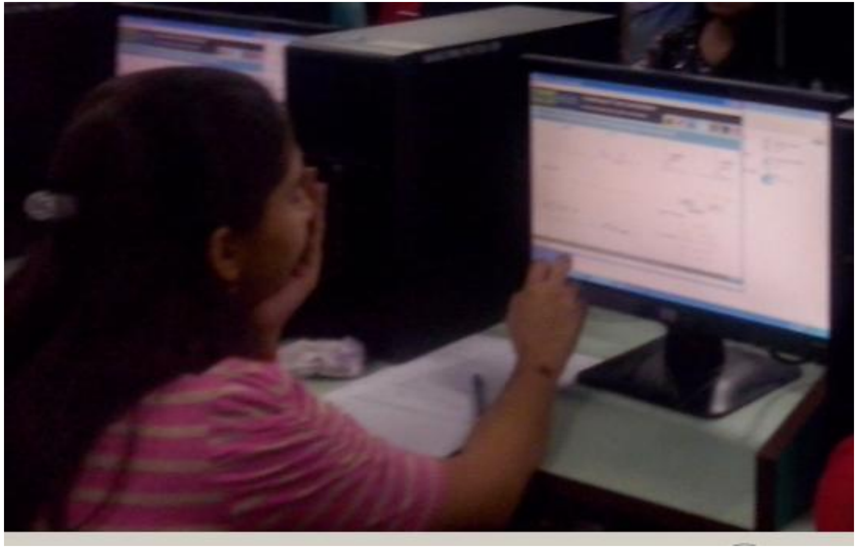
•**Inconsistent results**; learning success is not overwhelming (Kombartzky, 2007).

• higher level of interaction **could not guarantee positive learning effects** (Boucheix & Schneider, 2009)

•Interactions **may just provoke students to play** with different dynamic objects forgetting the real meaning (Guzman, Dormido, and Berenguel, 2010).

•deep learning is not promoted unless **careful consideration is given to interactive features** (Moreno, & Valdez , 2005)

Do learners learn from ILEs?



Mixed and conditional results

- **<u>Inconsistent results</u>**; learning success is not overwhelming (Kombartzky, 2007).

- higher level of interaction **<u>could not guarantee positive learning effects</u>** (Boucheix & Schneider, 2009)

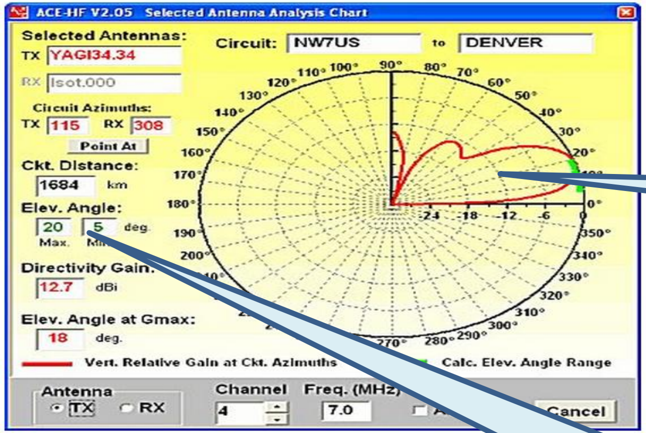
- Interactions **<u>may just provoke students to play</u>** with different dynamic objects forgetting the real meaning (Guzman, Dormido, and Berenguel, 2010).

- deep learning is not promoted unless **<u>careful consideration is given to interactive features</u>** (Moreno, & Valdez , 2005)

Overarching Research Issue

Under what conditions, ILE leads to effective learning?

Exploring Interactive Learning Environments



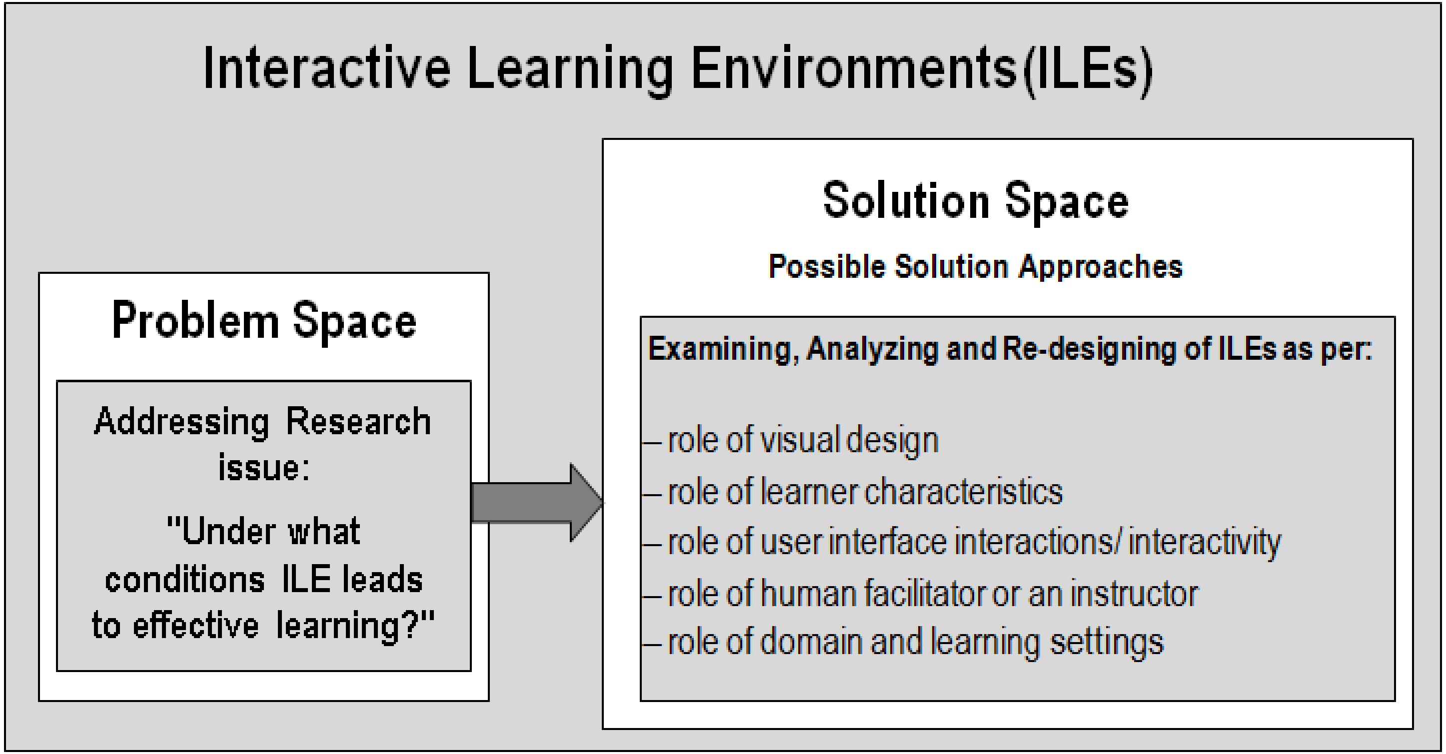
an animated or simulated model of the content*

a user interface that allows interactions with the dynamic content being presented*

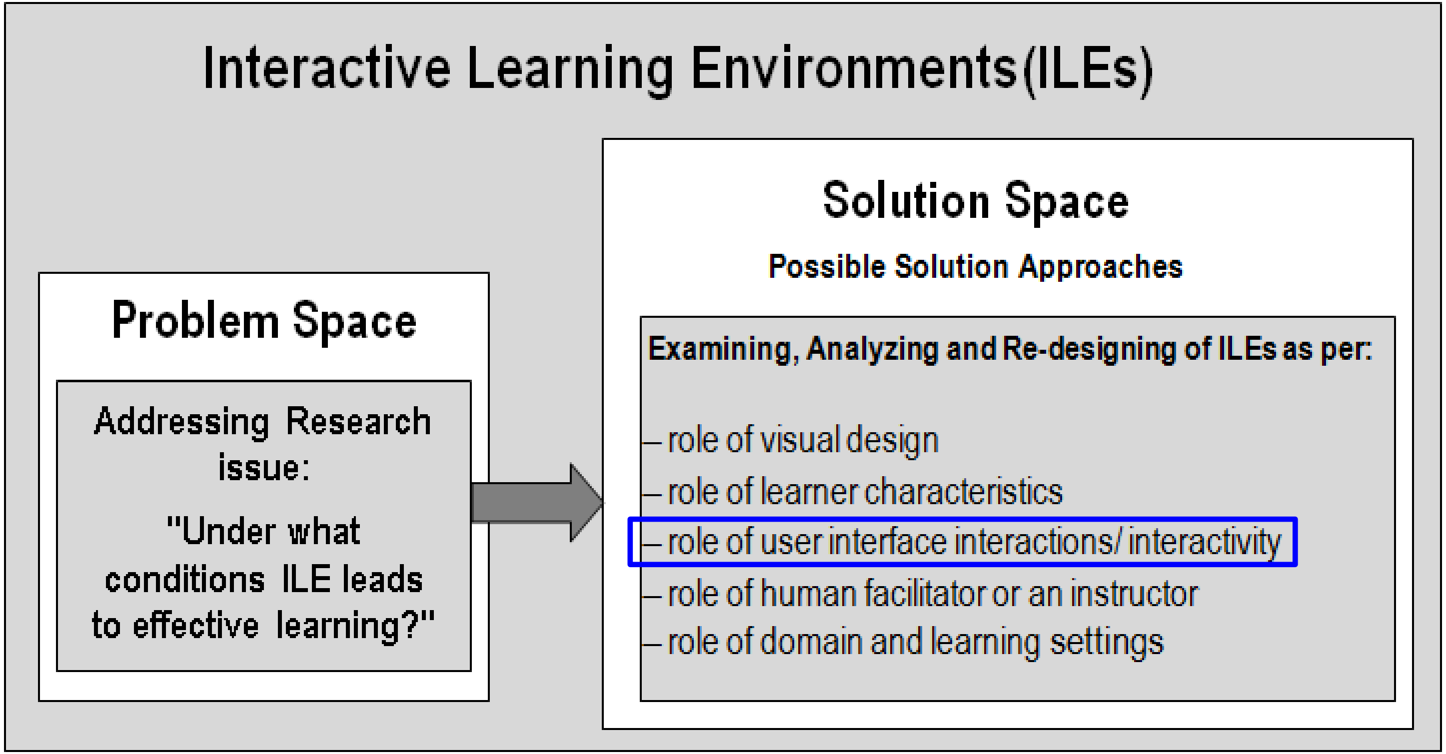
a human facilitator or an instructor for briefing and debriefing sessions*

* Quadrat-ullah, 2010

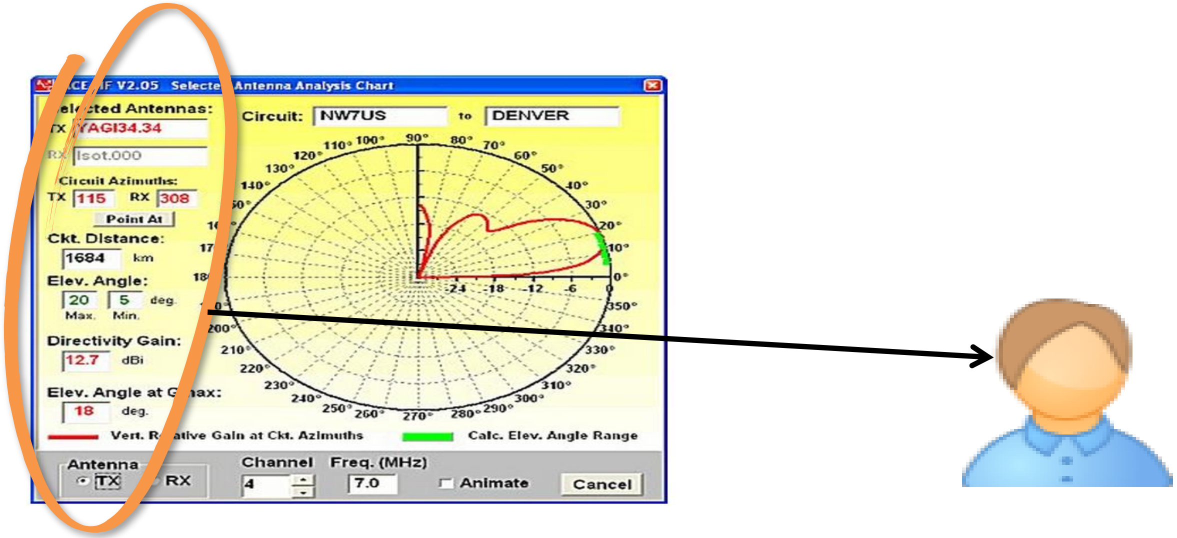
Possible solution approaches in ILEs



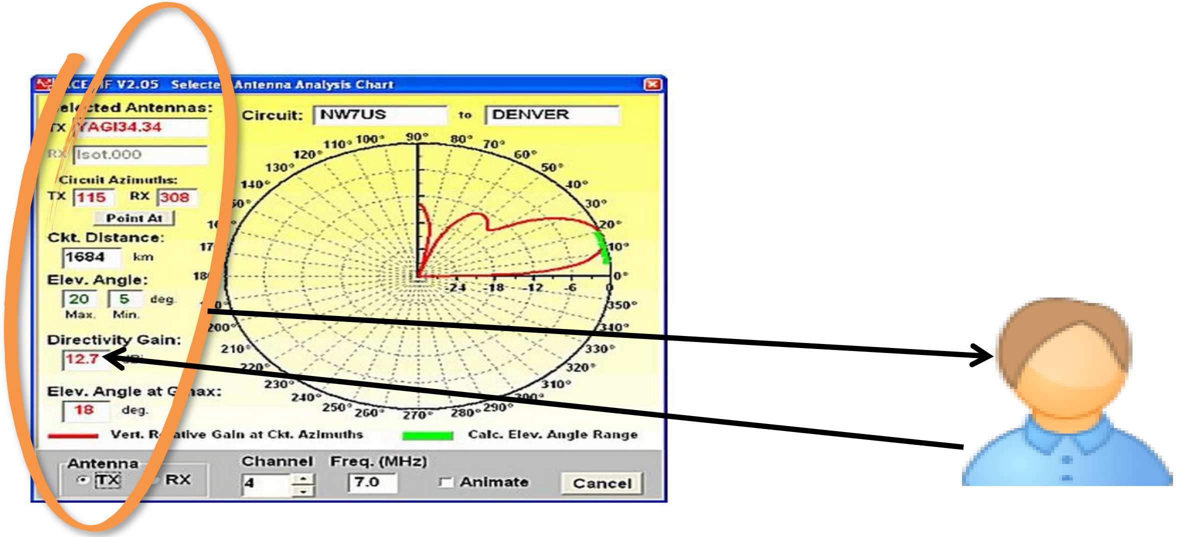
Solution approach selected for the study



