Determining Interactivity Enriching Features for Effective Interactive Learning Environments

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by

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Dedication Sheet

Dedicated

to

my Family members

and

the Almighty

Thesis Approval Sheet

This thesis entitled **"Determining Interactivity Enriching Features for Effective Interactive Learning Environments"** by Mrinal Patwardhan is approved for the degree of Doctor of Philosophy.

Examiners

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Abstract

Interactive learning environments (ILEs) are computer-based simulation environments which allow learners to interact with the learning material using various interaction features. The varied levels of interaction offer varied learning experiences and learning outcome from ILEs. While ILEs have shown potential for improved learning in various domains, empirical studies have shown mixed learning results. Particularly, studies have shown that the interactive nature of ILEs could not always lead to better learning. On this background, the broad research objective of this thesis is: 'Under what conditions do ILEs lead to effective learning?' The context of study is a course on 'Signals and Systems', a foundational undergraduate course in Electrical Engineering.

The research issue was addressed by examining, analyzing and re-designing learning-conducive interaction features in ILEs, which would offer the required cognitive support to learners while learning from ILEs. We proposed 'Interactivity Enriching Features (IEFs)', which are additional interaction features needed to unleash the learning potential of ILEs. The overall solution approach included establishing the need for IEFs, identifying and designing of IEFs for variable manipulating interactions, investigating learning effectiveness of IEFs and exploring effect of IEFs on learners' cognitive load. As a part of thesis work, four IEFs were designed: Permutative Variable Manipulation, Productively Constrained Variable Manipulation, Discretized Interactivity Manipulation, Reciprocative Dynamic Linking.

Five research studies using explanatory sequential mixed method approach were carried out that included quasi-experimental studies (N_{total}= 437) and qualitative strands. The participants were students from second year of engineering from colleges affiliated to University of Mumbai, a large public urban university in India. The assessment instruments were designed to address the requirements of engineering curriculum and focused on 'understand' and 'apply' cognitive levels and 'conceptual' and 'procedural' types of knowledge within the chosen topics. Qualitative data in the form of screen captures and semi-structured interviews were used wherever needed as per the research design.

The results showed that higher level of interaction need not necessarily lead to higher learning but depended on the cognitive level and type of knowledge of the content. The findings provided evidence for the inclusion for IEFs to enhance learning from ILEs. The findings showed that learners learnt better with IEFs and thus, the need for strategic designing of interactions to meet learning demands of learners was emphasised. The improvement in germane load of learners could confirm the role of IEFs in offering the required cognitive support to learners that led to improvement in learning.

The major contributions of the thesis are: determining the IEFs for effective ILEs, designing of four IEFs for content manipulation interactions, recommendations in the form of Interactivity Design Principles based on the findings of empirical studies conducted to test effectiveness of IEFs, and development of Interactivity Enriched Learning Environments for three different topics in Signals and Systems.

Keywords: Interactive Learning Environments, simulations, interaction, interactivity, cognitive load

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Abbreviation Notation and Nomenclature

ANCOVA	Analysis of covariance
ANM	Animation
CLT	Cognitive Load Theory
CMI	Content Manipulation Interaction
CTML	Cognitive Theory of Multimedia Learning
DIM	Discretized Interactivity Manipulation
DLMR	Dynamically Linked Multiple Representations
ECL	Extraneous Cognitive Load,
eIDT	Enriched Interactivity Design Tool
GCL	Germane Cognitive Load
ICL	Intrinsic Cognitive Load
IDI	Information Delivery Interaction
IEF	Interactivity Enriching Feature
IELE	Interactivity Enriched Learning Environments
ILE	Interactive Learning Environment
MER	Multiple External Representations
MIELE	Model for Interactivity Enriched Learning Environment
Non-ILE	Non-Interactive Learning environments
PCVM	Productively Constrained Variable Manipulation
PVM	Permutative Variable Manipulation
RDL	Reciprocative Dynamic Linking
RSI	Representation Strategy Interaction
S&S	Signals and Systems
SIM	Simulation
SSCI	Signals and Systems Concept Inventory
TEL	Technology Enhanced Learning

Declaration

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

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(Name of the student)

(Roll No.)

Date: ______________

1. Chapter 1

Introduction

1.1 Background and Motivation

Computer-based interactive learning environment often refers to a sufficiently general range of computer-based simulation environments, that facilitates learning of complex and dynamic phenomenon (Quadrat-ullah, 2010). The onset of computer-based technologies in education has produced various forms of computer-based learning environments. Some of these are: animation, interactive simulation, gaming environment, smart boards, adaptive learning environments, ubiquitous learning environments and various system simulators. In this thesis, we refer 'Interactive Learning Environments' (ILEs) to computer-based dynamic learning environments; which present content in an interactive manner, permitting interactions between a learner and learning material with the help of different kinds of interaction features. Use of ILEs is being advocated and suggested extensively as an instructional aid and has penetrated in various domains of education. Right from elementary level school students, up to university, students use ILEs for a diverse range of topics. ILEs have been used in the teaching-learning of elementary level science concepts (Barak, Ashkar, & Dori, 2011), as well as complex concepts or processes in engineering and allied courses (Boucheix & Schneider, 2009; Lattu, Meisalob, & Tarhioc, 2003; de los Santos Vidal, Jameson, Iskander, Balcells, & Catten, 1996; Wang, Vaughnb, & Min Liu, 2011). They have special value as they offer a high potential for interactive learning (Yaman, Nerdel, & Bayrhuber, 2008) and are capable of developing deeper and clearer understanding of a topic.

In general, the interactive nature of ILEs plays a pivotal role while learning from them. Interactivity is referred *to 'the reciprocal activity between a learner and a learning system, in which the [re]action of the learner is dependent upon the [re]-action of the system and vice versa'* (Domagk, Schwartz, & Plass, 2010). The interaction in ILEs is said to occur when some response is elicited from learners and in turn, the learning environment is able to respond to the learners' inputs. The quality of such interactions has been referred to as interactivity (Sedig & Liang, 2006). The hierarchical nature of learner control offered in ILEs is referred to as 'levels of interactions'. Lower interactivity implies a behaviourist character of learners, while higher interactivity leads to constructivist learning, such as discovery learning. Interactivity levels also reflect the level of learners' mental engagement and learners' roles from being passive learners to active learners (Schulmeister, 2003). Thus, analyzing the influence of higher levels of interactivity on: learning efficiency, quality of learning process and learning outcome has always been important issues for ILE researchers.

Interactive animation and simulation are two important and very widely used forms of ILEs. As per an intuitive dictum, *"a picture is worth a thousand words"* and *"a video (dynamic content) is worth a thousand pictures"*; animations and simulations were considered to be superior when compared with the static depiction of learning content. Initially, there was much excitement about the potential of these new ILEs for improving quality of education and training. There were several empirical studies that showed positive results across a range of topics and context. These findings showed that ILEs improved comprehension, shortened learning time, stimulated students' interest, motivation, engagement; and overall improved a range of abilities and skills (Barak et al., 2011; Rutten, Van Joolingen, & Van der Veen, 2011). These positive results in ILEs raised expectations regarding their learning success. Nevertheless, ILEs research studies also showed that interactivity in ILEs could not always lead to better learning. Due to mixed learning results it could not be claimed unequivocally that ILEs improved learning (Hansen, 2002; Moreno & Valdez, 2005; Domagk, Schwartz, & Plass, 2010). Thus, there was a need to analyze the role of interactivity in learning in ILEs.

This analysis is important for ILE researchers and practitioners. It is also of paramount importance to instructional designers and content creators while creating learning-conducive instructions for apt designing of interactivity in ILEs. Analyzing the notion of learning in ILEs and how learners learn from ILEs, also brings in relevant cognition theories as one more thread to be explored. Thus, along with instructional designers/ content creators, cognitive scientists also have a motivation to take up this task of analyzing the role of interactivity in effective learning from ILEs.

1.1.1 Personal motivation

The initial success of ILEs in delivering effective learning has not just attracted the school level educators, but also the higher and professional level educators in science, technology and engineering education. Computer-based visualizations like animations and simulations are being considered as effective teaching-learning resources at tertiary level of education across domains. They assist in the creation of mental models (Reed, 1987) by making the invisible visible (Gobert & Buckley, 2000) or by displaying a phenomenon using multiple representations (Blake & Scanlon, 2007).

As an Electrical Engineering educator for almost past fifteen years, personally, I always felt the need to explore various avenues for creating and using computer based interactive learning environments as teaching-learning aid. The need was even stronger while dealing with the abstract nature of content from engineering curriculum. Various concepts, phenomena and processes from different domains of engineering curriculum, especially the abstract ones, pose themselves as learning obstacles for learners. I have witnessed students struggling hard to comprehend such topics and have also experienced how an appropriate Technology Enhanced Learning (TEL) environment is of immense help to students at times. While teaching 'Signals and Systems'- a fundamental course from Electrical Engineering program, the need to use effective ILEs became all the more compelling to me; as the content demanded learners to learn various abstract notions using multiple representations. This being perceived as a universal issue by signal processing instructors' community across universities, numerous interactive learning resources in the form of Java applets, MATLAB/Simulink® models, and LabVIEW® models are available and are frequently being used as a learning aid (Guan, Zhang, & Zheng, 2009; Kehtarnavaz, Loizou, & Rahman, 2008). However, the inconsistent nature of learning impact of ILEs as reported in ILE literature made me apprehensive initially, but eventually stimulated me to investigate the aptness of such learning resources in the context of Signals and Systems. Overall, the thesis derived its motivation from the three directions as shown in Figure 1.1.

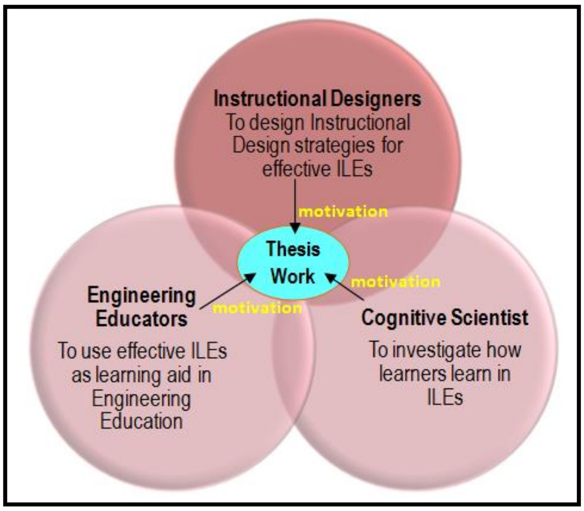


Figure 1.1. Thesis Motivation

1.2 Research Objective

As reported in a number of empirical studies, the mere presence of higher level of interactivity was found to be insufficient to ensure effective learning. Learning benefits were ensured in the presence of various learning environment conditions and features such as, interface, control, engagement level, successful use of multimedia principles, quality of instructional design (Tversky, Morrison, & Betrancourt, 2002; Lin & Atkinson, 2011; Spanjers, Van Gog, Wouters, & Van Merriënboer, 2012; Hansen, 2002; Liang, 2006; Rey, 2011, Moreno & Valdez, 2005; Domagk, Schwartz, & Plass, 2010). The research findings supporting learning contribution of higher level of interactivity, as well as the findings challenging the contribution of interactivity in ILEs strongly highlighted the mixed nature of the learning impact of interactivity in ILEs. These findings neither refuted the inherent learning potential of interactivity in ensuring expected learning, nor could it give due credit to the presence of interactivity for effective learning in ILEs. Due to this, in order to investigate learning impact of ILEs, a more exploratory approach was strongly advocated by the research community. As per this approach, the research questions needed to become more divergent in terms of *"whys," "whens," and "for whoms" in addition to whethers" and "how muchs*"

(Carney & Levin, 2002). All this demanded an intense analysis of 'what makes learning happen in the presence of interactivity in interactive learning environment?'