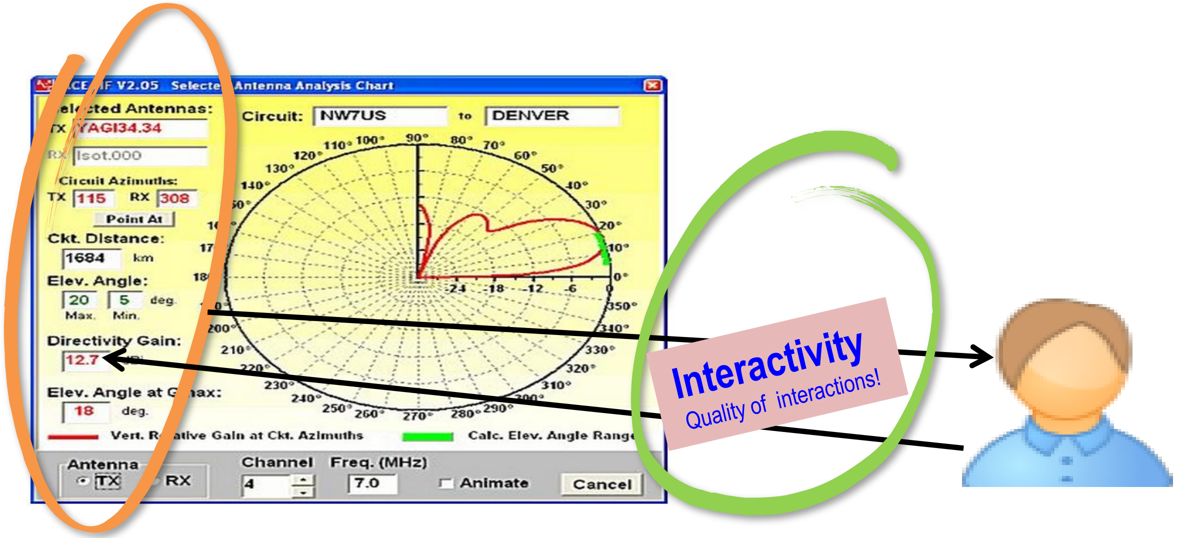
Interactions and Interactivity in ILEs



Interactions and Interactivity in ILEs



Interactions and Interactivity in ILEs

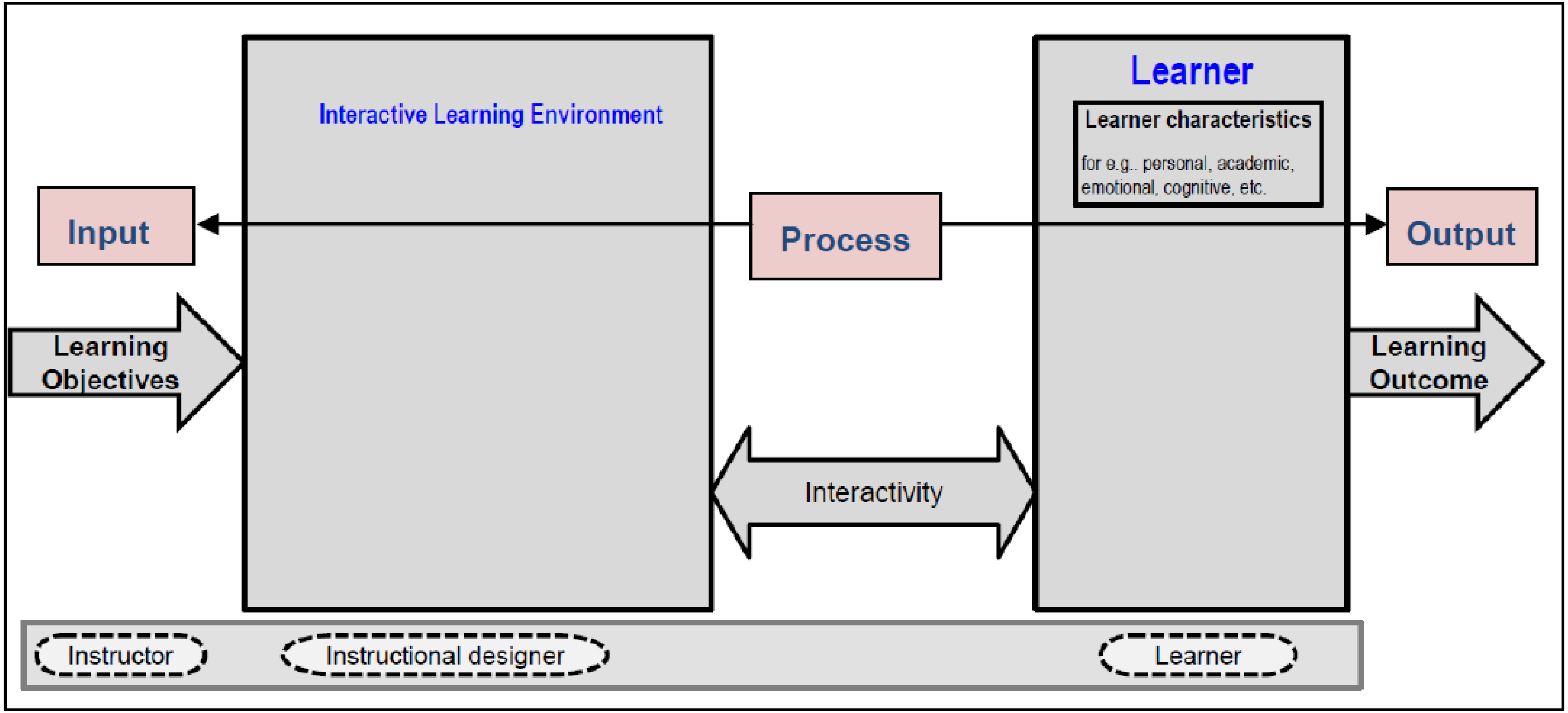


- learners' behaviour depends on the action of the system, which in turn depends on the reaction of the learner, and so on (Domagk et al., 2010)

Link

Synthesizing Literature Survey

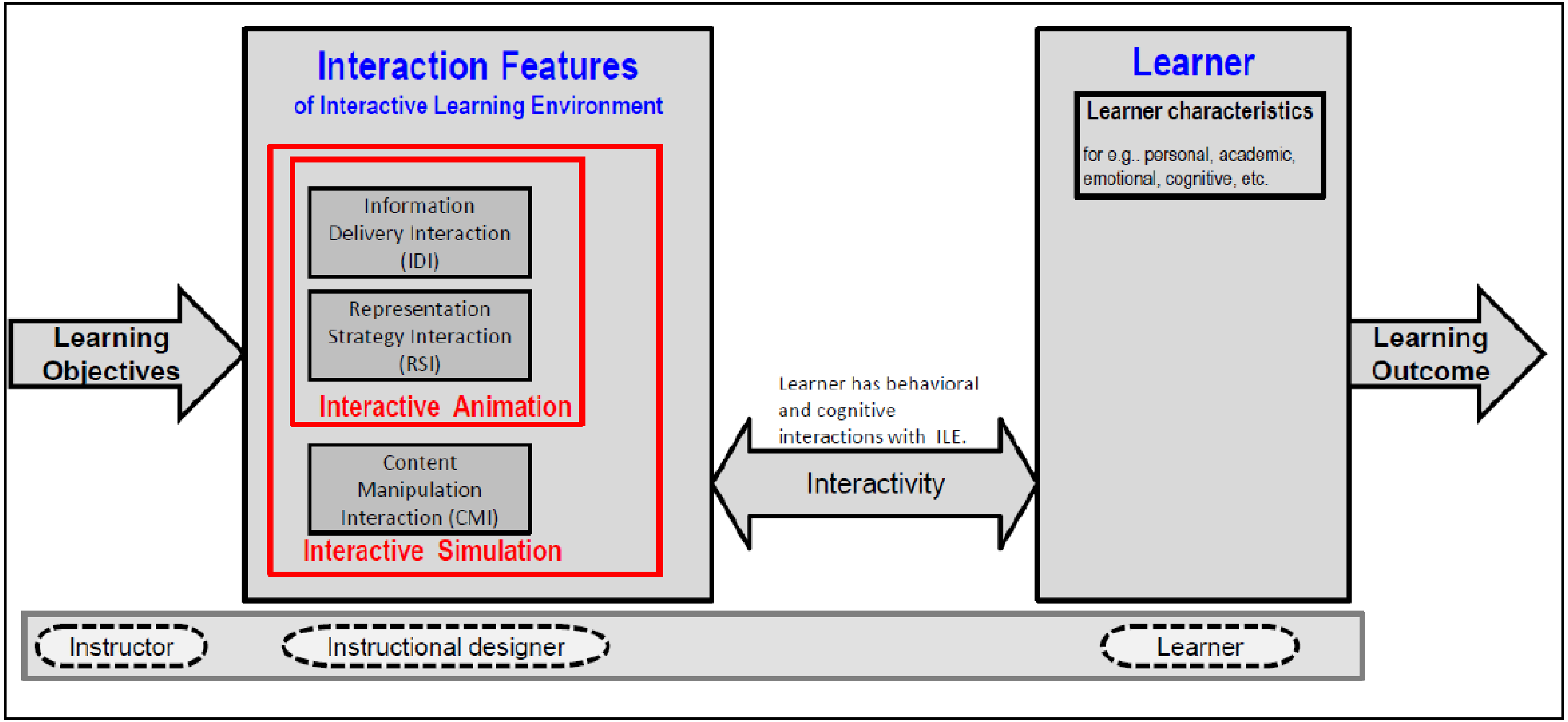
Learning process of Interactive Learning Environment and its basic stake-holders



Link

Synthesizing Literature Survey

Interactions in ILEs



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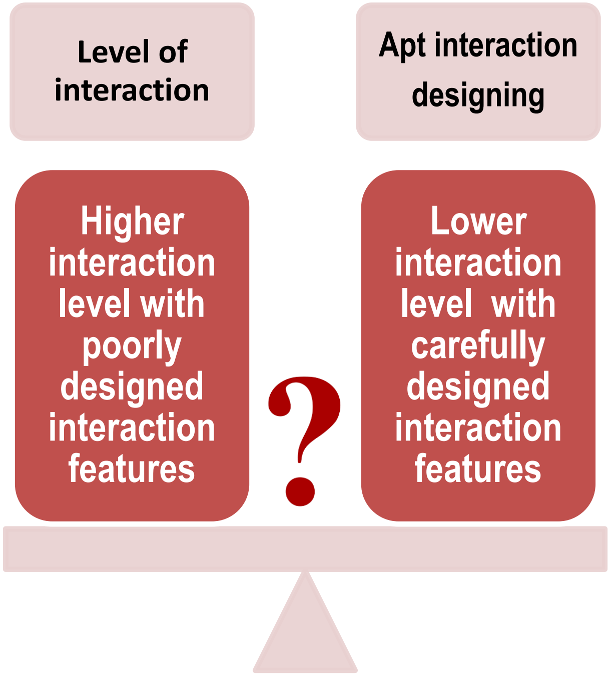
Literature Synthesis to Research Questions



Literature Synthesis to Research Questions

Level of interaction

Apt interaction designing

Needed rigorous validation

Higher interaction level with poorly designed interaction features

?

Lower interaction level with carefully designed interaction features

RQ1:
"Does higher level of interaction lead to effective learning in ILE?"

What will be '*carefully designed*' interactions?

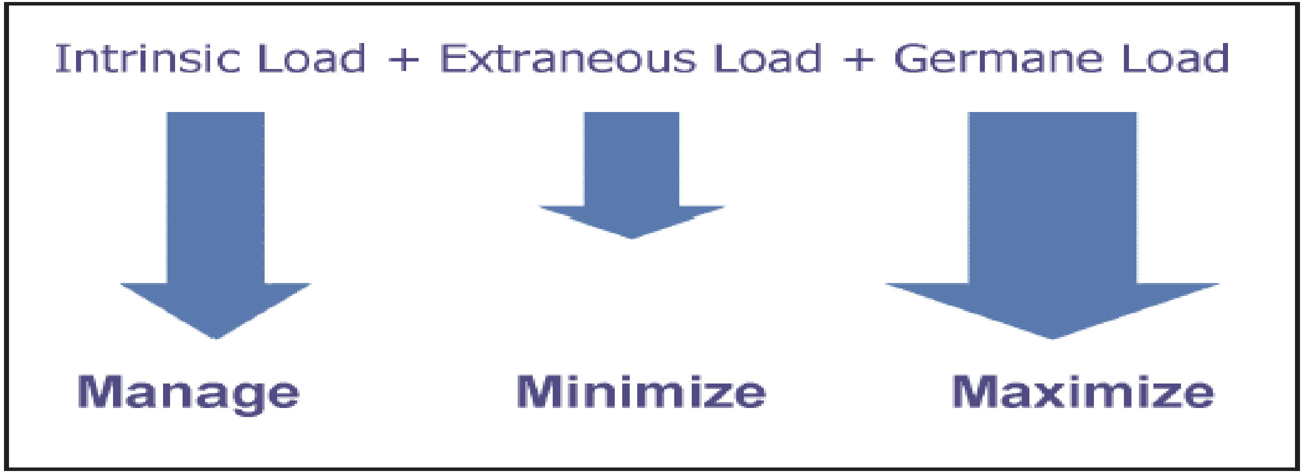
Exploring through an associated Research Issue: Cognitive Processing of learners

the essential material or information to be learned.

reduces the chances that transfer of learning

activity of organizing and integrating information

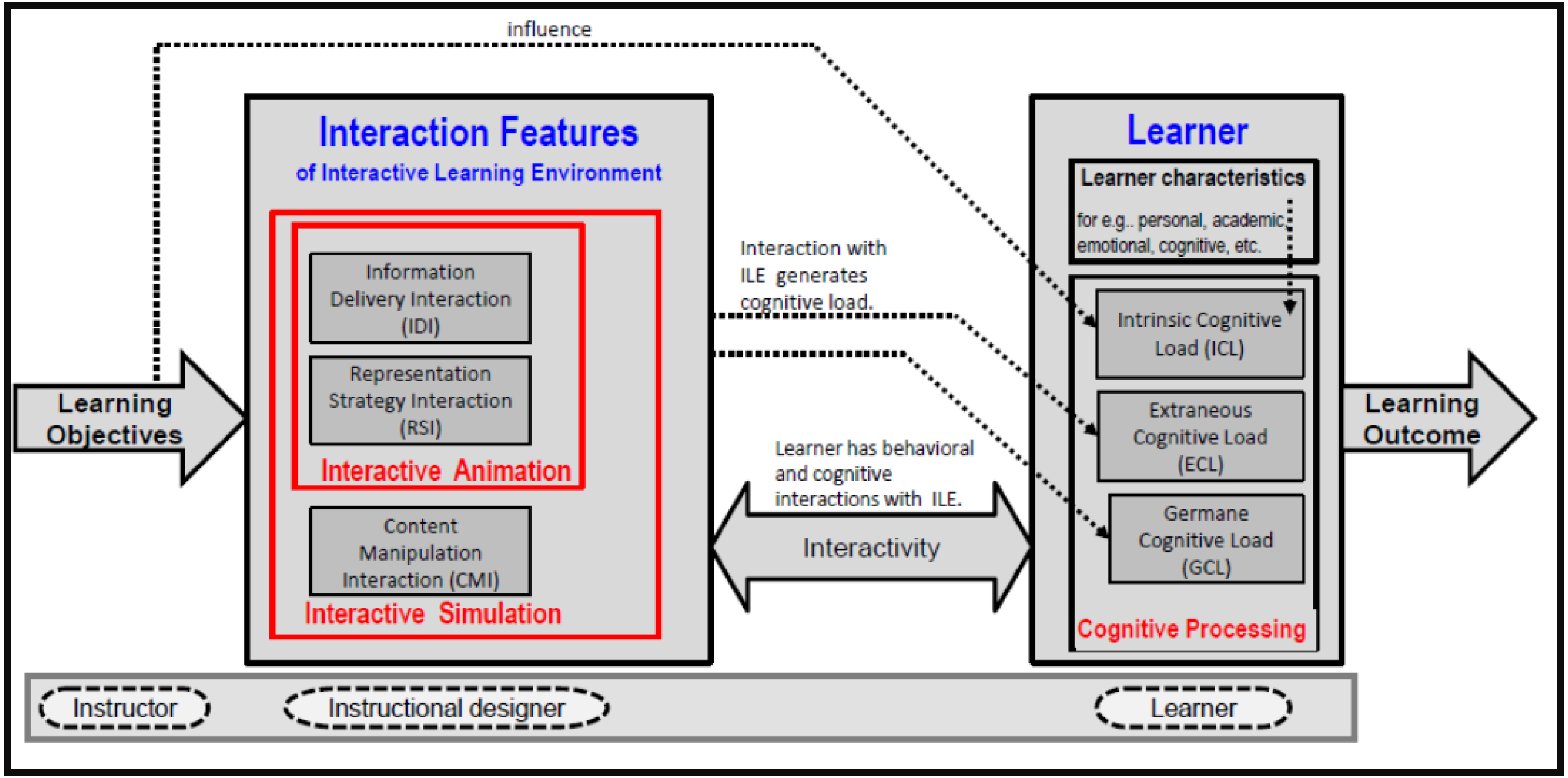
A major goal of multimedia learning and instruction→ "*manage essential processing, reduce extraneous processing and foster generative processing*".



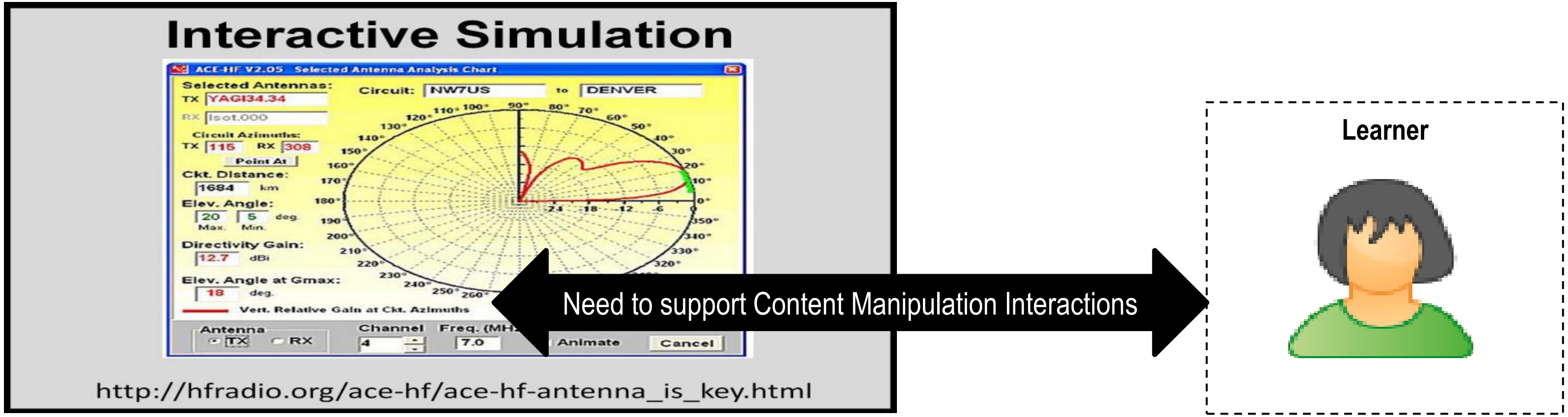
Triarchic model of cognitive load (Mayer, 2009)

Synthesizing Literature Survey

Cognitive processing in ILEs



Need to augment Interactivity in ILEs?

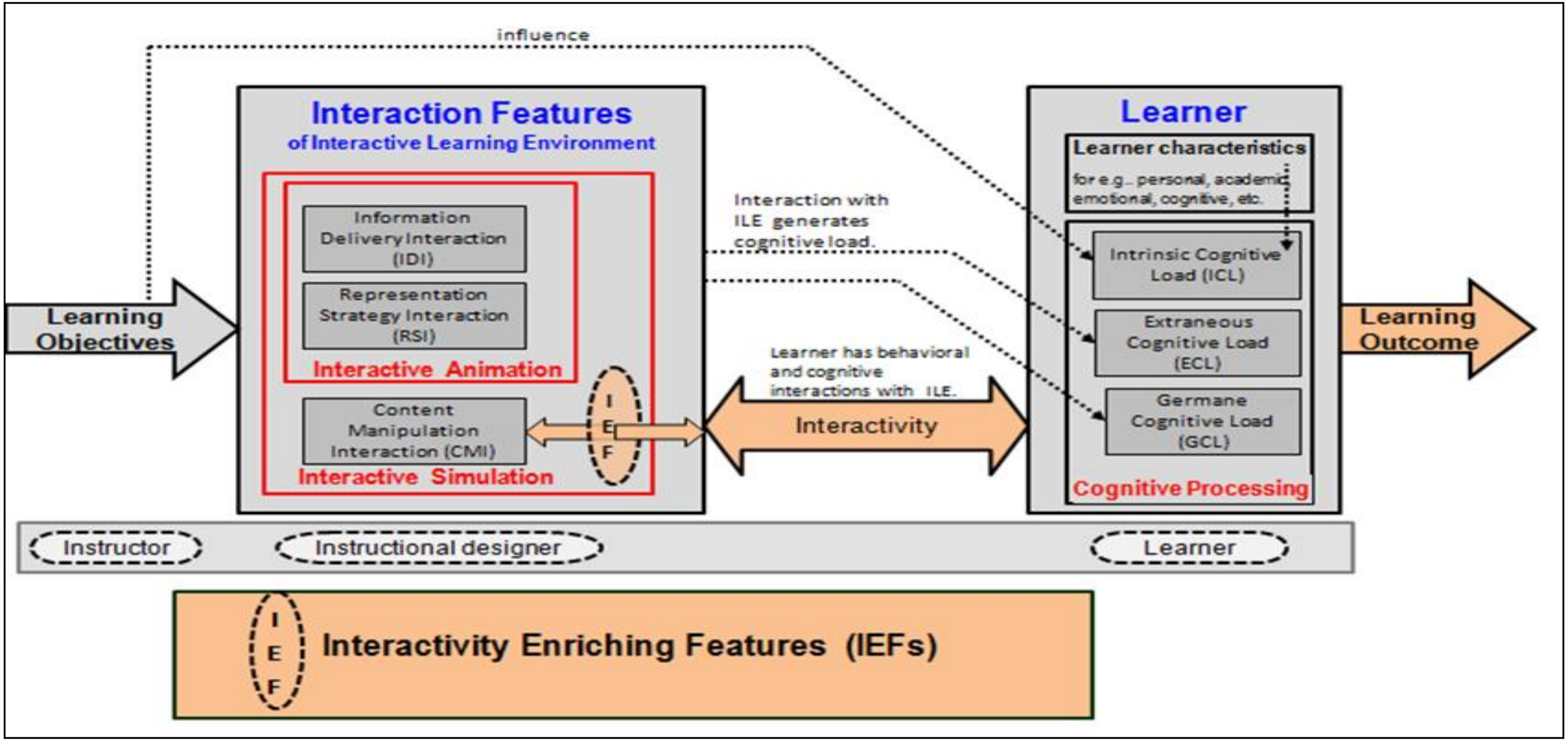


Multimedia principles and Cognitive Load Theory of Multimedia learning →guidelines for designing support to learners while learning from ILE (Mayer, 2008).

However, the recommendation primarily fulfil design requirements for Information delivery and Representation Strategy Interactions.

There is a dearth of such recommendations for designing Content Manipulation Interactions, especially needed in Interactive Simulations.

Proposing 'Interactivity Enriching Features' (IEFs) in ILE



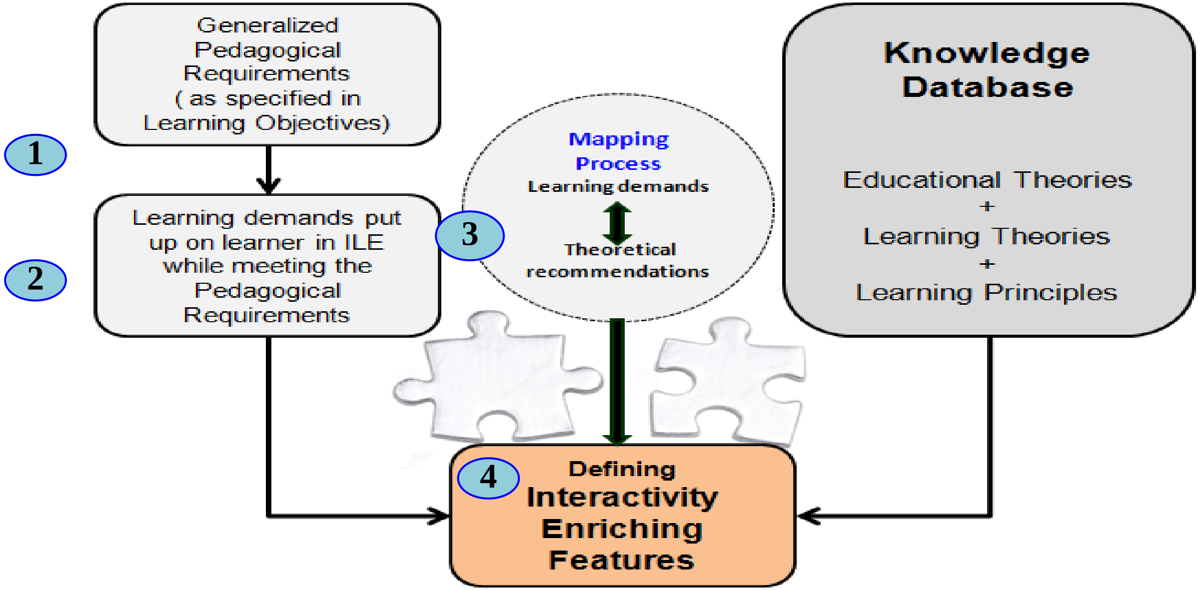
Proposing 'Interactivity Enriching Features (IEFs)'

- 'Interactivity Enriching Features' (IEFs) are conceptualized as **interaction features in ILE offered to user in the form of an affordance.**

- IEFs can take form of **add-on features** added to the basic level of interactivity present in ILE.

- The features are referred to as 'Interactivity Enriching Features', as it is anticipated that **these features would enrich the quality of interactions.**

Determining Interactivity Enriching Features (IEFs)



1. Define generalized pedagogical requirements (as specified in Learning Objectives)

2. Identify learning demands that can be put up on learner in ILE while meeting these pedagogical requirements.

3. Search the Knowledge Database (Educational Theories, Learning Theories, Learning Principles) to establish mapping between the learning demands and theoretical recommendations.

4. Define IEFs by establishing mapping between learning demands and theoretical recommendations.

Proposed IEF
Productively Constrained Variable Manipulation PCVM
Permutative Variable Manipulation PVM
Discretized Interactivity Manipulation DIM
Reciprocative Dynamic Linking RDL

Generalized pedagogical requirements	Expected learning demands on learners in ILEs	What an IEF should do?	Theoretical recommendations selected from the Knowledge Database	Proposed IEF
Why an IEF is needed?		What features an IEF should have?	How is IEF formulated?	
				Productively Constrained Variable Manipulation PCVM
				Permutative Variable Manipulation PVM
				Discretized Interactivity Manipulation DIM
				Reciprocative Dynamic Linking RDL

Generalized pedagogical requirements	Expected learning demands on learners in ILEs	What an IEF should do?	Theoretical recommendations selected from the Knowledge Database	Proposed IEF
Why an IEF is needed?		What features an IEF should have?	How is IEF formulated?	
To build up the whole knowledge by mastering its individual knowledge chunks and interlinked concepts	To manage the manipulation of variables aligned with the learning goals	To offer variable manipulation for progressive learning combined with unguided exploration experience	Tool-mediated Learning: To offering tool-mediated productive constraint to attain the desired learning objective (Podolefsky, Moore & Perkins, 2013)	***Productively Constrained Variable Manipulation PCVM***
To flexibly use and apply algorithms, procedures in line with the learning objectives	To mentally visualize of all possible permutations/ 'what-if scenario' while executing a procedural task	To offer an interaction that can facilitate flexibility in applying procedures.	Congruence principle extended for manipulation interactions: to establish congruence between manipulation interactions and the intended learning objectives (Tversky, Morrison, & Bétrancourt, 2002)	***Permutative Variable Manipulation PVM***
To comprehend and relate multiple steps in a given procedural task at the granularity of sub-steps to be followed for its execution	To develop a discretized mental model of the continuous event/ task to be accomplished.	To offer interactivity that facilitates learners to get access to the discrete individual steps of the tasks while its execution.	Event Cognition: To learn a complex procedural task by means of meaningful segmented events (Kurby & Zacks, 2007).	***Discretized Interactivity Manipulation DIM***
To translate from one MER to another MER and to integrate different representations integration MER: Multiple External Representation	To visualize and relate mentally the reciprocal relation between representations	To allow manipulation of all the required representations	Distributed and embodied cognition: to facilitate actions like manipulations for promoting integration of MERs (Glenberg, Witt & Metcalfe, 2013)	***Reciprocative Dynamic Linking RDL***

Interactivity Enriching Features designed

Productively Constrained Variable Manipulation: PCVM

Select Variables to be manipulated

☑ Only variable 1 ☐ Only 2 Variable 2 ☐ Only variable 3 ☐ All variables

Offer all the variables for manipulation yet, in a constrained manner as per the pedagogical requirement

- Variable 1
- Variable 2
- Variable 3

Link

Discretized Interactivity Manipulation: DIM

Steps to be followed

- Step 1
- Step 2
- Step 3
- Step N

For a multi-step procedural task, offer variables for manipulation those control discrete-step level granularity of the task.

Link

Permutative Variable Manipulation: PVM

Select Variables to be manipulated

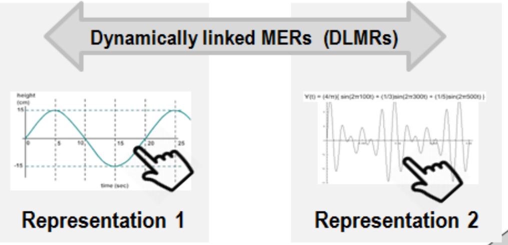
- Set step variable 1
- Set step variable 2

- Execute Step 1→Step2
- Swap the sequence

In a multi-step procedural task, offer variable that allows swapping of the steps as per the pedagogical requirement

Link

Reciprocative Dynamic Linking: RDL



Select representation to be manipulated

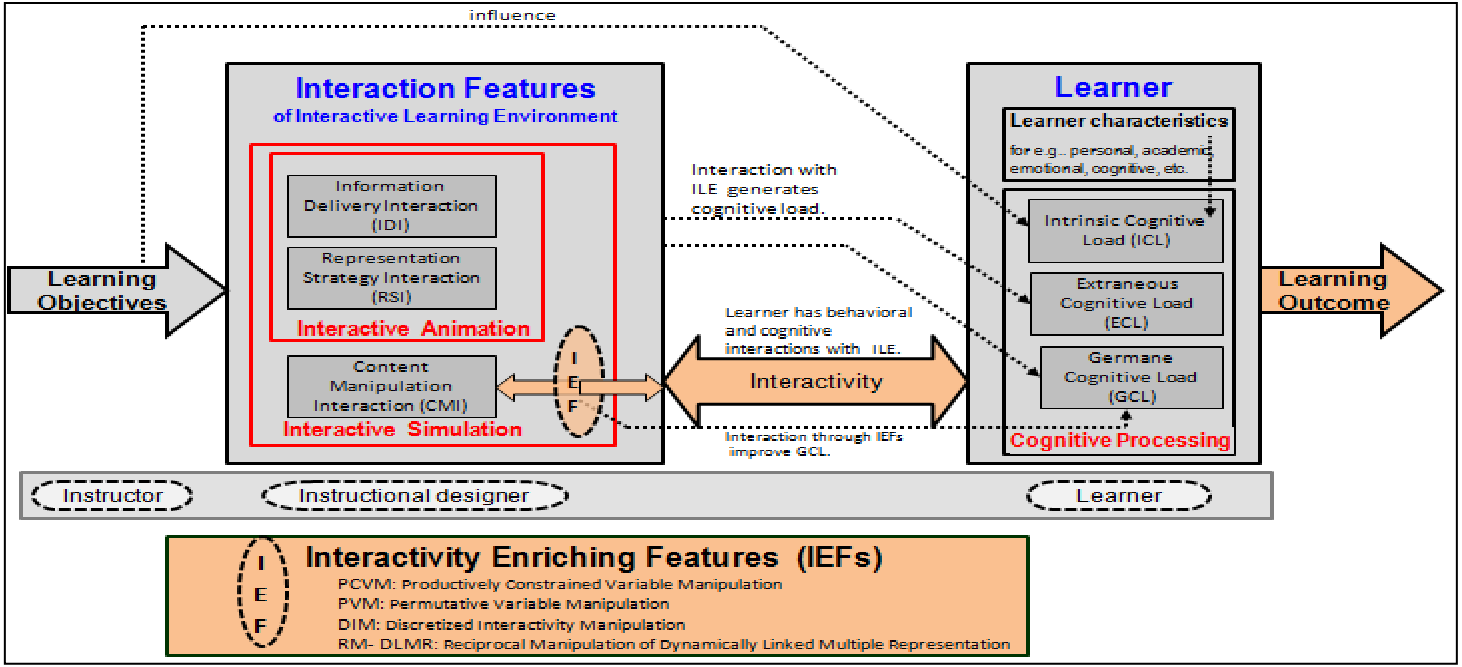
☑ Representation 1 ☐ Representation 2

Offer interactivity that allows learners to manipulate DLMRs in a reciprocative manner.

Link

Refining Research Questions

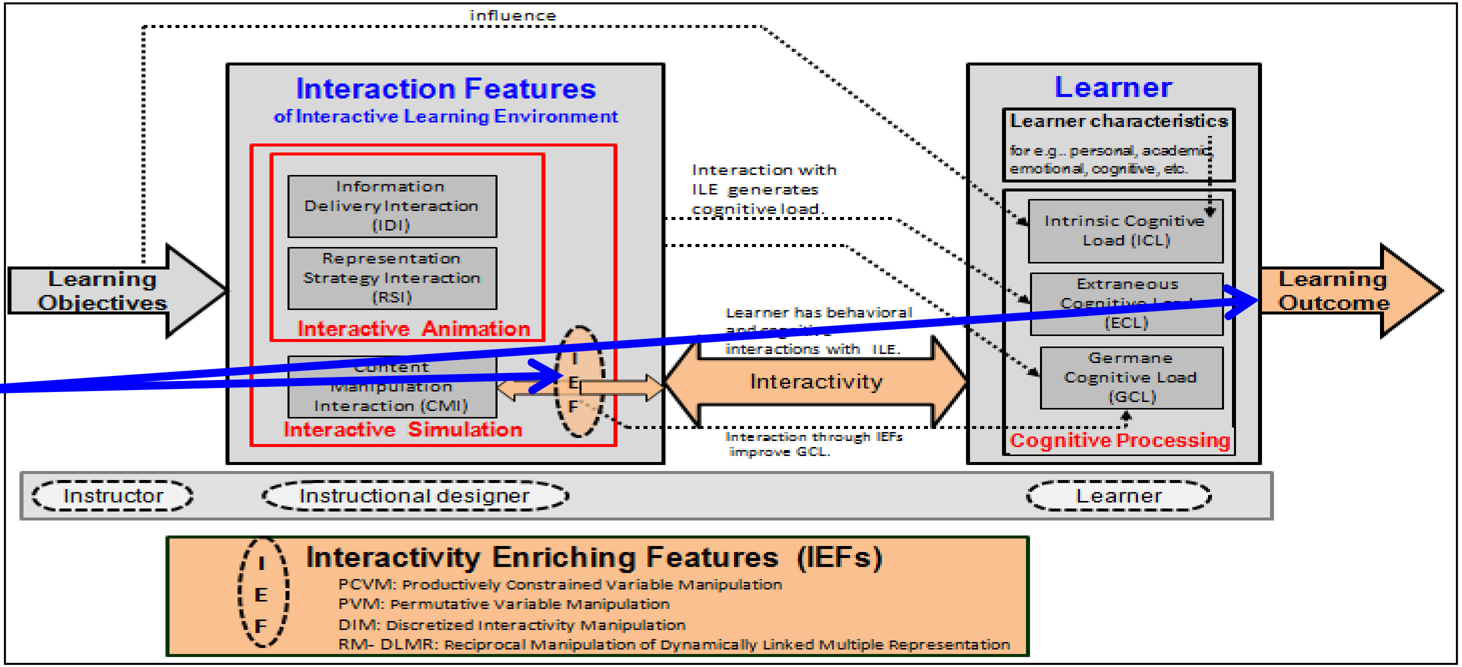
RQ1. Does higher level of interaction lead to effective learning in ILE for a given type of knowledge and cognitive level?