Against this backdrop of mixed nature of learning impact of ILEs, 'under what conditions ILEs lead to effective learning?' has been the broad research objective of my research work, with the research context being a course of 'Signals and Systems' from undergraduate program in Electrical Engineering. The broad research goals were firstly to identify the probable reasons for failure of interactivity in ensuring desired learning in ILEs and then to offer solutions for ensuring that interactivity leads to desired learning outcome in ILEs. Synthesis of literature highlighted that poorly designed interactions, even when offered at higher interaction level, could not allow the basic interactive nature of ILEs to deliver its learning benefits. On the other hand, an effective design of interactions could exhibit the potential to manifest itself into a quality interactive learning environment, even at lower level of interaction. To test this statement rigorously, we stepped back to ask a more fundamental question pertaining to the contribution of interactivity in ILEs. We set in to investigate, "Does higher level of interaction lead to effective learning in ILEs?" and took this up as our first research question.

1.3 Solution Approach

The synthesis of literature survey emphasized the need to scrutinize the role of interactivity in ensuring effective learning in ILEs. In order to come up with the solution approach, it was necessary to examine, analyze and re-design some of the basic components of ILE and then scrutinize their contribution in ILEs while delivering the expected learning outcome. Thus, to further analyze possible solution approaches to address the research issue, we looked at basic components of ILEs. Primarily, the elemental blocks of an ILE include an animated/ simulated depiction of content, a user interface for interactions, and a human facilitator, along with learner (Quadrat-ullah, 2010). Intuitively, therefore identifying the conditions for effective learning in ILEs involve redesigning/ reconsideration of these basic blocks. In line with this, the possible solutions approaches were identified as examining, analyzing and re-designing role of: visual design, learners' characteristics, user interface interactions, human facilitator, domain and learning settings. They are shown in Figure 1.2. While not exhaustive, it is an indicative list of possible solution approaches.

All the approaches mentioned therein derive their base from the need to offer the required learning support to learners while learning from ILEs; either internal or external to ILEs. Synthesis of the literature reviewed showed that such support was typically designed in the form of visual design features, embedded instructional strategies, human scaffolding or learning-conducive interaction features. Considering the motivation, context and scope of the thesis work the approach of examining, analyzing and re-designing learning-conducive interaction features was shortlisted for further consideration. For this approach; 'how different interaction features in ILEs affect students learning?' was analyzed.

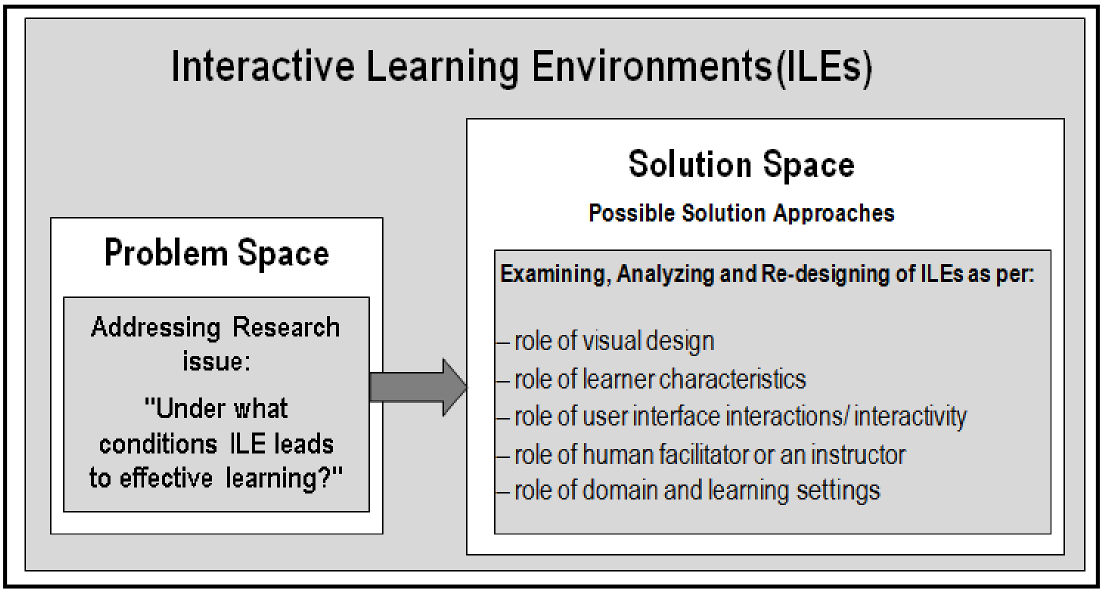


Figure 1.2. Problem space and solution space of the thesis work

In order to determine what kind support was needed for learners while learning from ILEs for meeting specific pedagogical requirements, we explored the relevant educational theories. The broad theoretical basis considered for the solution approach was derived from theories such as Cognitive Theory of Multimedia Learning (CTML), contemporary theories of cognition such as Distributed and Embodied Cognition (Glenberg et al., 2013), concept of Event Cognition (Kurby & Zacks, 2007), and relevant interaction design principles (Tversky, Morrison, & Bétrancourt, 2002). While CTML recognizes the concept of cognitive load as a crucial factor in the learning, the contemporary theories of cognition postulate that external representations play more roles than merely decreasing cognitive load and can support learning in ILEs. As proposed by the theory of event cognition, making sense of the continuous procedural tasks by means of meaningful segmented events simplifies learning.

The next step was to determine and design learning-conducive interactive features that meet learning demands in ILEs. We referred to such features as 'Interactivity Enriching Features (IEFs)'. We hypothesized that learning from ILEs could be improved by including these IEFs into the learning environment. The IEFs were expected to foster learners' cognitive processing and to offer the necessary cognitive support by increasing germane cognitive load. Figure 1.3. shows the overview of the broad research issue and the solution approach.

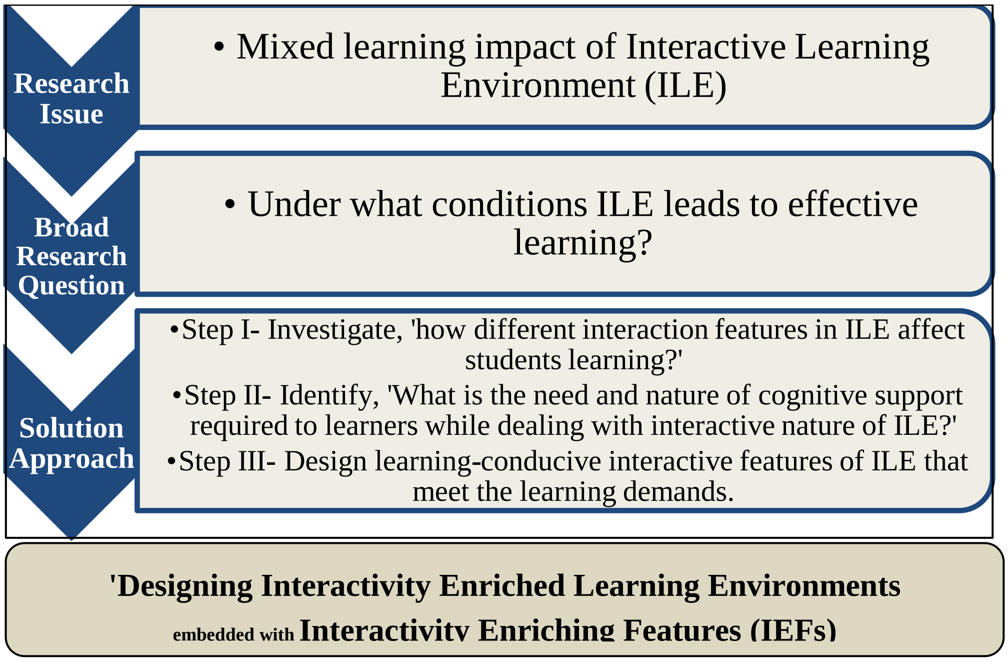


Figure 1.3. Overview of the broad research issue and solution approach

IEFs were conceptualized as interaction features in ILEs, offered to users in the form of affordance. The IEF determining and designing process of IEFs was built up by answering questions such as, "Why an IEF is needed?, What an IEF should do?, and How is IEF formulated?" The first question was answered by taking into consideration generalized pedagogical requirements and expected learning demands on learners due to these pedagogical requirements. As IEFs were designed to meet these demands, learning demands indicated the specific task that a particular IEF was expected to carry out while offering the required support to learners. Thus, IEFs were formulated by matching these expectations with the appropriately selected theoretical recommendations from relevant knowledge database.

Based on this process, four IEFs were designed as a part of this thesis work. It was expected that users' physical interactions with these features would lead to an improvement in learning from ILEs. The ILEs prepared with theses IEFs were referred to as 'Interactivity Enriched Learning Environments (IELEs)'. Figure 1.4. shows a screenshot of one such IELE developed. The screenshot shows two IEFs (Productively Constrained Variable Manipulation - PCVM and Permutative Variable Manipulation- PVM) incorporated in the learning environment. Productively Constrained Variable Manipulation was designed to provide progressive learning combined with unguided exploration experience to learners. It offered tool-mediated productive constraint while manipulating variables by channelizing learners' exploration opportunities. Another IEF of Permutative Variable Manipulation offered additional interactivity for applying procedures in a flexible manner. It allowed learners to explore all possible permutations in which a given procedural task could be implemented and their implications on the procedure outcome.