Refining Research Questions

RQ1. Does higher level of interaction lead to effective learning in ILE for a given type of knowledge and cognitive level?

RQ2. How do Interactivity Enriching Features affect students' learning outcome?

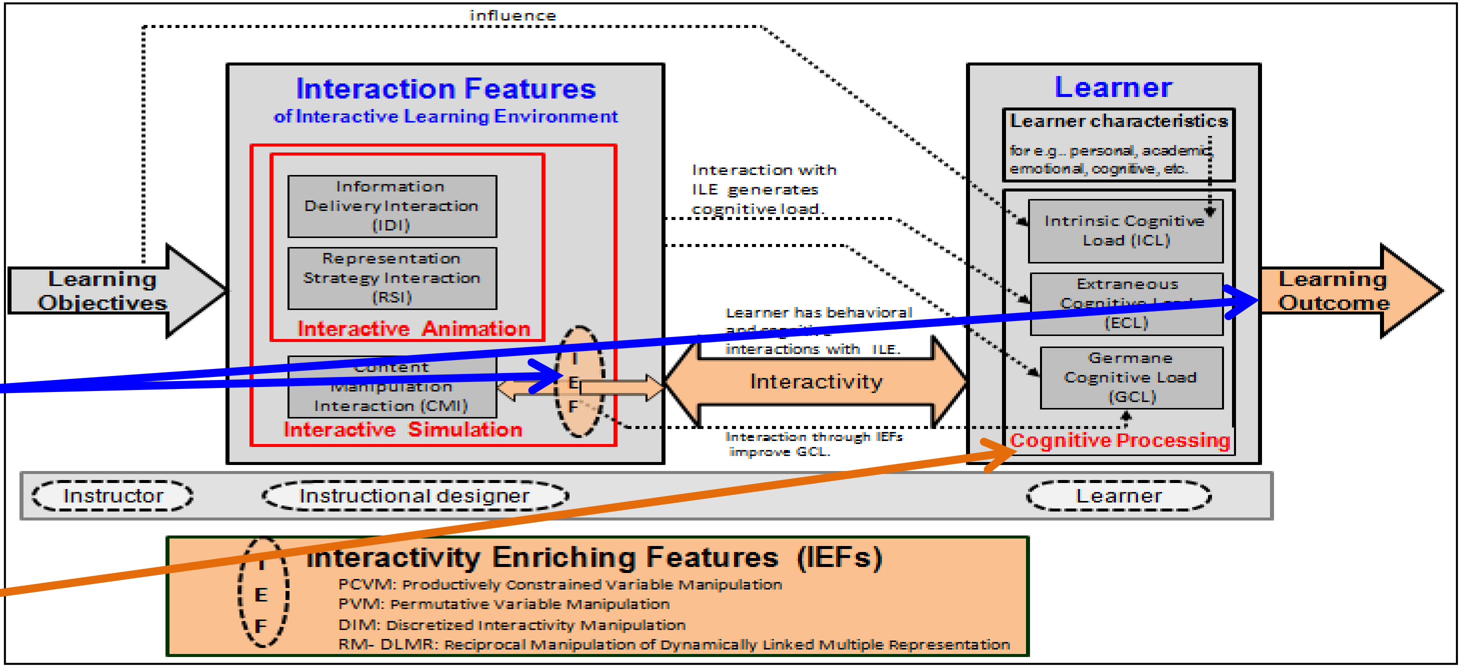


Refining Research Questions

RQ1. Does higher level of interaction lead to effective learning in ILE for a given type of knowledge and cognitive level?

RQ2. How do Interactivity Enriching Features affect students' learning outcome?

RQ3. What is the effect of including Interactivity Enriching Features on students' cognitive load?



Research Scope

- Students learn from ILE in **self-learning mode**. (Instructor support is not being considered as a variable).

- **Interactions** being considered are only those **between ILE and learner**. The interactions between instructor and learner or among learners are excluded from the scope of this research work.

- **ILEs are overall well-designed to begin with**, i.e. ILEs are in accordance with the well-established multimedia learning principles and are aligned with learning objectives.

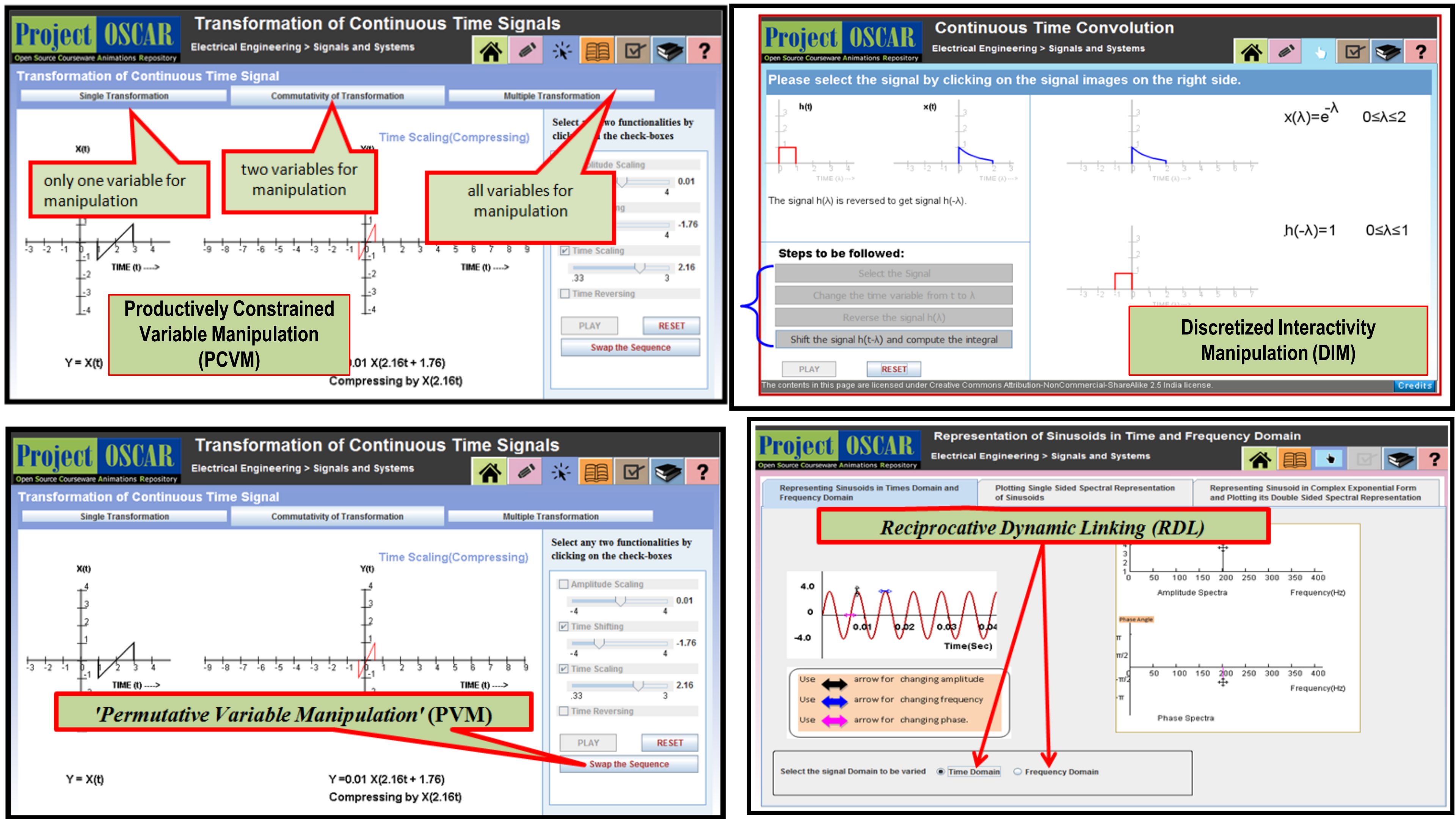
- **Variation in the learner characteristics** or customization of learning material as per this variation are **not being considered** as variables of this research work.

Research Context:
ILEs in 'Signals and Systems' Education

- Signals and Systems, a course second year from Electrical Engineering and allied undergraduate programs.

- One of the foundation courses in the field of Communication and Signal Processing.

- Findings from Signals and Systems Concept Inventory (SSCI) and supporting disciplinary research articles were referred while determining pedagogical requirements and topics of research studies.



Transformation of Continuous Time Signals
Electrical Engineering > Signals and Systems
Transformation of Continuous Time Signal
Single Transformation
Commutativity of Transformation
Multiple Transformation
only one variable for manipulation
two variables for manipulation
all variables for manipulation
Productively Constrained Variable Manipulation (PCVM)
Continuous Time Convolution
Please select the signal by clicking on the signal images on the right side.
The signal h(λ) is reversed to get signal h(-λ).
Steps to be followed:
Select the Signal
Change the time variable from t to λ
Reverse the signal h(λ)
Shift the signal h(t-λ) and compute the integral
Discretized Interactivity Manipulation (DIM)
The contents in this page are licensed under Creative Commons Attribution-NonCommercial-ShareAlike 2.5 India license.
'Permutative Variable Manipulation' (PVM)
Select any two functionalities by clicking on the check-boxes
Amplitude Scaling
Time Shifting
Time Scaling
Time Reversing
PLAY
RESET
Swap the Sequence
Y = X(t)
Y =0.01 X(2.16t + 1.76)
Compressing by X(2.16t)
Representation of Sinusoids in Time and Frequency Domain
Reciprocative Dynamic Linking (RDL)
Use arrow for changing amplitude
Use arrow for changing frequency
Use arrow for changing phase.
Select the signal Domain to be varied
Time Domain
Frequency Domain
Amplitude Spectra
Phase Spectra

Research Issue

- Mixed learning impact of Interactive Learning Environment (ILE)

Broad Research Question

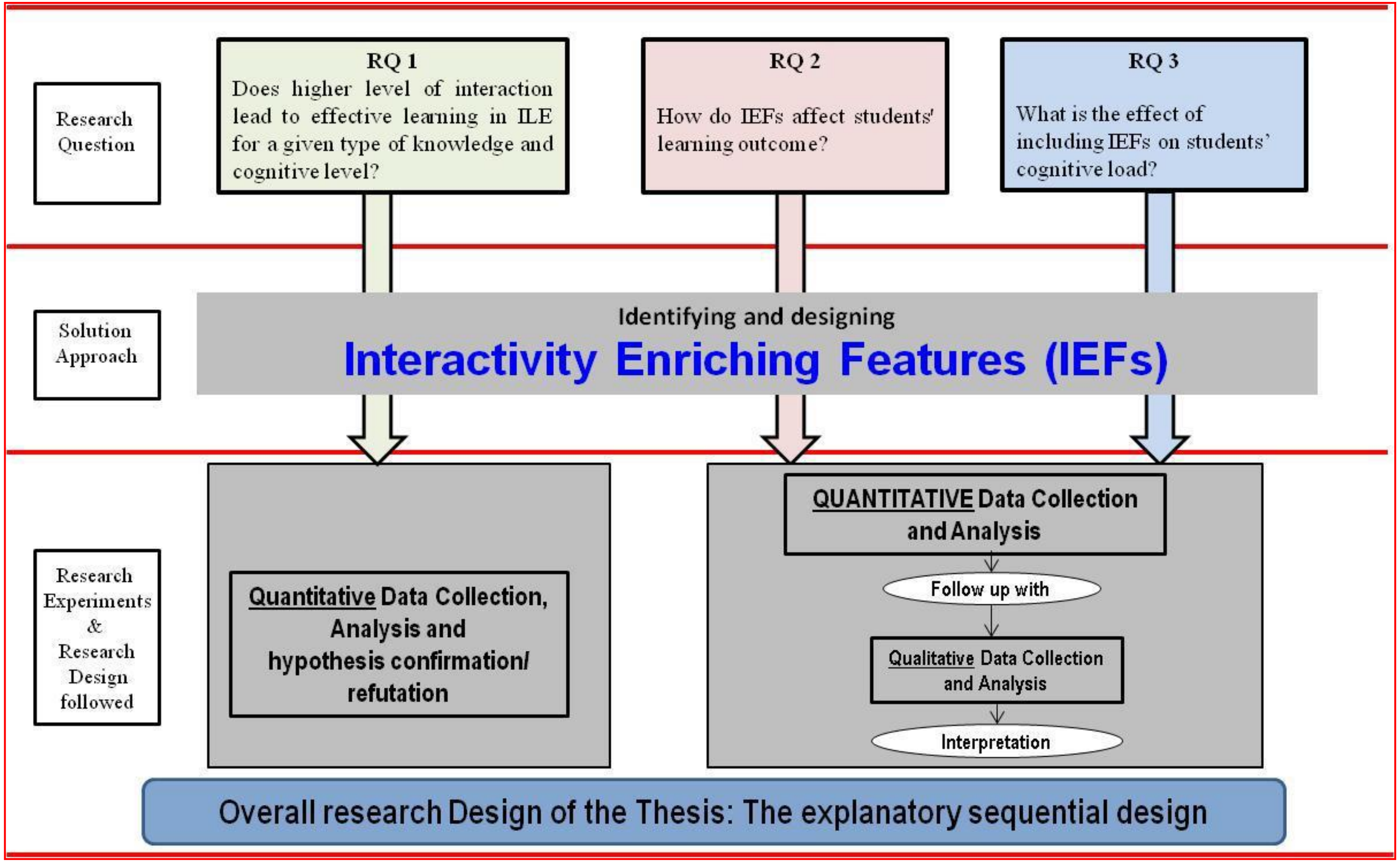
- Under what conditions ILE leads to effective learning?