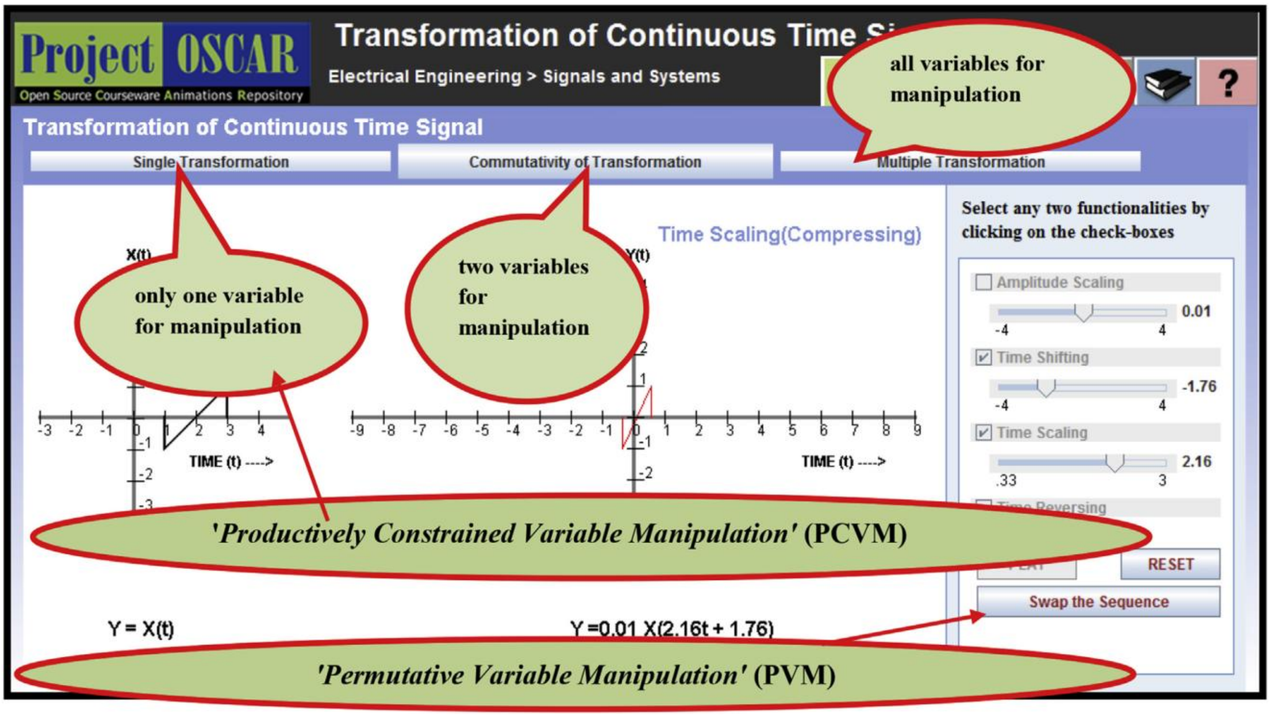


Figure 1.4. A screenshot of the Interactivity Enriched Learning Environment for a topic on Signal Transformation

1.4 Research Methodology

The main research aim of this thesis is to determine and design IEFs for improving learning in the context of a course on Signals and Systems, and to investigate their effectiveness and learning impact. To address this, the following research questions (RQ) were investigated:

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

RQ2. How do IEFs affect students' learning outcome?

RQ3: What is the effect of including IEFs on students' cognitive load?

The following research actions were needed to answer the above mentioned research questions.

i. Investigating whether higher level of interaction can always lead to better learning
ii. Determining and designing IEFs to improve learning based on the generalized pedagogical requirements and expected learning demands on learner in the context of Signals and Systems
iii. Investigating whether the proposed solution approach (i.e. designing learning environments with Interactivity Enriching Features) improved students' learning
iv. Analyzing effect of the proposed solution approach on students' learning process and cognitive load

Research approaches are plans and procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation (Creswell, 2013). As this research issue involves real-world practice oriented topic, we took the Pragmatic Worldview. The research plan for this thesis work demanded i) the quantitative assessment to support improvement in the learning score due to IEFs and ii) the qualitative exploration to see how learners use the IEFs to improve learning. Both the above mentioned measures were needed to generate evidence-based conclusions in favour of IEFs. Thus, the mixed methods research approach was considered appropriate for addressing the research problem.

The need to compare learning scores of learners while studying with and without the interactivity enriched learning environments and also the need to explore how learners use the IEFs to improve learning indicated that the overall research was suitable for explanatory sequential mixed method research. While the quantitative studies conducted answered the questions related to learning and improvement in learning due to the treatment given, the qualitative data collected thereafter helped i) to explain the initial quantitative results and ii) to get more insights about learning and the factors influencing learning in ILEs.

The study has been carried out in the context of a course on Signals and Systems. It is one of the foundation courses from Electrical Engineering and allied programs, focusing on Communication and Signal Processing. Students from second year of engineering from colleges affiliated to University of Mumbai selected by convenience sampling participated in the studies. The total number of participants was 437. The research experiments followed 'Two group Post-test only' research design on matched-random assignment groups. The studies were conducted in different topics of Signals and Systems: Signal Transformation, Fourier Transform Properties, Convolution and Signal Representation.

1.5 Delimitations of thesis

The scope of research studies and the overall research approach is as follows.

Scope of the Interactive Learning Environment: Although technological developments have given rise to a variety of ILEs, interactive animations and simulation still remain the two important and very widely used learning environments. Looking at the volume occupied by research articles existing in the research space of interactive multimedia learning environment and relevant cognitive theories, it is still imperative even today to address issues related to learning effectiveness of interactive animations and simulations. Thus, in this research study, Interactive Learning Environment covers interactive animation and interactive simulation as two widely popular and prevalent forms of ILEs.

It has been assumed that ILEs considered were overall well-designed to begin with, i.e. we have chosen ILEs which were in accordance with the well-established multimedia learning principles and were aligned with the intended learning objectives.

Scope of the domain, content and instrument: The study has been carried out in the context of a course on Signals and Systems in Electrical Engineering. Signals and Systems is one of the foundation courses in the field of Communication and Signal Processing. The kind of analytical abilities needed to learn the content and the type of knowledge to be learnt are relevant to many courses from engineering program.

Numerous interactive visualizations in the form of Java applets, MATLAB/Simulink® models, and LabVIEW models are available and are frequently used as a learning aid (Guan, Zhang, & Zheng, 2009; Kehtarnavaz, Loizou, & Rahman, 2008). Various resources containing interactive visualizations such as SYSTOOL, SSUM, J-DSP Tutor, and ‘Interactive learning resources for Signal, Systems and Controls’ (Crutchfield & Rugh, 1997; Rabenstein, 2002; Shaffer, Hamaker, & Picone, 1998; Spanias, Chilumula, & Huang, 2006; Sturm & Gibson, 2005) have been recommended for learning of Signals and Systems. The need to visualize abstract concepts, to understand multiple representation forms of these concepts, and to apply multiple computational steps (Nelson, Hjalmarson, Wage, & Buck, 2010) are some of the reasons that have made interactive simulations prevalent in the Signals and Systems teaching community.

The topics covered are Signal Transformation, Fourier Transform Properties, Convolution and Representation of Sinusoids in Time and Frequency Domain. The topic selection was based on the important and difficult topics highlighted by Signals and Systems Concept Inventory research work (Nelson, Hjalmarson, Wage, & Buck, 2010). The assessment instrument was developed to test students' learning in terms of ‘understand’, ‘apply’ and 'analyze' cognitive levels and ‘conceptual’ and ‘procedural’ types of knowledge. Work on the Signals and Systems Concept Inventory (SSCI) (Wage, Buck, Wright, & Welch, 2005) and the work reported (Hiebert & Lefevre, 1986) have reported the necessity to focus on both these types of knowledge as well as on their co- existence.

Scope of the instructional setting: Our focus was on tertiary education, specifically in domains of engineering and science. Instructor support was not considered as a variable and it was expected that students learn from ILEs in self-learning mode.

1.6 Contribution of the Thesis

This thesis makes contribution in the field of Interactive Learning Environments in terms of design guidelines, design process, products and research knowledge based on the empirical studies conducted. Firstly it introduces the notion of 'Interactivity Enriching Features'. It explains and supports the claim how students' learning from ILEs can be improved due to IEFs that fosters learners' cognitive processing. The solution approach of supporting learners with learning-conducive interaction features has resulted in designing of IEFs.

The major contributions of the thesis are:

- 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 (N_{total}= 437) in four topics of Signals and Systems to test effectiveness of IEFs
- Interactivity Design Principles for designing variable manipulation interactions in ILEs useful for instructional designers, content creators and instructors.
- Interactivity Enriched Learning Environments (IELE) created for three different topics of Signals and Systems.

Minor contributions:

- Model for Interactivity Enriched Learning Environment (MIELE) that describes IEF designing, explains the underlying phenomenon related to cognitive processing of learners that makes IEFs improve learning from ILE and offers recommendations derived from experimental findings for designing enriched interactivity in ILEs

- *e*IDT: Enriched Interactivity Design Tool: MIELE based IEF selection guiding tool for instructional designers and instructors.
- Validated instruments in the topics of Signal transformation, Convolution, Fourier Transform Properties, Representation of Sinusoids in Time and Frequency Domain.

1.7 Structure of the Thesis

This thesis is organized as follows:

Chapter 2 discusses the background required for our research work. It presents the related work and points at the need to investigate the research issue of "Under what conditions ILE leads to effective learning?" It analyses various issues such as; the conditional nature of learning impact of ILEs, role of interaction features in learning from ILEs, strong linkage between learner's cognitive processing, instructional design principles, and interplay between various elements of ILEs.

In Chapter 3, while forming the solution approach, we explore ILEs and delve deeper to learn more about the process of learning from them. Based on this, in Chapter 3, we propose the concept of IEFs and indentify specific IEFs for content manipulation interaction.

Chapter 4 discusses the overall research methodology and methods adopted for the studies planned for testing learning effectiveness of IEFs . Chapters 5, 6 and 7 present the details of the empirical studies conducted. Chapter 8 of the thesis offers the discussion on the research questions. The chapter also presents Model for Interactivity Enriched Learning Environment (MIELE). Chapter 9 of the thesis summarizes thesis contribution, concluding remarks, and prospective future research directions.

2. Chapter 2

Review of Literature

This chapter summarizes and synthesizes literature on ILEs, learning impact of ILEs and role of cognitive processing while learning from ILEs. It then puts forward the identified gaps in existing work, and the emerging research questions in the appropriate research context.

2.1 Process of literature review in this thesis

While investigating learning effectiveness of Interactive Learning Environments (ILEs), the relevant literature was reviewed to address the broad research question of 'Under what conditions ILE leads to effective learning?' The process of literature review not just helped in firming up the research questions, but also brought out other supplementary issues on the surface. All these collectively helped in laying the base for the proposed solution approach.

The literature review, a process of locating and summarizing studies about a topic, was carried out in a stepwise manner (Creswell, 2013). The key words, such as *'interactive* *learning environments, interactions, interactivity, simulation, animation, multimedia learning, cognitive load'* were used for identifying relevant research articles. The above mentioned key words were used to search articles from computerized databases. Approximately 150+ research articles were reviewed covering a span from year 1985-2015. The research context being a course on Signals and Systems, the articles related to Signals and Systems education were also reviewed. Additionally, articles reviewed also included research articles covering seminal work in the field of multimedia learning, multimedia principles, and theories related to science of learning and instruction, even prior to year 1985.

The literature review process referred to the taxonomy proposed by Cooper (Cooper, 1988). To answer broad research question, literature review adopted 'outcome-oriented research focus' with a major goal to integrate generalized findings. Literature review has been presented as a 'neutral' and objective representation. Interactive Learning Environment is a phrase that encompasses many variants and has number of interpretation as to what can qualify as an interactive learning environment. Thus, keeping in mind the definition of an ILE under the purview of this study, literature coverage was 'exhaustive with selective citation'. In order to present a coherent structure, we preferred 'conceptual' organization of literature review and the targeted audience comprise 'specialized researchers' working in the area of ILEs, designers and practitioners of ILEs.

Use of ILEs has penetrated right from school education to higher level professional education. The research space in this domain consists of research studies covering a wide range of learner characteristics, educational settings, domain and societal aspects. Due to this diverse nature of literature space, some systematic method was needed while synthesizing the reviewed literature. The studies were organized on the basis of their results and findings instead of other parameters (such as learner profile, domain etc.). This aspect further led to three different research streams, as presented in section 2.3 of this Chapter.

2.2 Parent Discipline: Interactive Learning Environments

This section presents an overview of ILEs: definitions, various types of ILEs with a focus on interactive animations and simulations, nature of interactions and interactivity, and learning benefits of ILEs.

The onset of computer-based technologies for education changed the teaching-learning scenario drastically in the last two decades. ILEs have been equipped with a wide variety of interactions features. While this change has been welcomed due to its benefits, it has also opened up a plethora of associated research issues. Various educational and learning theories evolved over the years have also brought in more maturity to understand learning process in technology enhanced learning environments and the role of interactivity in learning. They have also broadened the scope of ILEs. The whole scenario is no longer limited to; 'a learner', 'an instructor' or 'learning material/content' as isolated entities. It has now evolved into a learning environment consisting of various constituents such as the learner, learning material, interaction between learner and learning material, cognitive aspect of learning, instructional strategies, automated feedback from learning environments, adaptation in learning environments and so on. All these are considered to be collectively responsible for the learning outcome from such learning environments (Domagk, Schwartz, & Plass, 2010).

Generally, computer-based interactive learning environments visualize and/or simulate the learning content being presented. The term ‘computer-based interactive learning environment’ is used to refer to a sufficiently general range of computer-simulation based learning environments, that facilitate learning of complex and dynamic phenomenon (Quadrat-ullah, 2010), including animation, interactive simulation, gaming environment, smart boards, adaptive learning environments, ubiquitous learning environments and various system simulators. Although they exist in different forms, ILEs derive their learning potential basically from their abilities: i) to depict dynamic visualization of complex concepts and ii) to respond dynamically to learner's explorative actions (Park & Kim, 2009). The extent to which these two abilities have been operationalized has given rise to the diverse range of learning environments. In addition to these two characteristic features, each learning environment comes with its own unique interaction and interface design features.

Although technological developments have given rise to a variety of interactive learning environments; interactive animation and simulation still remain the two important and very widely used learning environments. Use of interactive animation and simulation is being advocated and suggested extensively as an instructional aid and has penetrated in various domains of education. It is being used by, right from elementary level school students up to university students, in a diverse range of topics. They have been used in the teaching-learning of elementary level science concepts (Barak, Ashkar, & Dori, 2011), as well as complex concepts or processes in engineering and allied courses (Boucheix & Schneider, 2009; Lattu, Meisalob, & Tarhioc, 2003; de los Santos Vidal, Jameson, Iskander, Balcells, & Catten, 1996; Wang, Vaughnb, & Min Liu, 2011). They have special value as they offer a high potential for interactive learning (Yaman, Nerdel, & Bayrhuber, 2008). While they are popular and useful as an instructional aid and have been around for more than two decades; even today there are numerous open research issues related to their learning efficiency. Looking at the volume occupied by articles in the research space of interactive multimedia learning environment and relevant cognitive theories, it is imperative even today to address issues related to learning effectiveness of interactive animations and simulations. Further, over the years, research questions in the area have become very intense and focussed. A good number of researchers have contributed by steering future research direction in the area by stimulating the research community to ask right questions (Daniel, 2010; Plass, Homer, & Hayward, 2009).

Taking into consideration the educational value of animations and simulations and their penetration in science and technology education, we focus on interactive animations and simulations in this thesis and refer to these two forms while using the term 'Interactive Learning Environments'. The evolved nature of visualizations in ILEs demanded additional means for interacting dynamically with learning environments. This was primarily due to the fact that visualizations in ILEs have evolved over the years from a simple static diagram to various forms like; a video, an audio-video enabled animation and further evolving up to an interactive simulation in which a learner can manipulate variables to explore dynamicity presented in visualizations. As a result, different types of interaction features allowing learners to interact with learning environments have become an integral part of such ILEs. ILEs, as referred to in this thesis work, is a computer-based (technology supported) multimedia environment that allows interactions between a learner and learning material through its interaction features. In the following sub-section, we proceed further to define and elaborate on interactions and interactivity in ILEs.

2.2.1 Interactivity and Interaction in Interactive Learning Environments

The interactive nature of ILEs is highly influenced by different types of interaction features embedded in them. The interaction in ILEs is said to occur when learner feeds in or selects some input through interaction features and, in turn, the learning environment is able to respond to the learner's input. The quality of such interaction has been referred to as interactivity (Sedig & Liang, 2006). Interactivity refer to "*a reciprocal activity between a learner and visualization based learning system, in which the [re]action of the learner is dependent upon the [re]action of the system and vice versa*" (Domagk, Schwartz, & Plass, 2010). Interaction and interactivity are central terms used very often in the context of learning environment. It is worth noting here that, interactivity is not merely an interaction. Interaction refers to different kinds of actions initiated by learners to act upon or to interact with learning environment. Due to this to and fro interactions between a learner and learning environment, in a way, learner's behaviour depends on the action of the system, which in turn depends on the reaction of a learner, and so on (Domagk, Schwartz, & Plass, 2010) leading to the desired learning outcome in ILEs. Interactivity refers to the feel and quality of such actions- reactions. Thus, interactivity also reflects learners' level of cognitive engagement with ILE.

We refer to the hierarchical nature of learners' possible actions in ILEs as 'level of interaction'. Learners' interaction with the learning environment can be at a very basic level of 'observation' mode, and can further progress right up to an 'experimentation' mode giving learners the experience of inquiry based learning. There exist various ways of classifying these levels in learning environments, such as:

i) 'control behaviour → interactive behaviour' (Bétrancourt, 2005)
ii) 'control → response → manipulate →co-construct' (Tang, 2005)
iii) 'observation → controlling →creation' (Pahl, 2004)
iv) 'no interactivity → navigation within the presentation→ interaction with graphical model → interaction with simulation model→ immersion' (Chick, WeSánchez, Ferrin, & Morrice, 2003)

Depending on different levels of interaction in learning environments, El Saddik has proposed the following categories of interactive content presentation: still images; animated pictures; visualization with display adjustments such as play-stop-speed; visualization selection and arrangement capabilities such as repeat-rewind; visualization with changing input-zooming,-panning; visualization with interactive decision points, for example, changing data while running; and finally visualization generated by students. Another well-defined hierarchy of interaction levels proposed by Schulmeister (Schulmeister, 2003) was based on the work by El Saddik (El Saddik, 2001) and included five levels: Level I - viewing still pictures, level II- viewing video (including play, stop, speed, repeat, rewind etc.), level III - manipulating video display and viewing order (rotating, zooming, jumping to other parts of a video), level IV- manipulating video or visualization contents through data input, and level V- generating videos or visualizations through programs or data.

Irrespective of the number of interaction levels and nomenclature, one common point observed in the above classification schemes is that all these levels start from the lowest such as 'observing the content', subsequently reach to the highest level of interaction of, 'exploring or creating content in learning environments'. This relates to learners' roles in the learning process and explains how a learner transforms from a passive learner to an active learner. Learning theories like behaviourism, cognitivism and constructivism reflect this transformation (El Saddik, 2001). While lower interactivity implies a behaviourist character of a learner, higher interactivity leads to constructivist learning, such as discovery learning.

Animation and simulation are examples of learning environments exhibiting differing level of interaction. Animations are dynamic representations which very often visualize phenomenon changing over time/ space, and offer simple controls to learner such as starting, stopping, forwarding and rewinding the animation (Kombartzky & Ploetzner, 2007). In comparison to animations, in simulations learners are provided with higher degree of interaction and can manipulate parameters to explore and change the educational content of ILEs (Gogg & Mott, 1993; Towne, 1995).

The interaction features in animations and simulations serve various functions. The functions of interactions in animation are to: play/pause/ reset animation, to change pace of presentation, to change navigational sequence, to change representation format (for example, temporal / spatial aspect, dimension of the presentation, cuing affordances, zoom in - zoom out, rotation of the content, multiple representation type). In addition to these functions, interactions in simulations serve the purpose of selecting variable/s for manipulation, selecting number of variables to be manipulated, varying value/ range of the variable selected, keying-in value of variables to be manipulated etc. These features play a significant role by influencing learning from ILEs.

2.2.2 Learning benefits of Interactive Learning Environments

The dynamic representation of the content knowledge in ILEs makes them a very popular learning aid, especially in science and technology education. The ability of these interactive dynamic environments to visualize invisible or abstract phenomenon has proven them to be an effective educational aid (Buckley, 2000) as they facilitate depiction of unseen and offer means for showing phenomena that are too small, large, fast, or slow for the human eye. Such computer supported, interactive, visual representations of content is known to amplify cognition (Tory & Möller, 2002). ILEs are used in the teaching-learning of elementary level science concepts (Barak, Ashkar, & Dori, 2011), as well as complex concepts or processes in engineering and allied courses (Wang, Vaughnb, & Min Liu, 2011; Boucheix & Schneider, 2009; Lattu, Meisalob, & Tarhioc, 2003; de los Santos Vidal, Jameson, Iskander, Balcells, & Catten, 1996). Various research studies have confirmed interactive dynamic learning environments to be educationally effective as compared to non-interactive learning material (Wouters, 2007) and (Ayres, Marcus, Chan, & Qian, 2009, Schwan & Riempp, 2004). In a meta-analysis of instructional animation versus static pictures (Höffler & Leutner, 2007), instructional animations were found to be more effective as compared to static pictures.