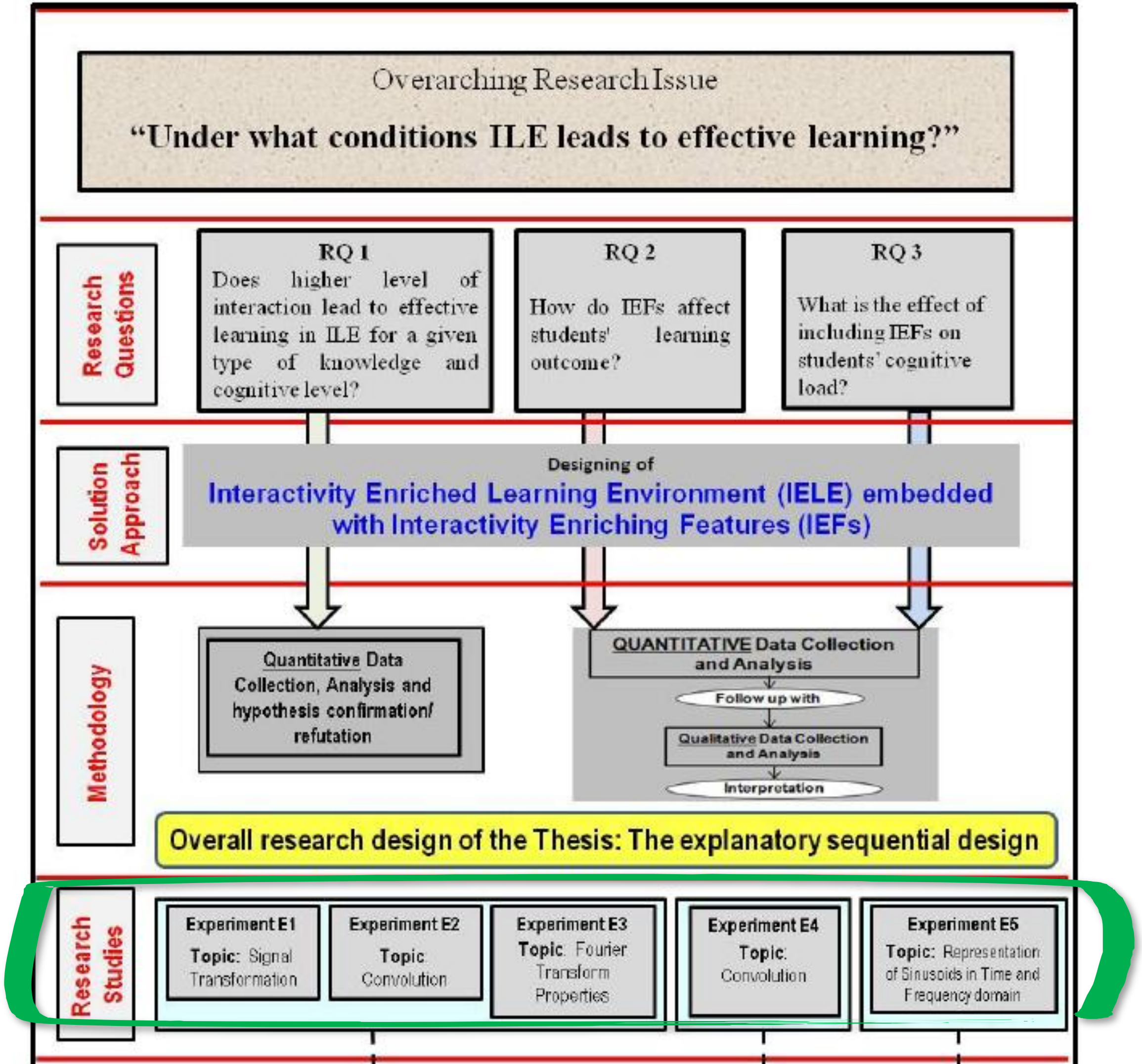
Solution Approach

- Step I- Investigate, 'how different interaction features in ILE affect students learning?'
- Step II- Identify, 'What is the need and nature of cognitive support required to learners while dealing with interactive nature of ILE?'
- Step III- Design learning-conducive interactive features of ILE that meet the learning demands.

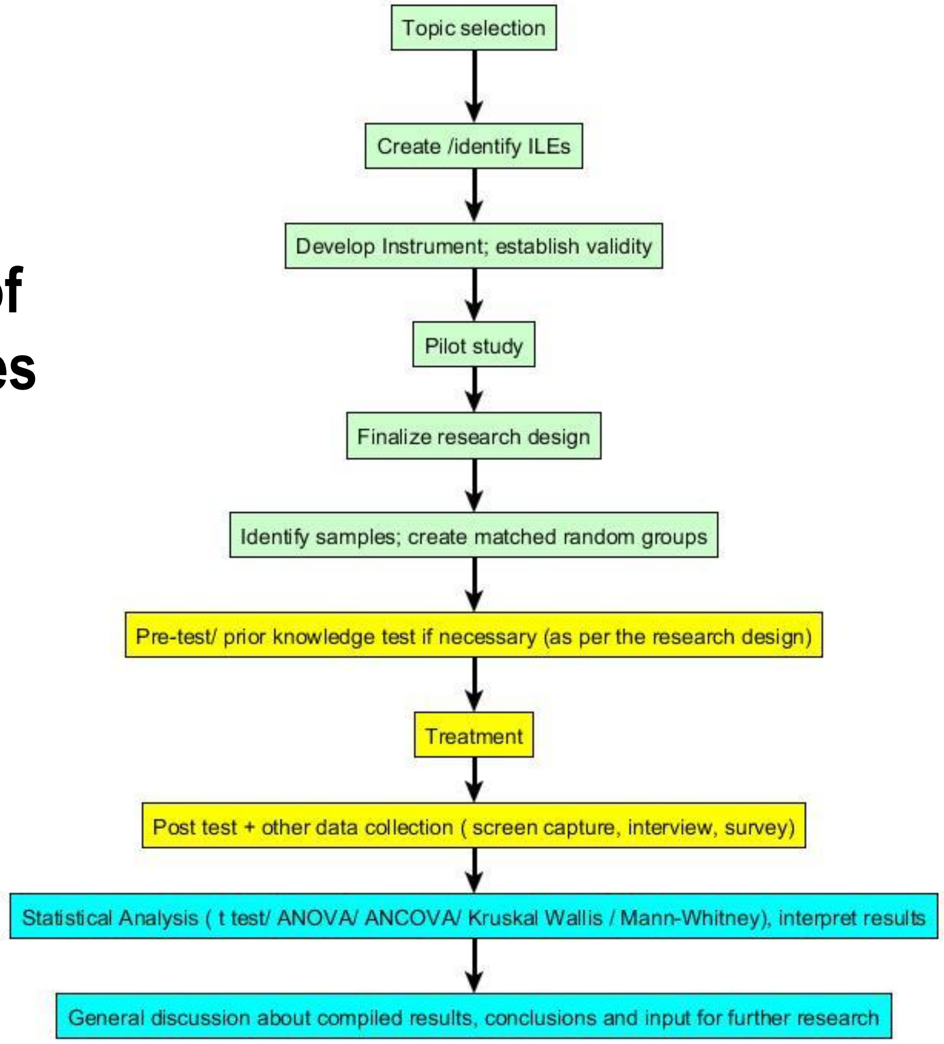
'Designing Interactivity Enriched Learning Environments embedded with **Interactivity Enriching Features (IEFs)**

Overview of the research design




Overarching Research Issue
"Under what conditions ILE leads to effective learning?"
Research Questions
RQ 1
Does higher level of interaction lead to effective learning in ILE for a given type of knowledge and cognitive level?
RQ 2
How do IEFs affect students' learning outcome?
RQ 3
What is the effect of including IEFs on students' cognitive load?
Solution Approach
Designing of
Interactivity Enriched Learning Environment (IELE) embedded with Interactivity Enriching Features (IEFs)
Methodology
Quantitative Data Collection, Analysis and hypothesis confirmation/ refutation
QUANTITATIVE Data Collection and Analysis
Follow up with
Qualitative Data Collection and Analysis
Interpretation
Overall research design of the Thesis: The explanatory sequential design
Research Studies
Experiment E1
Topic: Signal Transformation
Experiment E2
Topic: Convolution
Experiment E3
Topic: Fourier Transform Properties
Experiment E4
Topic: Convolution
Experiment E5
Topic: Representation of Sinusoids in Time and Frequency domain

General Overview of the procedure followed for Validating the effectiveness of Interactivity Enriching Features



Validating the effectiveness of Interactivity Enriching Features: Research experiments to answer RQ1

Research Experiments	E1	E2	E3
Research Method	Quantitative research	Quantitative research	Quantitative research
Research Context	Signal Transformation	Convolution	Fourier Transform Properties
Research Design	Quasi experiment with 'post test only'	Two group Quasi experiment with 'pre-test post-test'	Two group Quasi experiment with 'pre-test post-test'
Sample	Second year Electrical Engineering students (N=41+ 35+23 resp.)	Second year Electrical Engineering students (N=70+71 resp.)	Second year Electrical Engineering students (N=36+ 35 resp.)
Treatment	Non-Interactive Learning Environment (Non-ILE) Animation (ANM) Simulation (SIM)	Animation (ANM) Simulation (SIM)	Animation (ANM) Simulation (SIM)
Data Collection	Post test	Pre-test and post-test	Pre-test and post-test
Instruments	Validated peer-reviewed test Instrument fo r UC, UP and AP link	Validated peer-reviewed test Instrument for AC, UP and AP link	Validated peer-reviewed test Instrument for AC, UP and AP link
Statistical Analysis methods	Independent Sample t test, ANOVA, Kruskal Wallis test, Mann-Whitney test	Independent Sample t test, Paired Sample t test, ANCOVA	Independent Sample t test, Paired Sample t test

Answering RQ1

Research Experiments	E1	E2	E3
Results and findings	Non-ILE ≈ ANM ≈ SIM (UC) Non-ILE > ANM~SIM (UP) Non-ILE≈SIM ≈ ANM (AP) link	ANM ≈ SIM (AC) ANM ≈ SIM (UP) ANM ≈ SIM (AP) link	ANM > SIM (AC) ANM ≈ SIM (UC) ANM ≈ SIM (AP) link

Research Question RQ1:
Does higher level of interaction improve learning in ILE?

Answering RQ 1 :

➢Higher level of interaction does not necessarily lead to effective learning in ILE.

➢Different knowledge types and cognitive levels require different level of interaction for effective learning in ILE.

Validating the effectiveness of Interactivity Enriching Features: Research experiments to answer RQ 2

Research Experiments	E1		E4		E5	
Research Method	Mixed Research Method (Explanatory sequential design)		Mixed Research Method (Explanatory sequential design)		Mixed Research Method (Explanatory sequential design)	
Research Context	Signal Transformation		Convolution		Time and Frequency domain representation of sinusoids	
Research Design	Two group Quasi experiment with 'post test only'		Two group Quasi experiment with 'post test only'		Two group Quasi experiment with 'post test only'	
Sample	Second year Electrical Engineering students (N=23+35 resp.)		Second year Electrical Engineering students (N=33+34 resp.)		Second year Electrical Engineering students (N=12+12 resp.)	
Treatment	Simulation (SIM) (ILE without IEF)	Interactivity Enriched ILE (IELE) [PCM+PCVM]	Simulation (SIM) (ILE without IEF)	Interactivity Enriched LE(IELE) [DIM]	Simulation (SIM) (ILE without IEF)	Interactivity Enriched LE(IELE) [RDL]
Data Collection	Post test + screen capture + semi-structured interviews		Post test+ CL test+ survey + semi-structured interviews		Post test+ CL test+ survey + semi-structured interviews + screen capture	
Instruments	Validated peer-reviewed test Instrument for UC, UP and AP link		Validated peer-reviewed test Instrument for AC, UP and AP link		Validated peer-reviewed test Instrument for AC, UP and AP link	
Statistical Analysis methods	Independent Sample t test, Kruskal Wallis test, Mann-Whitney test		Independent Sample t test		Independent Sample t test	

Answering RQ2

Research Experiments	E1	E4	E5
Results and findings	SIM ≈ IELE (UC) IELE>SIM (UP) IELE>SIM (AP) link	SIM ≈ IELE (AC) IELE> SIM (UP) IELE>SIM (AP) link	SIM ≈ IELE (UC+AC) IELE>SIM (AP) IELE>SIM (ANP) link

Research Question RQ2:
How do Interactivity Enriching Features affect students' learning outcome?

Answering RQ 2:

Interactivity in ILE can lead to higher learning only after getting augmented by strategically designed Interactivity Enriching Features (IEFs) for Apply and Analyze Procedural knowledge.

Validating the effectiveness of Interactivity Enriching Features: Research experiments to answer RQ 3

Research Experiments	E4		E5	
Research Method	Mixed Research Method (Explanatory sequential design)		Mixed Research Method (Explanatory sequential design)	
Research Context	Convolution		Time and Frequency domain representation of sinusoids	
Research Design	Two group Quasi experiment with 'post test only'		Two group Quasi experiment with 'post test only'	
Sample	Second year Electrical Engineering students (N=33+34 resp.)		Second year Electrical Engineering students (N=12+12 resp.)	
Treatment	Simulation (SIM) (ILE without IEF)	Interactivity Enriched LE (IELE) [DIM]	Simulation (SIM) (ILE without IEF)	Interactivity Enriched LE(IELE) [RDL]
Data Collection	Post test+ CL test+ survey + semi-structured interviews		Post test+ CL test+ survey + semi-structured interviews + screen capture	
Instruments	Validated peer-reviewed test Instrument for AC, UP and AP link		Validated peer-reviewed test Instrument for AC, UP and AP link	
Statistical Analysis methods	Independent Sample t test		Independent Sample t test	

Answering RQ3

Research Experiments	E4	E5
Results and findings	Mental effort scores SIM ≈ IELE Germane Cognitive Load scores (measured construct Mental difficulty) SIM ≈ IELE …AC, SIM > IELE …UP, SIM > IELE …AP link	Mental effort scores SIM ≈ IELE Germane Cognitive Load scores (measured construct Mental difficulty) SIM ≈ IELE …UC+AC, SIM > IELE …AP, SIM > IELE …ANP link

Research Question RQ3:
What is the effect of including Interactivity Enriching Features on students' cognitive load?

Answering RQ3 :

Learners learning with (IELE) designed with 'Interactivity Enriching Features' (IEFs) exhibited same mental effort (indication of equal Intrinsic Cognitive Load), but lower perceived mental difficulty level (indication of higher Germane Cognitive Load) as compared to learners learning from the ILEs without IEFs.

IEFs supported learners by improving their Germane Cognitive Load.

Summarizing findings

Claims	Findings as evidence
Higher level of interaction does not necessarily lead to effective learning in ILE.	a) For procedural knowledge at understand level, non-interactive visualization performed better than animation and simulation. The animation and Simulation were found to be equally effective. b) For conceptual knowledge at apply level, simulation was found to be better than animation. (Based on experiments in three different topics in S&S)
Different knowledge types and cognitive levels require different level of interaction for effective learning in ILE.	
ILE can lead to higher learning only after getting augmented by strategically designed Interactivity Enriching Features (IEFs).	Learners performed better with Interactivity Enriched Learning Environment (IELE) using 'Interactivity Enriching Features' (IEFs) as compared to the ILEs without IEFs. When augmented with appropriate IEF, ILEs could deliver its learning benefits, especially for procedural knowledge for given cognitive levels. (Based on experiments in three different topics in S&S)
Interactive Simulation designed with 'Interactivity Enriching Features' improves learning in ILE by fostering Germane Cognitive Load.	Learners learning with Interactivity Enriched Learning Environment (IELE) using 'Interactivity Enriching Features' (IEFs) exhibited same mental effort (indication of equal Intrinsic Cognitive Load), but lower perceived mental difficulty level (indication of higher Germane Cognitive Load) as compared to learners learning from the ILEs without IEFs. (Based on experiments in two different topics in S&S)

OVERALL CLAIM: The findings from the research studies validated learning effectiveness of IEFs.

Discussion

Investigating learning effectiveness of IEFs
and
their impact on cognitive processing

→

Presenting findings in the form of model: **MIELE**

Extent of generalizability

Limitations

Future directions

The concept of **Interactivity Enriching Features** and characterizing its role in learning from ILEs

→ Determine, design →

Four Interactivity Enriching Features PCVM, PVM, DIM, RDL

↓

Interactivity Enriched Learning Environments (IELE)

Five empirical studies to test effectiveness of IEFs with the designed IELEs

→ Investigate →

Interactivity Design Principles

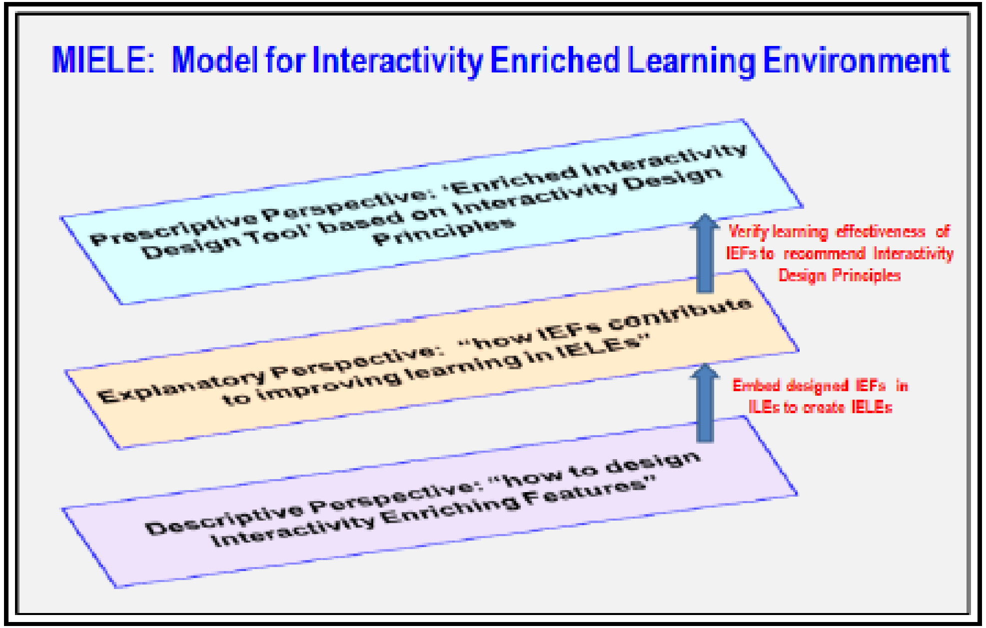
Impact of IEFs on germane cognitive load