Apart from facilitating a dynamic representation of content, a major success of ILEs lies in the manner in which it stimulates learners' engagement through its interactive features in interactive simulation. Interactive simulations not only offer control of information delivery to learners like as in animation, but also promote discovery learning through its constructivistic approach and exploratory nature. They encourage learners to infer through experimentation while characterizing the phenomenon being presented (de Jong & Joolingen, 1985). The exploration opportunities in simulation encourage learners to carry out 'what-if analysis' and 'scenario analysis' (Lahtinen, Ahoniemi, & Salo, 2007) making it more suitable for engineering education (Chaturvedi & Osman, 2006; Vidal et al., 1996; Aleksandrova & Nancheva, 2007; Mcmanus & Rebentisch, 2008; Engin, 2006).

Learning benefits from ILEs have been of varied nature. ILEs offer an enhancement in the instruction delivery in classroom setting, in a pre-laboratory set-up. It improves comprehension, and shortens learning time (Millard, 2000; Pinter, Radosav, & Cisar, 2010; Rutten et al., 2012). The content represented by means of visualization in an interactive manner develops a deeper and clearer understanding of a topic (Barak et al., 2011; Lengler & Eppler, 2007). With regard to affective domain, ILEs are known to stimulate students' interest, motivation and their engagement in the teaching-learning process (Barak et al., 2011; Rutten et al., 2012). While challenging learners' exploratory, interpretational, and sense-making abilities (Chen, 2004; Imhof, 2011; Jonassen, 2006; Liang & Sedig, 2010; Spence, 2007; Thomas & Cook, 2005), such interactive tools push learners to come up with their own investigative strategies, thus following a constructivist approach to build knowledge (Liang & Sedig, 2009).

2.2.3 Summary and Implications of research on ILEs

Section 2.2 has presented an overview of ILEs. In this thesis work, we limit the scope of ILEs to computer-based dynamic learning environments; interactive animations and simulations being the most widely used types of ILEs. Interactive animations and simulations became an integral part of learning and instruction, especially for science and engineering curricula (Rutten, 2012, Chaturvedi & Osman, 2006) and were accepted as an effective instructional aid.

Interaction and interactivity influence learning from ILEs. As learner moves up the ladder of interactions, the learning process becomes more learner-centric. As a consequence, the premise, "higher level of interactions delivers improved learning" became a well accepted view in the initial use of ILEs. Thus, early research in multimedia learning and in ILEs focussed on empirical studies that proved this view with statistical results. Many of the studies making this claim were primarily inclined towards media comparison; wherein supportive statistical evidences were offered to show better learning from the learning material with higher level of interaction over the learning material with lower level of interaction. However, despite the widespread belief that, 'more interactive nature of ILEs assist learners in achieving the desired learning outcome', this 'so called' well-accepted conviction was questioned by results reported from many research studies. This mixed nature of results further initiated a search for more systematic approach to design ILEs. It changed the focus of research and contributed to the formation of more intense and focussed research questions in the future for investigating conditions to ensure effective learning from ILEs. In the next sub-section, we have looked into the conflicting nature of learning impact of ILEs.

2.3 Learning impact of Interactive Learning Environments

Use of multimedia in ILE for learning and instructions has been around for several decades. Before we start reporting and summarizing the relevant work, in the following paragraphs we take overview of the work.

In case of multimedia learning, as mentioned by Kalyuga (Managing Cognitive Load in Adaptive Multimedia Learning, 2008), the research focussed on '*search for an effect'*, *'search for design principles'*, and *'search for boundary conditions'*. Considering overview of the research published in the last decade related to ILEs and learning associated with them, we are also tempted to draw a parallel between multimedia learning phases and ILE learning impact in the form of research streams.

We consider three streams covering research studies related to: I) use of higher level of interactivity to improve learning in ILEs II) failure of interactivity in ensuring desired learning in ILEs, and III) conditional nature of learning and conditions to ensure desired learning from ILEs. The following sections present the relevant literature review and research findings in a stream-wise manner.

2.3.1 Research Stream-I of ILE learning: Establishing learning potential of ILEs

With the onset of animations and simulations in instruction and learning, it was hypothesized that interactive learning environments like animations and simulations would lead to superior learning when compared with their traditional predecessors i.e. non-interactive learning environment like static representations. This was especially due to the fact that animations and simulations could depict dynamic representations of phenomenon to learners, whereas a learner had to mentally assume such changes while learning from conventional static representations. In this subsection, as research stream-I, we present review of studies that confirmed such a learning potential of ILEs.

While providing evidence for high potential of animations in educational setting, (Bétrancourt, Dillenbourg, & Clavien, 2008) showed that animation-facilitated learners performed better on transfer questions compared to learners who studied from successive static graphics. The experiment offered consistent results with that of Tversky et al. (Tversky, Bauer-Morrison & Betrancourt, 2002) confirming learning benefits of animation. Another experiment related to nautical knots showed that use of interactive dynamic videos led to more efficient forms of learning as compared to traditional, non-interactive means; control group needed substantially more time than users of the interactive videos to acquire the necessary skills (Schwan & Riempp, 2004). Yet another study (Ayres, Marcus, Chan, & Qian, 2009) conducted on animation–static comparisons proved that animations led to superior learning when compared with static diagrams while performing task related to construction of knots and puzzle rings. While Kombartzky and Ploetzner (Kombartzky & Ploetzner, 2007) reported that on an environmental related topic, the animation group outperformed significantly than the static pictures group while acquiring conceptual and procedural knowledge, the use of animated movies in science curriculum was found to be beneficial for students' explanation ability and their understanding of scientific concepts in a study reported by Barak, Ashkar and Dori (Barak, Ashkar, & Dori, 2011). Findings also indicated that theses students developed higher motivation to learn science, in terms of: self-efficacy, interest and enjoyment, connection to daily life, and importance to their future, compared to the control students. Overall, use of animation/ simulation led to improvement in learning in few more studies reported by (Liang, Parsons, & Wu, 2010; Wouters, 2007; Höffler & Leutner, 2007; Kühl, Scheiter, Gerjets, & Edelmann, 2011).

Apart from learning benefits, an ability of ILEs to interact with them and to control of the learning pace were seen as important motivational factors supporting the learning process (Urhahne & Harms, 2006). In a review paper on the experimental research of the past decade on learning effects of computer simulations in science education, the authors provided robust evidence related to the learning benefits of computer simulations (Rutten, Van Joolingen & Van der Veen, 2011).

To sum up, over last one and a half decade numerous studies from different domains have reported learning superiority of higher interactivity in ILEs and has proved its benefits over the non/ lower interactive ILEs. The approach of comparing learning effectiveness of two different media received a strong criticism at a later stage (Rey, 2011). Nevertheless, the contribution of these studies could not be neglected as they grabbed attention of research community towards the appropriate research issues.

2.3.2 Research Stream-II of ILE learning: Failure in confirming the learning potential of ILEs

While number of studies reported learning benefits from animations and simulations, there were appreciable number of studies that did not support these findings. In this sub-section, we report findings wherein learning effectiveness of interactive animations or simulations could not be confirmed unequivocally when compared with their lower interactive learning environments. In these studies, while the experimental group learning material was embedded with higher interaction features, the control group learning material was without such higher interaction features. As per the notion of 'higher interaction leading to higher learning', it was hypothesized that the learning material embedded with higher interaction features would offer better learning results. However, the same could not be confirmed from the study findings. Some studies even reported that static visualizations were superior as they did not find animations to be superior to static pictures (Lewalter, 2003; Mayer, Hegart, Mayer, & Campbell, 2005; Swezey, 1991). The research direction shifted and challenged the widespread assumption that dynamic visualizations (higher interaction) were intrinsically superior to static graphics (lower interaction) (Lowe, 2003). Below is the summary of some such results reporting failure of interactivity in ensuring desired learning in ILEs as a form of research stream II.

As reported by Kriz & Hegarty (Kriz & Hegarty, 2007), experiments 1–3 examined whether adding interactivity and signalling to an animation could benefit learners in developing a mental model of a mechanical system. Although learners utilized interactive controls and signalling devices, their comprehension of the system was no better than that of learners who saw animations without these design features. Furthermore, the majority of participants developed a mental model of the system that was incorrect and inconsistent with information displayed in the animation. Through these results the authors highlighted the fact that dynamic visualization of content and interactivity need not necessarily lead to better learning and further cautioned about the complex interplay between various aspects of learning process in animations and ILEs. In a study about fish locomotion principles, the effects of dynamic and static visualizations were investigated. No differences were observable between the dynamic and the static condition concerning any of the learning outcome measures (Kühl, Scheiter, Gerjets, & Gemballa, 2011).

The use of static images was found to be better for supporting learning of procedural and conceptual knowledge rather than the use of an animated structure (Vogel-walcutt, Gebrim, & Nicholson, 2010). The authors replicated the past work in the context of human systems. Although the earlier work had led to more efficient knowledge acquisition, but when the same processes were applied in the context of understanding of human systems, it could not deliver the desired results.

In a study by Lowe (Lowe, 2003), animation group subjects used a dynamic depiction of weather map changes to help them predict the future pattern of meteorological markings on a given map. The study reported mixed results. Although useful information was extracted from animation, its potential for helping learners construct higher-quality mental models was found to be limited. Authors further suggested that merely providing an accurate animated depiction of the to-be-learnt material might not be sufficient to produce the coherent and comprehensive knowledge structures required for learners to build high-quality mental models of dynamic content, in spite of the interaction and extensive user control offered. This undoubtedly challenged the simplistic assumption of dynamic content to be intrinsically superior to static presentation. The findings further put forward the view that if animations simply display processes without providing further instructional enrichment, their educational potential may be compromised. A review paper by (Tversky, Morrison, & Betrancourt, 2002) has analyzed in detail the reason why dynamic representations like animations might fail to establish the advantage of being a better representational format for representing change over time than static graphics. As reported therein, in many cases animations had no learning advantages over static pictures, and if they had, it was due to some additional information.

Even, studies on how computer simulation improves learning performance have produced confusing results. In spite of these high expectations, some studies (Leutner, 1993;

Mayer, 2004; Swaak & de Jong, 2001) showed that a general conclusion could not be made about the effectiveness of simulations on learning. A meta-analysis by Höffler and Leutner (Höffler & Leutner, 2007) on the other hand, revealed a medium-sized overall advantage of dynamic over static visualizations. This is why some authors have suggested taking a closer look at the conditions under which dynamic visualizations might be best suited for instructional purposes (Bétrancourt, 2005; Schnotz & Lowe, 2008).

To sum up, while there are a number of studies favouring use of animations/ simulations; there also exist a sufficient number of studies unable to prove learning effectiveness of ILEs in a simplistic manner. Higher level of interaction in ILEs could not always deliver better learning when compared to lower level of interaction. This has been a thought-provoking observation. These findings led to the third stream of research in ILE learning. The consequence of these findings have been a research stream that initiated investigative efforts to find out what in ILEs can make them deliver learning benefits. Thus, this third stream of ILE learning discussed in the next section leads to the research problem area. We report and discuss about this in the following section.

2.3.3 Research Stream-III of ILE learning: Conditional Learning in ILEs

The failure or limitation of ILEs in delivering their learning benefits prompted researchers to revise design strategies related to certain conditions within learning environments. The learning effectiveness of ILEs is governed by many conditions such as; interface design, features provided to interact with the learning environment, pedagogical strategies, learner characteristics etc. The empirical studies that explored these conditions with an objective to improve educational effectiveness of learning environments constituting the research stream-III are reported here.

Overall these studies suggested that in spite of the presence of a given level of interactivity in ILEs, the expected learning could happen only due to the presence of appropriate conditions. This is what we refer to as the conditional nature of the results which demonstrated how such conditions assisted the interactive nature of ILEs in meeting the expected learning outcome. While reporting the conditional studies, we classify them on the basis of their functionalities of features such as visual design features, pace control features, level of interaction, instructional strategy features.

Visual design features in ILEs:

While representing the content of the matter to be learnt, interactive animations and simulations make use of various visual aspects to support learners in the learning process. Following few paragraphs of this subsection report some studies, wherein different types of visual aspects were added to improve learning from ILEs. The basic level of interaction was augmented with these additional visual features of ILEs. The details of the said studies follow.

In a study to investigate whether animations were more effective than static graphics to promote learning on a topic on rock cycle, the participant studied from static graphics with visual cues, static graphics without visual cues, animations with visual cues, and animations without visual cues (Lin & Atkinson, 2011). Participants who studied from animations and with visual cues learnt better, in significantly less time and also displayed more instructional efficiency than their uncured peers. This research finding, thus, could prove the learning effectiveness of animation only when it was supported by attention guiding techniques in the form of visual cues.

In a study on piano mechanism, the authors evaluated effectiveness of animations cuing techniques with no cues (Boucheix, Lowe, Putri, & Groff, 2013). While the learners were assessed for mental model quality and knowledge of the mechanism's dynamics, the participants in animation with new form of cueing conditions were superior to those in uncued animation condition. A study (de Koning, Tabbers, Rikers, & Paas, 2010) assessed learning efficiency of the intervention using cued retrospective reporting and the quality of the constructed representation. The findings confirmed that cues could guide attention to regions containing task-relevant information. The findings from the study by Fischer and Schwan (Fischer & Schwan, 2010) were in favour of temporal scaling instead of attention guidance through signalling cues. All these studies conveyed how visual design features influenced learning outcome in ILEs in addition to their basic interactive nature.

Apart from visual cuing, other visual features such as presentation format, spatial arrangement, spatial proximity, use of labels or icons, visual design of interface have also been reported as conditions affecting learning from ILEs in addition to their interactive nature. One such study showed that processing integrated text and animation format required less mental effort than the separated format, and that the performance of the students in the group with integrated presentation format group was higher than that of students in the group with separated presentation format (Kablan & Erden, 2008). In yet another study, students were not able to make use of the dynamicity in visualizations and the results advocated the need of pedagogical measures in the form of iconic representations and dynamic stamp diagrams to successfully make use of dynamic visualizations (Ploetzner, Lippitsch, Galmbacher, Heuer, & Scherrer, 2009). The study on high school chemistry knowledge (Imhof, Scheiter, & Gerjets, 2011) examined the relative effectiveness of dynamic visualizations, compared to sequentially and simultaneously presented static visualizations. Although dynamic conditions outperformed static-sequential ones, but could not outperform the static-simultaneous conditions. Results confirmed that the superiority of dynamic visualizations compared to static visualizations was dependent on sequentiality of presentation formats used as control conditions.

The above mentioned studies used visual design features in various forms as moderators; needed to assist interactive nature of ILEs in meeting the expected learning outcome.

Learning pace control features in ILEs

One of the major challenges perceived in ILEs is managing the pace of content delivery to learner, as sometimes it could be overwhelming to learners (Lawless & Brown, 1997). Many studies, thus, looked upon learning pace control interactions as moderators in moderating ILE learning effectiveness. With inputs from well established multimedia principles and cognitive theories, researchers considered strategies like segmentation, chunking, giving pace control to learner as an affordance in the form of interactive features in addition to basic level of interaction already present in the learning environment to improve learning from ILEs.

The research work (Meyer, Rasch, & Schnotz, 2010) involved animations presented at different speeds to learn about the functioning of a four-stroke engine with user-controlled presentation speed. Results indicated that high presentation speeds accentuated global events (i.e. macro-events), whereas low speeds accentuated local events (i.e. micro-events). In a research study to teach primary school students the determinants of day and night (Hasler & Kersten, 2007), the influence of learner-controlled pacing in educational animation on instructional efficiency was investigated. The animations were either system-paced using a continuous animation, or learner-paced using discrete segments or learner paced using ‘stop’/ ‘play’ buttons. The two learner-paced groups showed higher test performance compared to the system-paced groups. This suggested that although all the three groups learnt from animations, the learning got moderated due to the pace control feature. In the research study by Moreno (Moreno, 2007), the group that studied from segmented video/animation outperformed non-segmented animations on all learning measures. It recommended segmenting instructional videos and animations as a moderator feature while learning from interactive dynamic learning environment. Yet another study by (Spanjers, Van Gog, Wouters, Van Merriënboer, Gog, Van, & Merriënboer, 2012) suggested that both pauses and cues played a role in improving learning in animations.

The above mentioned studies proposed control on information delivery or learning pace as a moderator whose presence was required to improve learning from interactive environment.

Embedded instructional strategy features in ILEs

Use of appropriate learning strategy embedded in ILEs in the form of some features has also been considered for supporting interactive nature of ILEs.

When students explored atomic interactions during hydrogen combustion using a dynamic visualization, the learners involved in an additional instructional strategy integrated more ideas about chemical reactions and made more precise interpretations than the control group. The treatment led to more productive explanations about ideas represented. In contrast, the control group was less successful in linking the visualization to underlying concepts and observable phenomena and wrote less detailed explanations (Zhang & Linn, 2011).

In a study on modelling of arterial blood flow in medical education, results showed successful use of simulation for learning complex concepts. The inclusion of pedagogical and psychological expertise was recommended by authors into the design and development of educational software (Holzinger, Kickmeierrust, Wassertheurer, & Hessinger, 2009). In another study that compared learning from animation with and without strategy, the results of the study revealed that in order to bring out learning benefits from animation, it needed support from the learning strategy (Kombartzky, Ploetzner, Schlag, & Metz, 2010). When two versions of a simulation program about respiratory chain were developed, differing only in the kind of tasks provided for instructional support, simulations with worked-out examples were shown to have positive effects on the learner's situational interest in the subject (Yaman, Nerdel, & Bayrhuber, 2008). All the above mentioned studies indicated the need for some additional features to work as moderators to assist learners while interacting with ILEs.

Other features in ILEs

In addition to the conditions already discussed, there are several others that have empirical support of acting as moderators in ILEs. Overall these condition suggested that in spite of the presence of a given level of interactivity in ILEs, the expected learning could happen only due to the presence of such appropriate conditions. We give a brief summary of such studies. The conditions include spatially integrated linked representations (Van der Meij & de Jong, 2006), integrated sequential static frames (Boucheix & Schneider, 2009), simulation in the form of manipulation (Schnotz & Rasch, 2005), video plus text condition (Arguel & Jamet, 2009), segmented-animation condition (Zamzuri, 2010), segmentation and learner control features (Chen, 2014), duration of interaction with visual representations (Liang, Parsons, & Wu, 2010), differing interaction level (Ruf & Ploetzner, 2014), static sequential/ dynamic visualizations (Imhof, Scheiter, Edelmann & Gerjets, 2011), nature of tasks (Rasch & Schnotz, 2009), symbolic and static versions of pictorial representations (Bodemer, Ploetzner, Feuerlein & Spada, 2004).

2.3.4 Summary and Implications of conditional learning impact of ILEs

Sections presented so far in this chapter form the background for understanding nature of the research problem area. The related work has been presented in a stream wise manner. Here, we present the synthesis of the related work and its subsequent implications.

Synthesizing related work from three research streams

At a fundamental level, learning potential of interactive animations and simulations could not be doubted. The first stream of ILE research highlighted this potential. It showed improvement in learning due to ILEs. Learning success of these tools could be attributed to the intrinsic potential that the learning environments possessed due to their inherent features.

Like any other newly arrived tool or technology; use of interactive animations and simulations as an instructional aid, created a wave of enthusiasm. However, many factors were not known and could not get evaluated during this phase. Various issues such as; influential features in ILEs, interplay among those features, their learning impact, knowledge about how learner uses these environments, cognitive processing of learners while learning from these environments, etc. were in the gestation stage during initial use of interactive animations and simulations. The so called 'unexpected' research findings reported as stream II of ILE learning could be attributed to the novice nature of the ILE field itself.

As more knowledge about these aspects of ILEs learning became available, there were some radical changes in the manner in which research community assessed the learning effectiveness of ILEs. The changes were manyfold: means of measuring learning effectiveness got refined; instruments became more precise; learning effectiveness became a multidimensional construct and learners' cognitive demands evolved as a major concern. Along with cognitive domain, the affective domain of learners and learner characteristics became central issues. All these changes affected the assessment of learning from ILEs. Interactive features of the environment were no longer considered as a sole influencing factor. An ILE was perceived as a learning environment wherein, basic interactive nature of ILE, along with interplay between its constituents and their functionalities were collectively responsible for its learning outcome. This has got highlighted from numerous empirical studies wherein the mere presence of interaction features in ILEs was unable to deliver the desired learning results. ILEs could show improvement in learning after a particular design feature/s of ILEs were redesigned or newly included in addition to the basic interactive nature of ILEs. Thus, such features are being referred to as moderators in ILEs as they exhibit the potential to moderate learning from ILEs. The knowledge base of relevant learning theories, knowledge about how people learn were utilized in redesigning these moderators to obtained conditional learning results. Stream III of ILE learning research reported such studies. The studies reviewed therein have reported how learning from ILEs got affected or rather got moderated due to the absence/ presence/ revision of interactions in animations and simulations such as visual design, cuing, presentation format, information control. In true sense, these interaction features play a role of 'moderator' in ILEs to make it deliver their learning benefits.