Model for Interactivity Enriched Learning Environment (MIELE)
Integrated perspective of IEF designing and its learning impact in ILEs

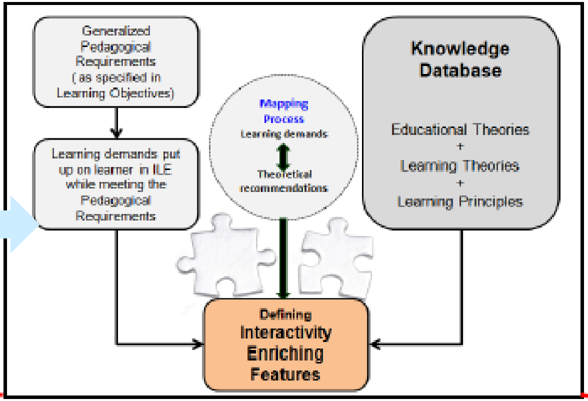
[eIDT: Enriched Interactivity Design Tool]

Thesis Overview

Presenting thesis findings as MIELE

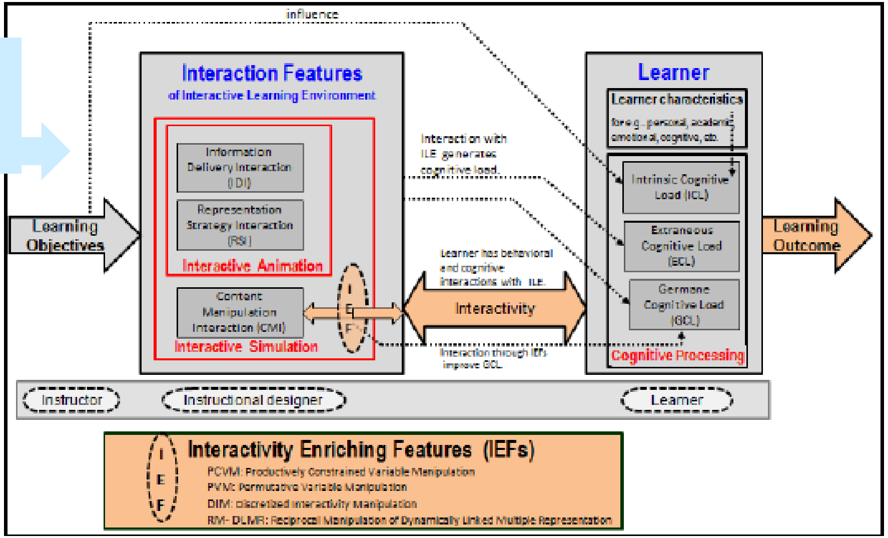


Descriptive perspective of MIELE

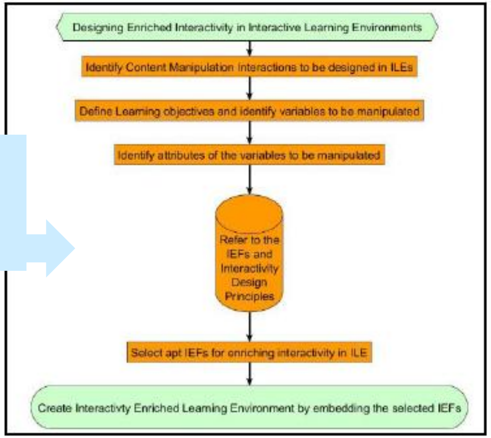


Generalized pedagogical requirements	Expected learning demands on learners in ILEs	Theoretical recommendations selected from the Knowledge Database	Proposed IEF
To build up the whole knowledge by mastering its individual knowledge chunks and interlinked concepts	To manage the manipulation of variables aligned with the learning goals	Tool-mediated Learning: To offering tool-mediated productive constraint to attain the desired learning objective	*Productively Constrained Variable Manipulation PCVM*
To flexibly use and apply algorithms, procedures in line with the learning objectives	To mentally visualize of all possible permutations/ 'what-if scenario' while executing a procedural task	Congruence principle extended for manipulation interactions: to establish congruence between manipulation interactions and intended learning objectives	*Permutative Variable Manipulation PVM*
To comprehend and relate multiple steps in a given procedural task at the granularity of sub-steps to be followed for its execution	To develop a discretized mental model of the continuous event/ task to be accomplished.	Event Cognition: To learn a complex procedural task by means of meaningful segmented events	*Discretized Interactivity Manipulation DIM*
To translate from one MER to another MER and to integrate different representations integration MER: Multiple External Representation	To visualize and relate mentally the reciprocal relation between representations	Distributed and embodied cognition: to facilitate actions like manipulations for promoting integration of MERs	*Reciprocative Dynamic Linking RDL*

Explanatory perspective of MIELE



Prescriptive perspective of MIELE



Extent of Generalizability

- **Generalizability of the IEFs**
  - role of domain in the designing of IEFs has been low, while the role of a particular interaction designed for manipulating variables is prominent.
  - the designing of IEFs derived its basis from relevant educational theories with pan-domain applicability

- **Generalizability of claims about testing effectiveness of IEFs**
  - Generalizable for specific types of knowledge from courses with similar pedagogical requirement for engineering student population

- Factors such as learner age and learner characteristics would need further investigation.

Domain	Topic	Features of the topic--> pedagogical requirements--> cognitive support	IEFs used
Signals and Systems	Signal Transformation	Exploration of multiple variables--> intentional exploration of multiple variables --> support for progressive learning	PCVM Productively Constrained Variable Manipulation
		Sequential procedural task--> Analyzing impact of sequencing the steps in a procedural task -->support for creating expected permutations	PVM Permutative Variable Manipulation
	Convolution	Multi-step procedural task--> mastering individual sub-steps to accomplish the whole procedural task--> support for comprehending a continuous event as a series of discrete events	DIM Discretized Interactivity Manipulation
	Signal Representation	Multiple External Representations --> need to develop cross-representational linkage among MERs--> support for being able to experience reciprocal relations between/ among MERs.	RDL Reciprocative Dynamic Linking

Establishing generalizability of the IEFs

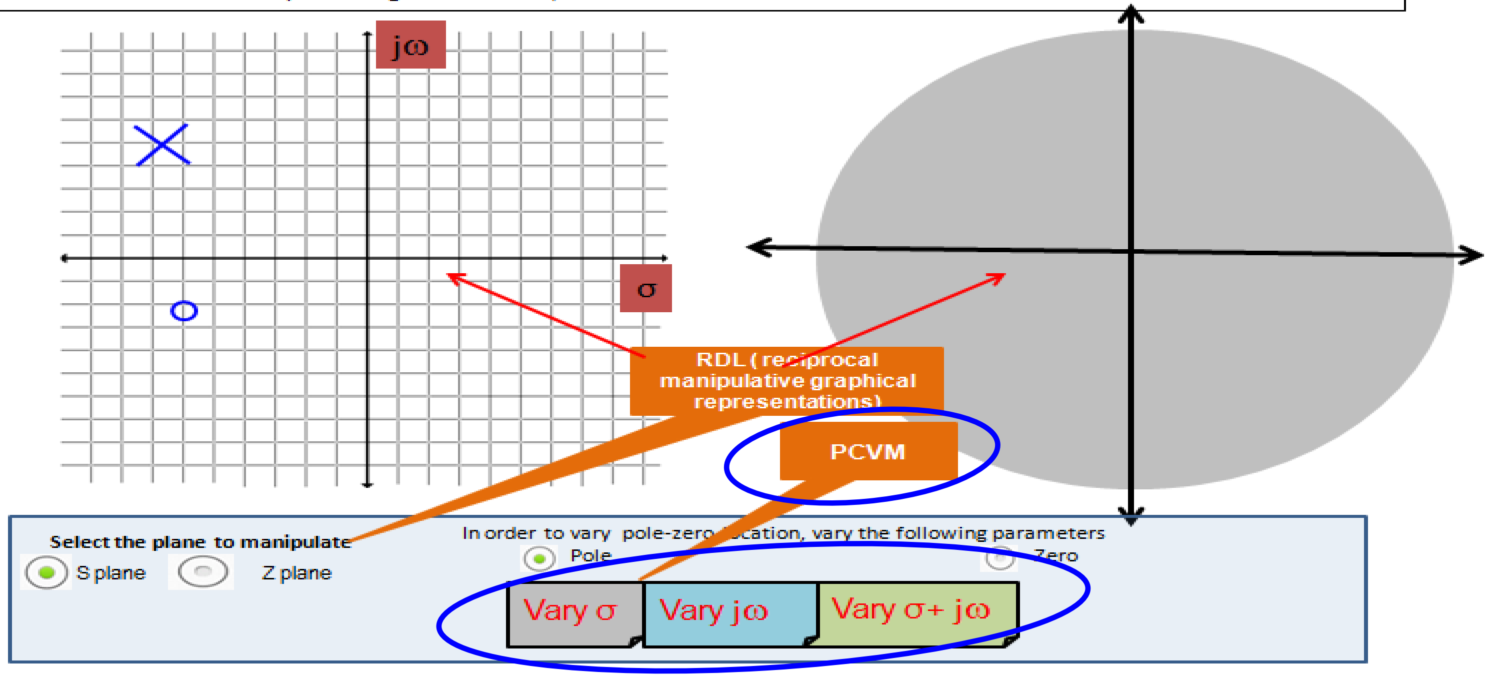
Features of the topic	Topics with the same features from the same domain (Signals and Systems)	Topics with the same features from the other domains
Exploration of multiple variables	→ Fourier Transform properties (Variables: different signals and different transform properties to be learnt) → LTI system characterises (Variables: Inputs signals, properties like linearity and time invariance) → Exploring Z plane and S plane (variables: pole location / zero location as a function of coordinates) → Sampling and reconstruction of signals in time/ frequency domain (Variables: signals frequency, sampling frequency, reconstruction filter cut-off frequency) → Frequency response from S/Z plane for pole zero position (Variable: location of poles and zeros) → Fourier Series Representation of a square wave (Variables: number of harmonics, amplitude and phase of the harmonics to be added) → Spectrum Analysis	**Discrete Time Signal Processing** → Design digital filters using pole-zero placement → IIR and FIR filter designing → Pole-zero plots and frequency response → Sampling and aliasing **Control Systems** → Bode servo analysis → Root Locus of a transfer function → designing of open loop and closed loop systems → PID controller Various applications in speech and image processing based on the fundamental topics from Signals and Systems , Discrete Time Signal Processing
Sequential procedural task	→ Verification of systems for linearity and time invariance properties (Sequencing in Time invariance verification: output for delayed input and delayed output) → Commutativity property of systems	→ Commutativity property of convolution
Multi-step procedural task	→ Plotting Frequency response of an LTI system → Plotting spectral representation	**Discrete Time Signal Processing** → Constructing Butterfly diagram → FIR/ IIR filter designing → Equalizer designing
Multiple External Representations	→ Exploring Z plane and S plane (MERs: pole location / zero location in S plane and Z plane) → Sampling and reconstruction of signals in time/ frequency domain (MERs: sampled signals in time domain and spectra of sampled signal in frequency domain). → Frequency response from S/Z plane for pole zero position (MERs: location of poles/zeros and Frequency response plotted)	**Discrete Time Signal Processing** → Pole-zero plots and frequency response → Bode servo analysis → Root Locus of a transfer function **Control Systems** → Bode servo analysis → Root Locus of a transfer function → designing of open loop and closed loop systems → PID controller

Topic: Mapping from S plane to Z plane

Learning Objectives:
After interacting with this learning environment, learner will be able to :

- establish relation between s plane and z plane
- translate a given pole-zero location in the s plane to its appropriate location in Z plane and vice versa

Recommended Interactivity Enriching Features: RDL, PCVM



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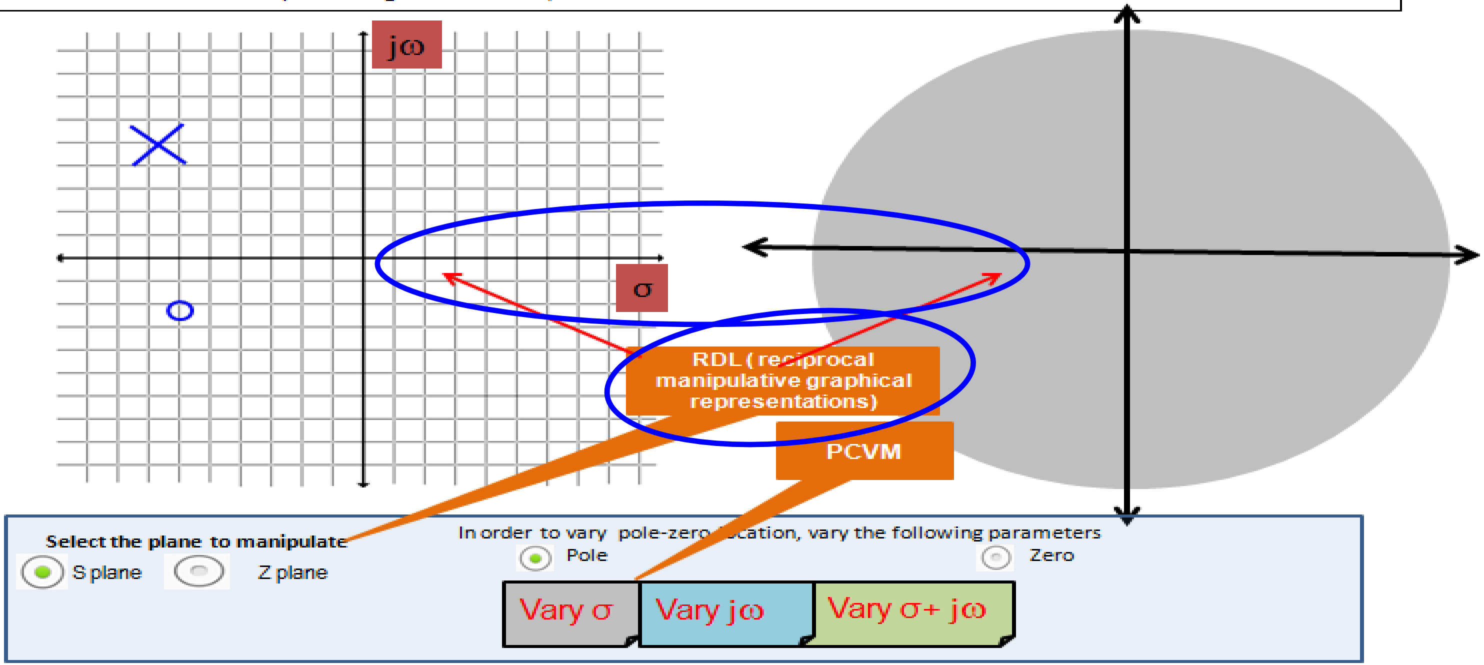


Limitations of the Thesis

- The results from this thesis need to be considered along with the following limitations.
  - Learner characteristics: Learner characteristics has not been a confounding variable considered.
  - Instructor and instructional strategies: Contribution of instructor's role has been kept outside this thesis.
  - Sample: Demographic details of the sample have assumed to be non-influential on the findings.
  - Domain and educational settings: The basic premises and assumptions might not hold true for school level (other than tertiary level educational setting) educational set-up.
  - Research Methods
    - the treatments given were of short duration nature
    - Assessment of lower cognitive levels
    - Use of self-reported cognitive load subjective rating scale.
  - IEFs need not be the only solution approach

Future Directions

"Creating learner-centric, technology-enabled effective learning environment that is capable of fully utilizing its potential to offer the most enriched learning experience to learners"

- **Validating IEFs for more topics from associated domains**
- **Validating IEFs for additional learner characteristics**
- **Validating IEFs in the presence of internal/external instructional strategies**
- **Investigating IEFs' effectiveness for higher cognitive levels**

Thesis Contributions

- The concept of Interactivity Enriching Features and characterizing its role in learning from ILEs.
- Four Interactivity Enriching Features: Determine, design and evaluate IEFs for interactive animations and simulations. The thesis contributed by conceiving and defining attributes of these IEFs.
  - Permutative Variable Manipulation (PVM)
  - Productively Constrained Variable Manipulation (PCVM)
  - Discretized Interactivity Manipulation (DIM)
  - Reciprocative Dynamic Linking (RDL)
- Five empirical studies to test effectiveness of IEFs
- Interactivity Design Principles
- Interactivity Enriched Learning Environments (IELE)
- Integrated perspective of IEF designing and its learning impact in ILEs in the form of three-layer Model for Interactivity Enriched Learning Environment (MIELE):
- eIDT: Enriched Interactivity Design Tool
- Validated instruments

Publications

- **Journal Publication**
  - Patwardhan, M., & Murthy, S. (2015). When does higher degree of interaction lead to higher learning in visualizations? Exploring the role of "Interactivity Enriching Features". *Computers & Education, 82, 292–305. doi:10.1016/j.compedu.2014.11.018*
- **Conference Publications**
  - Patwardhan M., S. Murthy, "How Reciprocative Dynamic Linking Supports Learners' Representational Competence: An Exploratory Study ", Proceedings of 23rd International Conference on Computers in Education, Hangzhou, China, November-December 2015.
  - Banerjee G., Patwardhan M., S. Murthy, "Learning Design Framework for Constructive Strategic Alignment with Visualizations", Proceedings of 22nd International Conference on Computers in Education, Nara, Japan, November- December 2014.
  - Banerjee G., Patwardhan M .& Mavinkurve M. (2013), "Teaching with visualizations in classroom setting: Mapping Instructional Strategies to Instructional Objectives", Proceedings of 5th IEEE International Conference on Technology for Education (T4E), IIT Kharagpur.
  - A. Diwakar, M. Patwardhan and S. Murthy, "Pedagogical Analysis of Content Authoring tools for Engineering Curriculum", selected for paper publication at "International Conference for Technology for Education (T4E) 2012" at IIIT Hyderabad, July 2012.
  - M. Patwardhan and S. Murthy, "Teaching-learning with interactive visualization: How to choose the appropriate level?," 2012 IEEE International Conference on Technology Enhanced Education (ICTEE), pp. 1-5, Jan. 2012.