In addition to empirical studies, researchers have suggested the need to explore research space more systematically to identify what works and what does not work in the context of ILEs. While the need of systematic exploration was emphasised by Carney and Levin in different context (Carney & Levin, 2002), it is also applicable for ILEs. The authors recommended that the research questions need to be more divergent such as “whys,” *“whens,”* and “*for whoms”* in addition to *"whethers”* and *“how muchs.”* In another article, Daniel discussed about the need for apt research theme for multimedia learning. The author cautioned that comparing different kinds of presentation modes seems to be an inappropriate research approach and would not lead to general conclusions. He further recommended that 'elaborating, extending or contrasting theories of multimedia learning, testing design principles or investigating moderator' are the correct future directions to be taken up (Daniel, 2010).

Major implication from the reported literature here is that the focus of measuring effectiveness of learning should not be limited to media comparison and that it needs to get deeper. Also, an intense analysis of 'what makes learning happen in the presence of interactivity in ILEs?' is vital for designing educationally effective learning environments.

Refining the research issue

It is worth observing at this point that majority of the empirical studies have focussed their attention on improvising the visual design features and pace control interactions of ILEs to improve learning. Multimedia principles and Cognitive Load Theory of Multimedia learning offer guidelines in this direction for designing support for learners while learning from ILEs. However, another powerful interaction in ILEs is variable manipulation interaction. This interaction is important especially for simulations, wherein learners are expected to explore the learning environment using these interactions. There appears to be insufficient mention and guidance from the research space in terms of how to aptly design interactivity that facilitates exploratory nature of ILEs and moderates learning from ILEs. We will discuss in details about this issue in Chapter 3.

2.4 Associated Research issue: Role of Cognitive Processing of learners in learning from ILEs

Another aspect that needs attention while dealing with learning from ILEs is the cognitive processing of learners. Cognitive theories play a crucial role in the discussion of ILEs. Cognitive scientists have tried to understand learner interactions with ILEs from cognitive perspective. Within the cognitive perspective, the Cognitive Load Theory (CLT) claims that working memory includes independent auditory and visual working memories that have a limited capacity (Sweller & Chandler, 1994). The other viewpoints include contemporary theories of distributed and embodied cognition (Glenberg et al., 2013), that postulate external representations to play more roles than merely decreasing cognitive load. CLT is the most widely used viewpoint. We focus on CLT to understand learners' interactions with ILEs.

Cognitive Load Theory recognizes the concept of cognitive load as a crucial factor in the learning of complex cognitive tasks. In fact, the control of cognitive load to attain transfer can be considered as the essence of the theory. The Cognitive load theory (Sweller, 1988; Sweller & Chandler, 1994) provides guidelines for the design of effective instructions. The theory builds upon an information processing view of cognition, defining long-term and working memory as the main structures of the human cognitive architecture (Sweller, 2004; Sweller, van Merrienboer, & Paas, 1998). CLT incorporates specific claims concerning the role of cognitive load within an instructional context. That is, cognitive load is not simply considered as a by-product of the learning process, but as the major factor that determines the success of an instructional intervention. Learning is hindered when cognitive overload occurs and working memory capacity is exceeded (de Jong, 2010).

2.4.1 Need to consider Cognitive Load Theory while assessing learning impact of ILEs

Learning occurs when new information is incorporated into schemas, which are stored in the long-term memory. First, however, the information needs to be processed in working memory, which has very limited capacity (Miller, 1956). CLT is concerned with identifying instructional formats that are the most successful in overcoming these inherent working memory limitations (Sweller et al., 1998; van Merrienboer & Sweller, 2005).

Since its conception nearly two decades ago, CLT has been recognized by many educational researchers as a useful framework for exploring the effectiveness of various instructional formats (Sweller et al., 1998; van Merrienboer & Sweller, 2005; de Westelinck, Valcke, de Craene, & Kirschner, 2005; Kester, Lehnen, Van Gerven, & Kirschner, 2006; Salden, Paas, & van Merrie¨nboer, 2006). The widespread use of CLT as a basis for experimental studies has aided the theory's validation and allowed new insights to be generated. Today, CLT provides a rich and multifaceted description of the interplay occurring between instruction and learner during the learning process. The theory is a source of valuable guidance in the development of effective instructional designs. However, to follow the CLT principles in designing of ILEs is a challenging task due to the increasing complexity of ILEs.

2.4.2 Cognitive load in Interactive Learning Environments

The basic idea of cognitive load theory is that cognitive capacity in working memory is limited; so that if a learning task requires too much capacity, learning will be hampered. The recommended remedy is to design instructional systems that optimize the use of working memory capacity and avoid cognitive overload.

DeLeeuw and Mayer (DeLeeuw & Mayer, 2008) theorize that there are three types of cognitive processing (essential, extraneous, and generative) and place them in the *triarchic model of cognitive load*. Mayer proposed this model for organizing framework for the cognitive theory of multimedia learning and stated that a major goal of multimedia learning and instruction is to *"manage essential processing, reduce extraneous processing and foster generative processing"* (Mayer, 2009). Intrinsic cognitive load occurs during the interaction between the nature of the material being learnt and the expertise of the learner. The second type, extraneous cognitive load, is caused by factors that aren't central to the material to be learnt, such as presentation methods or activities that split attention between multiple sources of information, and these should be minimized as much as possible. The third type of cognitive load, germane cognitive load enhances learning and results in task resources being devoted to schema acquisition and automation. Intrinsic cognitive load cannot be manipulated, but extraneous and germane cognitive loads can be manipulated.

For many years, research on cognitive load theory focused on instructional design intended to decrease extraneous cognitive load. More recently, some studies also focus on increasing germane cognitive load. These studies aim at further improving instructional design aspects in a way that supports the use of free working memory capacity during learning (Kirschner, 2002; Sweller et al., 1998; van Merrie¨nboer, Schuurman, de Croock, & Paas, 2002; Bodemer, Ploetzner, Feuerlein, & Spada, 2004).

2.5 Review of research in Signals and Systems Education

We digress briefly to review research in Signals and Systems education as this forms our research context. The research motivation and the research context has been presented in Chapter 1.

The thesis work has been carried out in the context of a course on Signals and Systems in Electrical Engineering. The course on Signals and Systems (S&S) is generally taught in the second /third year of engineering. It is an introduction to analog and digital signal processing It facilitates understanding of core concepts from the field of Communication and Signal Processing. It forms an integral part of Electrical engineering and allied programs as it covers many diverse areas, including video signal processing, communications, speech processing, image processing, defence electronics, consumer electronics, and consumer products. The challenge of dealing with the abstract nature of the course, its application in many streams of engineering and its positioning as a pre-requisite for many advanced courses have motivated us to consider this course for this research work.

The Signals and Systems education research literature dates back to 1992; but the most active period has been 2001 onwards. Numerous ILEs in the form of Java applets, MATLAB/Simulink® models, and LabVIEW models are available and are frequently used as a learning aid (Guan, Zhang, & Zheng, 2009; Kehtarnavaz, Loizou, & Rahman, 2008). Various resources containing interactive animations and simulations such as SYSTOOL, SSUM, J-DSP Tutor, and 'Interactive learning resources for Signal, Systems and Controls' (Crutchfield & Rugh, 1997; Rabenstein, 2002; Shaffer, Hamaker, & Picone, 1998; Spanias, Chilumula,& Huang, 2006; Sturm & Gibson, 2005) have been recommended for learning of Signals and Systems. The need to visualize abstract concepts, to understand multiple representation forms of these concepts, and to apply multiple computational steps (Nelson, Hjalmarson, Wage, & Buck, 2010) are some of the reasons that have made interactive simulations prevalent in the Signals and Systems teaching community. Work on Signals and

Systems Concept Inventory (SSCI) (Wage, Buck, Wright, & Welch, 2005) and the work reported in (Hiebert & Lefevre, 1986) have highlighted the necessity to focus on conceptual and procedural knowledge as well as on their co-existence. While assessing learning effectiveness of ILE in the context of Signals and Systems, we focus on conceptual and procedural knowledge types.

This research work, thus, attempts to cater to a broad level research issue in the context of Signals and Systems while assessing attainment of conceptual and procedural knowledge types.

2.6 Synthesizing the related work: Emergence of Research Question

Figure 2.1 shows an overview of the related work. With this backdrop, various issues such as the conditional nature of learning impact of ILEs, overall role of instructional design in the success of learning environment and strong linkage between learners' cognitive processing and instructional design principles advocate the need to analyze the interplay between these issues. Learning from ILEs is no longer a one-dimensional notion, but has emerged as a multi-dimensional construct.

In the backdrop of mixed and conditional nature of the results about ILE learning, we begin by asking a very fundamental question. Our broad level research question is "Under what conditions ILE leads to effective learning?"

The reviewed literature has highlighted that the basic interactive nature of ILEs, on its own, was not able to offer consistent assurance of the learning effectiveness from ILEs. We reproduce and paraphrase definitions of interaction and interactivity here to refine and position the research questions further.

"Interactivity is not merely an interaction. While interaction refers to various kinds of actions initiated by learner to interact with the different visualization features, interactivity refers to feel and quality of learner's actions which is also an indication of learner's engagement with the content of ILE. While lower interactivity implies a behaviourist character of a learner, higher interactivity leads to constructivist learning".

Now, looking at these definitions through the lenses of mixed results of ILEs, it appears that ultimately what matters is not the presence and type of interactions, but the quality of interactions and their contribution in creating learning-conducive learning environment. Thus, it is this quality of interactions, i.e. interactivity in ILEs, that is responsible for the learning success of ILEs. It will not be incorrect to deduce that interactivity, as a notion, has the potential either to unleash or to hold back learning effectiveness in ILEs. A possible implication of this deduction will be:- poorly designed interaction features, even at a higher level of interaction will not allow the basic interactive nature of ILEs to deliver their learning benefits. Whereas, an apt design of interactions will manifest itself into a quality interactive learning environment, even at a lower level of interaction.