- **Journal paper - Manuscript under review (Second revised version of the paper has been submitted on November 5th, 2016)**
  - Patwardhan, M., & Murthy, S. (2016), "Designing Reciprocative Dynamic Linking to improve learners' Representational Competence in Interactive Learning Environments submitted to Research and Practice in Technology Enhanced Learning (RPTEL)

Results of E1

Table 5.1. Mean and standard deviations of the test score for experiment E1

Question category	Non-interactive Learning Environment (Non-ILE) N=41		Animation (ANM) N=35		Simulation (SIM) N=23		Interactivity Enriched Learning Environment (IELE) N=35	
	M	*SD*	*M*	*SD*	*M*	*SD*	M	SD
Understand Conceptual knowledge	7.97	2.09	7.52	2.04	6.81	2.56	7.24	2.49
Understand Procedural knowledge	5.73	3.63	3.43	3.98	3.04	2.92	5.86	3.93
Apply Procedural knowledge	3.86	2.99	3.14	2.28	3.91	1.99	5.57	3.08

Results of E1

Table 5.2. Results of Mann-Whitney U test for experiment E1

Experimental Groups	Understand Conceptual knowledge		Understand Procedural knowledge		Apply Procedural knowledge	
	Mann-Whitney U	*p*	Mann-Whitney U	*p*	Mann-Whitney U	*p*
Non-ILE and ANM	632.500	0.321	485.000	0.010	638.500	0.395
Non-ILE and SIM	356.000	0.073	284.000	0.004	433.500	0.582
Non-ILE and IELE	607.500	0.209	699.500	0.840	473.000	0.010
ANM and SIM	347.500	0.324	397.500	0.931	315.000	0.145
ANM and IELE	582.500	0.698	413.000	0.013	313.500	0.000
SIM and IELE	370.000	0.575	242.000	0.006	249.500	0.013

Results of E2

Table 5.5 Mean and standard deviations of the test score for Experiment E2

Question category	Animation (ANM) N=71						Simulation (SIM) N=70					
	Pre-test Scores		Post-test Scores		Gain = Post-test score -pre-test score		Pre-test Scores		Post-test Scores		Gain = Post-test score - pre-test score	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Apply Conceptual knowledge	6.71	2.42	7.23	2.39	0.52	1.66	4.24	2.89	5.86	2.75	1.62	2.39
Understand Procedural knowledge	9.72	1.67	10.00	-	0.28	1.67	9.71	1.68	10.00	-	0.29	1.68
Apply Procedural knowledge	0.38	0.16	5.02	1.94	4.64	1.97	0.22	0.22	4.97	1.78	4.75	1.77

Results of E3

Table 5.6 Mean and standard deviations of the test scores for Experiment E3

Question category	Animation (ANM) N=35						Simulation (SIM) N=36					
	Pre-test Scores		Post-test Scores		Gain = Post-test score -pre-test score		Pre-test Scores		Post-test Scores		Gain = Post-test score - pre-test score	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Understand Conceptual knowledge	5.29	4.19	9.14	2.57	3.86	3.85	4.86	3.68	8.19	2.96	3.33	3.59
Apply Conceptual knowledge	5.76	2.33	8.86	1.80	3.10	2.92	5.42	2.77	7.69	2.74	2.27	2.62
Apply Procedural knowledge	3.88	2.00	6.02	1.72	2.14	1.73	3.87	2.21	6.88	2.16	3.01	2.12

Results of E4

Table 6.1 Mean and standard deviations of the Domain knowledge performance test score for experiment E4

Question category	Domain knowledge Performance Test Score			
	Simulation (SIM) N=33		Interactivity Enriched Learning Environment (IELE) N=34	
	M	*SD*	M	SD
Understand Procedural knowledge	8.33	3.68	9.85	1.85
Apply Conceptual knowledge	3.13	2.34	3.33	2.96
Apply Procedural knowledge	3.74	1.95	5.17	2.40

Results of E4

Table 6.3 Mean and standard deviations of the cognitive load scores for experiment E4

Question category	Self-reported difficulty level (germane cognitive load) scores			
	Simulation (SIM) N=33		Interactivity Enriched Learning Environment (IELE) N=34	
	M	*SD*	M	*SD*
Understand Procedural knowledge	3.61	1.28	2.74	1.42
Apply Conceptual knowledge	4.97	1.55	4.71	1.66
Apply Procedural knowledge	6.61	1.48	5.26	2.70

Results of E4

Table 6.3 Mean and standard deviations of the cognitive load scores for experiment E4

Question category	Self-reported difficulty level (germane cognitive load) scores			
	Simulation (SIM) N=33		Interactivity Enriched Learning Environment (IELE) N=34	
	M	*SD*	M	*SD*
Understand Procedural knowledge	3.61	1.28	2.74	1.42
Apply Conceptual knowledge	4.97	1.55	4.71	1.66
Apply Procedural knowledge	6.61	1.48	5.26	2.70

Table 6.4 Affective Domain ratings

Treatment Groups	Affective Domain Ratings	
	M	*SD*
Simulation(SIM) N=33	3.97	0.57
Interactivity Enriched Learning Environment (IELE) N=34	4.25	0.41

Results of E5

Table 7.2 Mean scores and standard deviations of the Domain Knowledge Performance Test Score for experiment E5

Question category	Domain Knowledge Performance Test Score			
	Simulation (SIM) N=12		Interactivity Enriched Learning Environment (IELE) N=12	
	M	*SD*	M	SD
Category I (Apply Procedural knowledge)	4.48	2.16	6.20	1.94
Category II (Understand + Apply Conceptual knowledge)	6.37	1.18	7.11	1.34
Category III (Analyze Procedural knowledge)	5.17	2.65	8.44	1.99

Results of E5

Table 7.3 Mean scores and standard deviations of the cognitive load scores for experiment E5

Question category	Self-reported difficulty level (germane cognitive load) scores			
	Simulation (SIM) N=12		Interactivity Enriched Learning Environment (IELE) N=12	
	M	*SD*	M	SD
Category I (Apply Procedural knowledge)	5.58	1.24	4.27	1.27
Category II (Understand + Apply Conceptual knowledge)	5.25	1.71	4.55	1.73
Category III (Analyze Procedural knowledge)	6.08	1.68	4.36	2.06

Qualitative Findings for E1

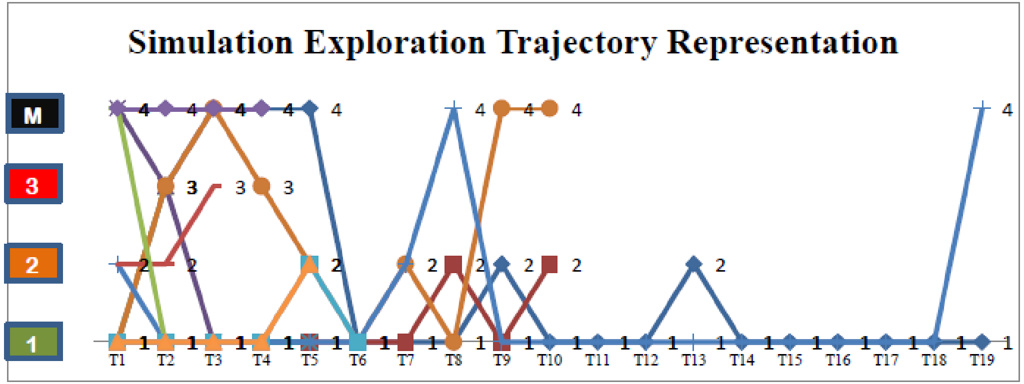
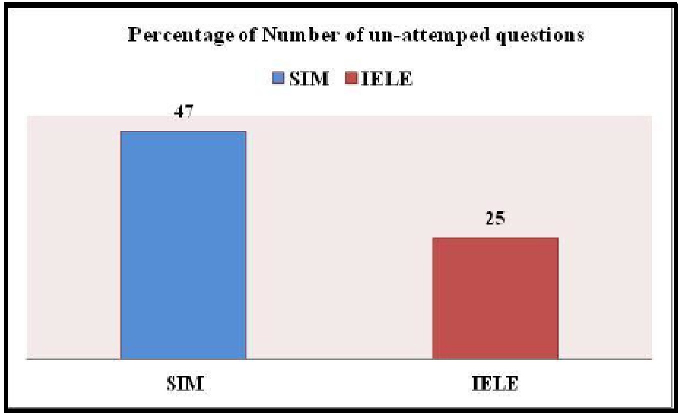


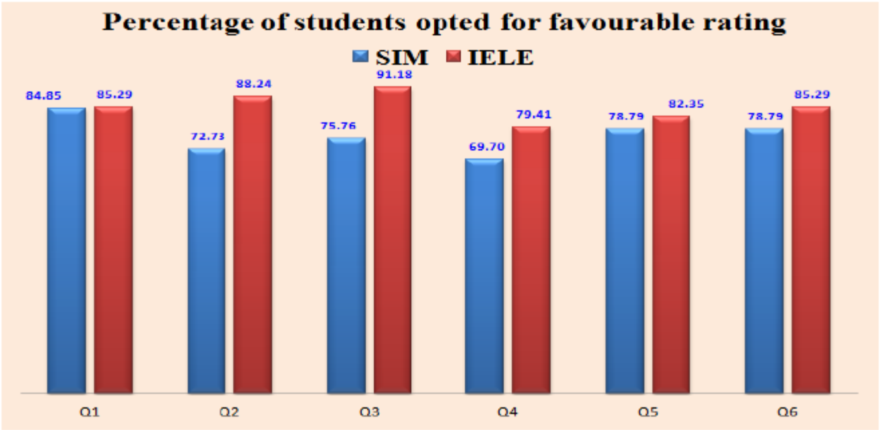
Figure 5.3. Simulation Exploration Trajectory Representation

Table 5.3 Coding categories and corresponding responses for experiment E1

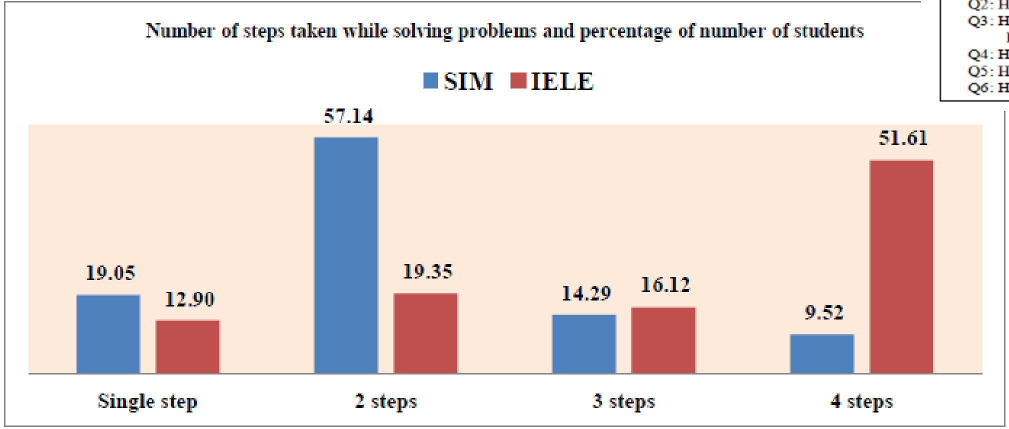
Student's response (verbatim)	Coding categories
" ...this applet allows only single option..." *".... It shows one step at a time...."*	Feature
"...one at a time and then you go for everything makes strong foundation blocks...." *"....visualizing signal transformation becomes easy with this (applet), if one is not able to visualize...."*	Reason
"..... incremental learning helps......" *"..... PDF version will be enough for basic understanding, simulation explains how to solve problems....*	Learning impact

Qualitative Findings for E4





Q1: How interesting was it to learn about graphical convolution today? : Interesting
Q2: How entertaining was it to learn about graphical convolution today? : Entertaining
Q3: How eager would you be to learn about some different topic from Signals and Systems in the same conditions you learned today?: Eager
Q4: How motivating was it to learn about graphical convolution today? Very motivating
Q5: How much did the JAVA applet help you to understand about graphical convolution?: Very much
Q6: How helpful was this JAVA applet for learning about Graphical helpful



Qualitative Findings for E5

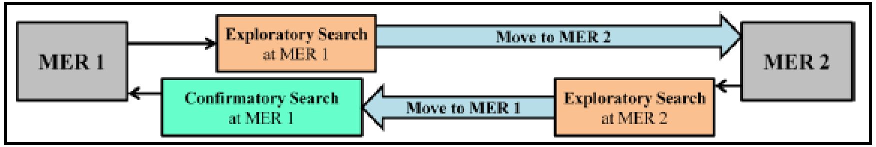


Figure 7.3 Exploration pattern observed from screen capture analysis

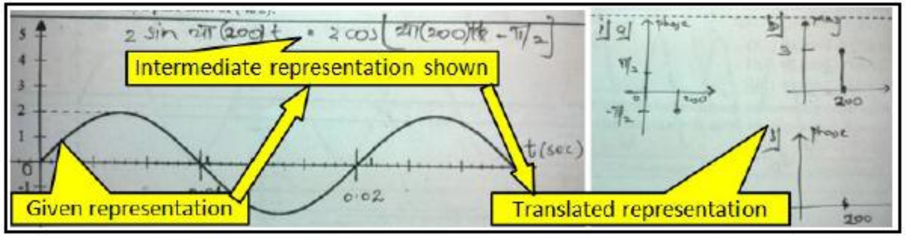


Figure 7.4. Translation process shown in the answer sheet

Learning pattern:

......"It's basically when one of them moves, I like to observe this one is increasing and what's happening to the next one, increasing or decreasing, that pattern I like to remember"........

..... Choosing anyone......so choose one and make changes over there see what changes happen in corresponding one then you can go for the second one...... make changes over there, then see.

Learning preferences:

... that would also be better because frequency domain ...we can correlate frequency and time domain simultaneously, so if both go hand in hand then that--that would also be a better option and this helps the equation, like the equation we have to think about what will be the Sin or Cos Sin wave or the waveform".......

...."if second changes and we need to find the changes in first then, uh, if the second option is selected then I will have to think it reverse, so it is difficult for me to you know think in other way. .... Okay......So if direct option is given to change in second and see the changes in first then that is obviously better.

....."if I understand, I don't need both ways manipulation.....one is also enough and sufficient"....

Feature impact:

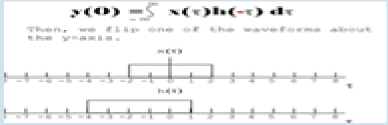
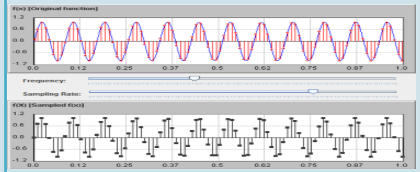
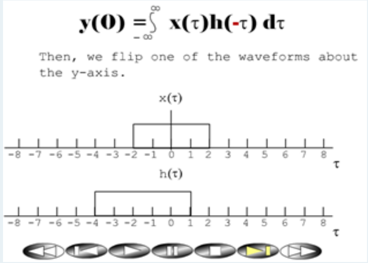
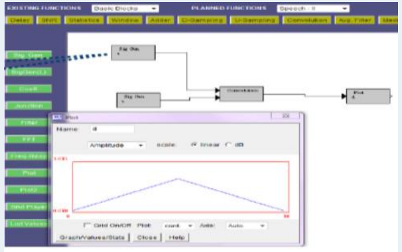
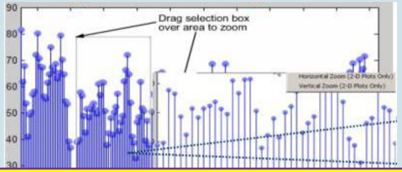
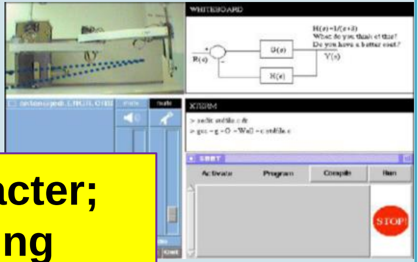
......"we are just back testing whatever changes we are seeing, are we are able to get the same changes mathematically back after changing this"......

....."It works as a good rechecking for myself that if I have understood the concept like I can try to predict that if I move the right one in which direction or vice versa how it should work, so it's a way of checking myself".........

...... "with this, we will be able to find relations between all these.... it will simplify lot of things".....

......"when one changes, the other has effects on it......... it creates a a..... like chain when more representations are there".....

Different levels of interactions (Schulmeister, 2003)

Interaction Level	Screenshot of example	Interaction Level	Screenshot of example
Viewing static picture, still images, no interaction		Manipulating visualization contents through different interaction features	
Viewing video, visualization that includes play, pause, stop, repeat, rewind, speed control		Allows generating visualizations through programs, data, model building	
Permits control functions such as viewing order (changing the order / sequence of viewing), zooming, rotating (no change in content)		Receiving feedback on manipulations of visual objects … virtual /remote labs for engineering applications	

Lower level of interaction → a behaviourist character; higher level of interaction →constructivist learning

What does literature say about ILE learning?

Learning impact of Interactive Learning Environments

- **Research Stream-I**
  Establishing learning potential of ILEs
- **Research Stream-II**
  Failure in confirming the learning potential of ILEs
- **Research Stream-III**
  Conditional Learning in ILEs

Highlights of the Research streams

Research Stream-I
Establishing learning potential

- learning success → inherent features of dynamic depiction and exploration affordance

Research stream-II
Failure in confirming the learning potential of ILE

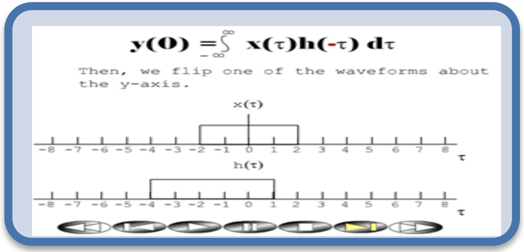
•Changing nature of ILE learning effectiveness.
•learning effectiveness became a multidimensional construct

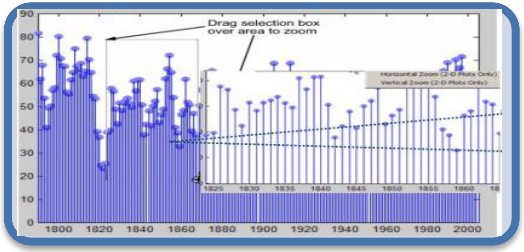
Research stream-III
Conditional Learning in ILEs

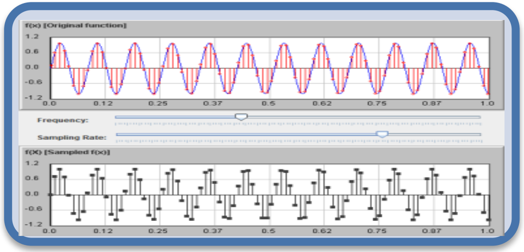
- The notion of 'moderators' in ILE got introduced
- more divergent RQs emerged. Such as *"whys," "whens," and "for whoms" in addition to whethers" and "how muchs."*

Categorizations of Interaction Features in ILE

Categorization of interaction features in ILE was done and the following overarching categories were created







Features that controls how information / content should get delivered to the learner (play/pause/ navigation / direction control etc.) (Choo, 1992).

Information Delivery Interaction (IDI)

Features that allow learner to observe the same educational content in different representation formats (zoom in/ zoom out/ 2D/3D etc.) (Reichert & Hartmann, 2004).

Representation Strategy Interaction (RSI)

Features that allows educational content of ILE to get manipulated dynamically (vary/ key-in/ select value etc.) (Choo, 1992).

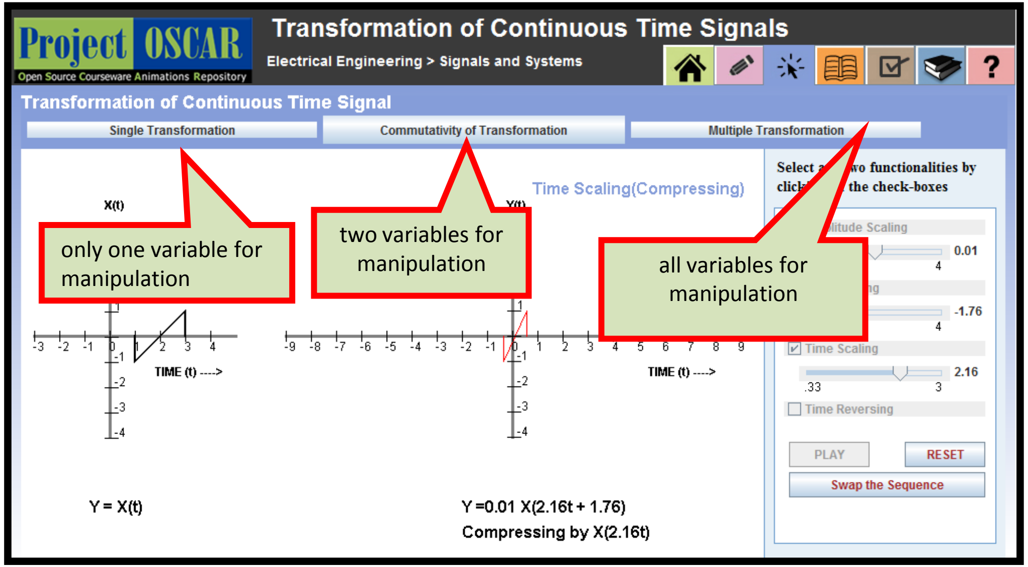
Content Manipulation Interaction (CMI)

PCVM: Productively Constrained Variable Manipulation

- It restricts the number of variables to be offered for manipulation simultaneously; yet allows full exploration opportunities.

- This ensures that learner uses all the exploration and learning opportunities provided in ILE.

- In spite of forcing learner to manipulate variables in a constrained manner, it is a 'productive constraint' as it will aid the learning process and will foster learning by aligning instructor's learning objectives with the exploration pattern of learner in an interactive simulation.

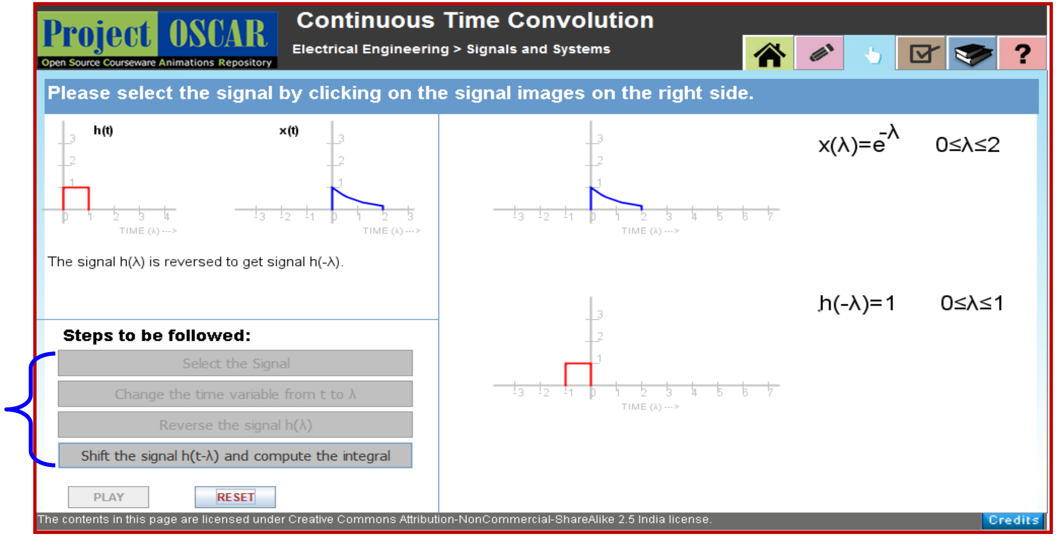


DIM: Discretized Interactivity Manipulation

- It allows learner to execute a given task / process / procedure in the form of discretized steps to strengthen internal mental representation of the task.

- Learning sciences related to Event Cognition report that while learning a given process/ event, generally learners construct an internal mental representation composed in several discrete steps.

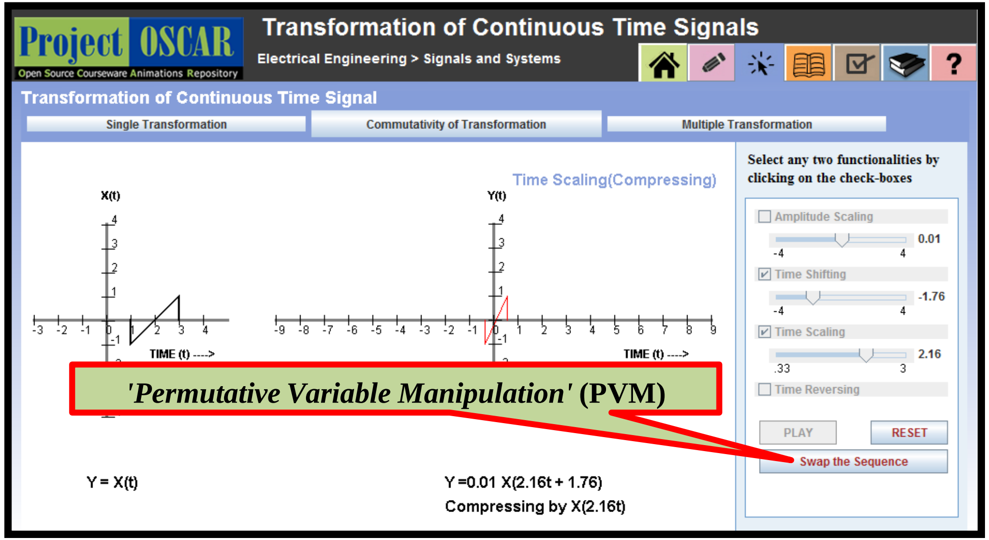
- As per DIM, ILE can offer interactivity that enables learner to select individual steps discretely, thus creating a discretized mental model of the continuous event/ task to be accomplished.



PVM: Permutative Variable Manipulation

While learning procedural knowledge in ILE, this affordance will enable learner to make decisions about sequencing the steps of procedural task (i.e. all possible permutations) to improves learning.

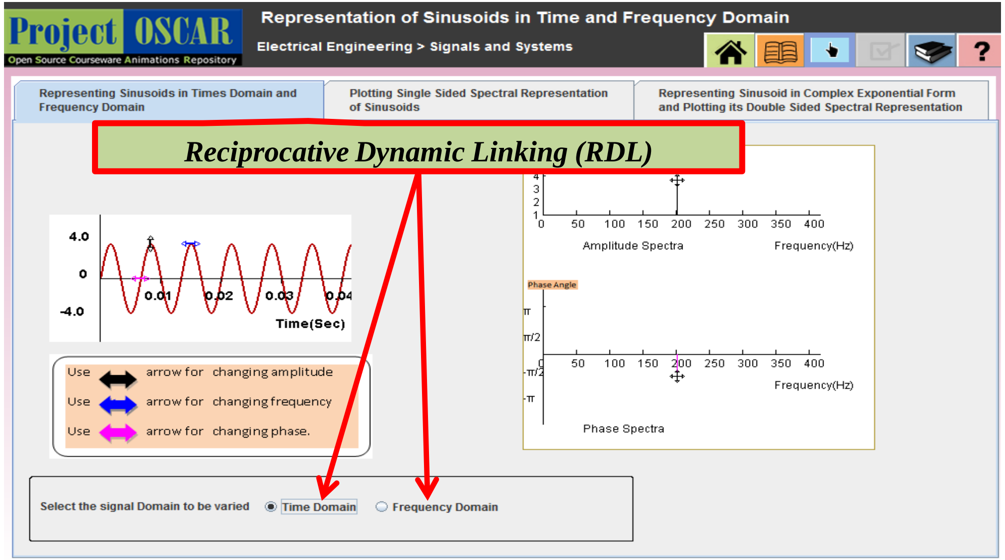
Embedding Permutative variable as an additional interactive feature will be useful for allowing number of permutations of action sequences especially while executing a procedural task. Due to PVM, learner will be able to see what change takes place in the outcome of the process due to change in the order of the steps (or different permutations).

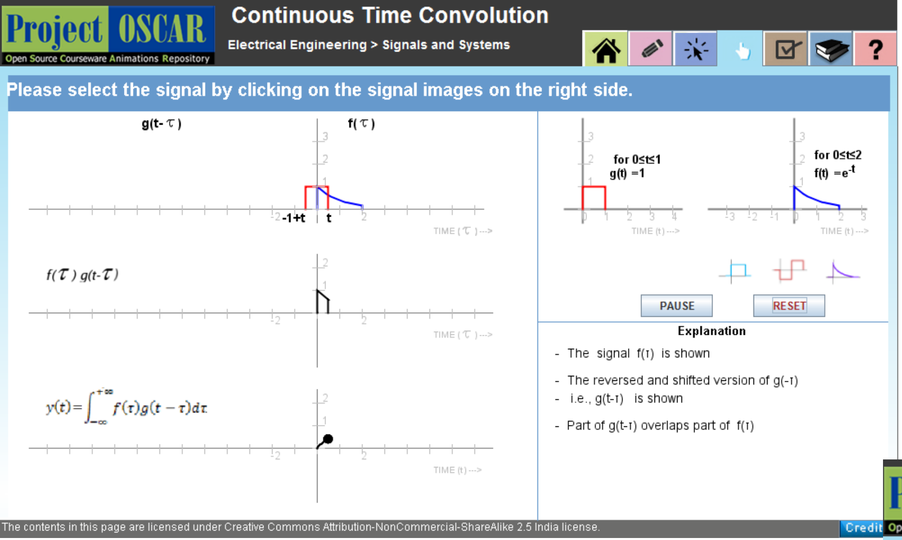


RDL: Reciprocative Dynamic Linking

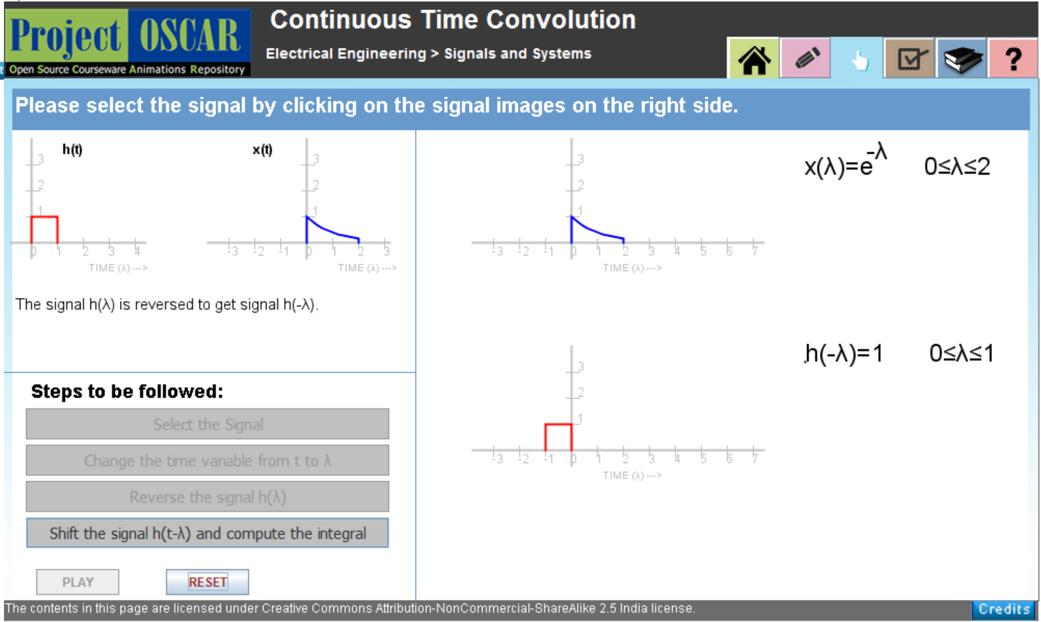
It is an affordance offered to select and manipulate each of the multiple external representations individually in a reciprocative manner.

While learning from Dynamically Linked Multiple Representations (DLMR), RDL will offer design interactivity using Reciprocative Dynamic Linking (RDL) feature which allows learners to manipulate both (or more) DLMRs in a reciprocative manner.





ILE without IEF



IELE: ILE with IEF ‘DIM’