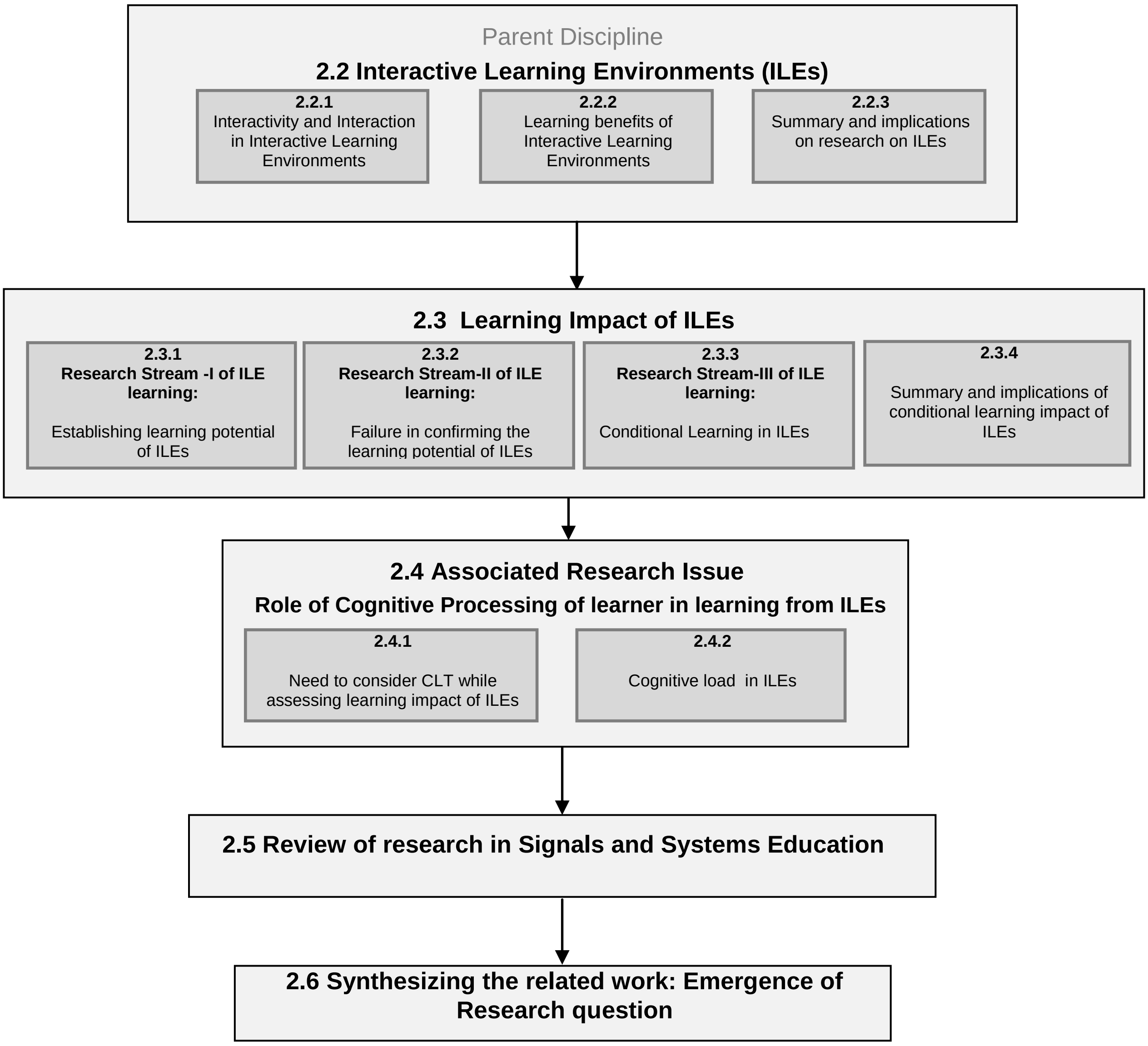


Figure 2.1. Overview of the related work

This statement definitely calls for more rigorous validation. Against this backdrop, we step back to ask a very fundamental question pertaining to the contribution of level of interaction in ILEs. We proceed to investigate,

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

and take this up as our first research question.

Further, it appears from the literature that effective learning from ILEs can be attributed to the logical mapping between learner's learning requirements and learning environment's abilities in fulfilling these requirements through its interactive design features. The key to use interactivity effectively in ILEs would be the apt designing of interactive features so as to meet the cognitive requirements of learners. Without this, ILEs may merely remain a fascinating learning tool, without being able to offer its full potential as learning aid. It appears that the assistance needed to the inherent interactive nature of ILEs needs to come from the designing of apt interactive features. It can be hypothesized that such aptly designed features will be able to unleash the learning potential of interactivity in ILEs. Taking into consideration the cognitive support needed to learners to meet their learning demands, it will be worth analyzing the contribution of such aptly designed features to the improvement of learning in ILEs and the extent to which these features would be able to offer the expected cognitive support to learners. However, we take this up for discussion in Chapter 3.

In order to identify the reasons for improving learning from ILEs and to offer means to improve the same, analyzing ILEs would be the next logical step. Generally, ILEs consist of three components i) an animated/ simulated model to adequately represent the domain or issue on hand, ii) a user interface that allows interactions with model/ content being depicted/ presented and (iii) a human facilitator or an instructor for briefing and debriefing sessions (Quadrat-ullah, 2010). Considering these three as major building blocks of ILEs, the possible solution approach should involve a particular or all of these building blocks. We take this up as a first step for framing the research and eventually for moving towards the solution approach. We discuss this in the next chapter of the thesis and wish to refine the research questions based on this discussion.

3. Chapter 3

Research Framework: Identifying Interactivity Enriching Features (IEFs)

Chapter 2 of this thesis presented the related work and pointed towards the need to investigate the research issue of "Under what conditions ILE leads to effective learning?" To address this question, we first explore how learning may happen when a student interacts with an ILE. More specifically, how do various components of the ILE relate to each other and contribute to the process of learning. To further analyze the possible solution approaches we carefully looked at the three components of ILEs (Quadrat-ullah, 2010); i) an animated or simulated model of the content to adequately represent the domain (i.e. dynamic depiction of the content), ii) a user interface that allows interactions with the dynamic content being presented, and iii) a human facilitator or an instructor for briefing and debriefing sessions. Additionally, we also consider the characteristics of the learners in this process.

We take this thread forward and first try to list various possible different directions the solution space can take to address the research issue. An ILE can be looked at as a system, designed to deliver the expected learning outcome. Thus, to address the issue of unsatisfactory learning outcome from ILE, we take up the solution approach that examines & analyzes the role of various components of ILEs and gives recommendations for their re-designing as needed. As presented in Figure 3.1, the components considered for the solution approach are; visual design, user interface interactions, human facilitator, learners' characteristics, domain and learning settings. While the list may not be exhaustive, it's quite indicative of components of ILEs worth considering as possible solution approaches. While visual design (for dynamic depiction of the content), user interface interactions and instructor directly map to the component of ILEs; the other two i.e. learners' characteristics, and domain-learning settings are also considered as influencing components in ILEs. The next step is to analyse each of these components to determine which ones are appropriate for further evaluation as a solution approach for our problem and context. The following section presents analysis of the possible solution approaches one-by-one and then focuses on the selected solution approach to address the main research issue.

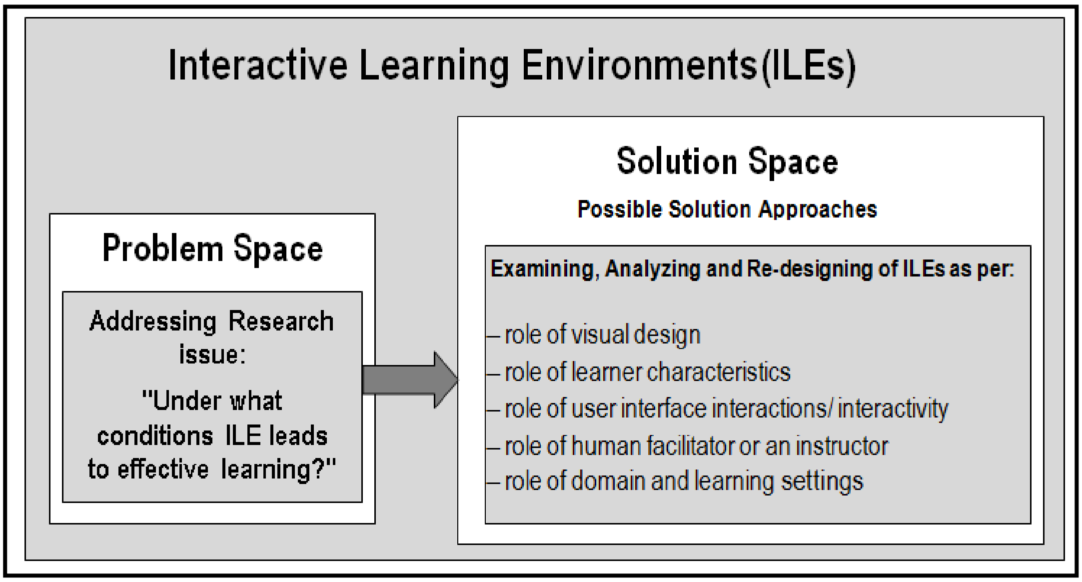


Figure 3.1. Problem space and solution space of the thesis work

3.1 Analyzing and selecting the solution approach

Role of Visual design in animation/ dynamic visualization of the content:

One of the major strengths of ILEs lie in their ability to depict the concept/ phenomenon dynamically in an animated form. The evidence based principles of 'Science of learning' and 'Science of Instructions' guide the visual design aspect of ILEs. The apt operationalization of these principles while creating ILEs has an important role to play in determining the learning success of ILEs. The ILE research space has numerous studies supporting the need for such science-based visual design recommendations for making learners learn the dynamic depiction of content effectively. The research findings highlight the need for instructional design strategies based on such evidence-based principles. They also caution about the possible negative impact on learning in the absence of such visual design strategies. Thus, examining and critically analyzing the extent to which visual design strategies are being followed and their impact on learning in the given ILE is one of the possible solution approaches. It is expected that the interactive nature of ILEs will be able to deliver its learning potential only if the content is presented in accordance with the relevant visual design principles (Plass, Homer, & Hayward, 2009). In short, this solution approach needs to ensure that the dynamic depiction of the content itself does not pose as a confounding variable in the learning process of ILEs.

Role of user interface interactions/interactivity in ILEs:

As reported in Chapter 2 of this thesis, some of the research studies have indicated that mere presence of interactivity in ILEs could not improve learning. There are research-based evidences that learning from higher level of interaction in ILEs was found to be at par with the learning from lower level of interactions. Thus, it appears that the presence of higher interactivity, unless perceived useful by learners, by itself would not result in improved learning. This point opens up discussion related to 'what kind of user interface interactions would be perceived as '*useful'* by learners?' and 'what exactly would be learning demands that learners would be looking for to be met through the construct *'useful'* interactions?' This suggests the need to examine and analyze 'what role interactivity plays in ILEs for effective learning?' and 'how the relevant interaction features need to be designed/re-designed to ensure the expected learning outcome?' This forms another important thread that could be taken up to address the research issue of the thesis.

Role of human facilitator or an instructor:

Although animations and simulations are known for their learning benefits, their learning effectiveness is also dependent on the instructional method used (Bratina et.al, 2002). Empirical studies show that role of instructor by creating use of constructivist (McConnell,

1996) strategies, enhances the interactive nature of such ILEs. Thus, examining 'how a human intervention in the form of an instructor or a facilitator influences the interactivity in ILEs in determining the learning outcome?', is yet another possible solution approach to be explored.

Role of learner characteristics:

A learner is an important stake holder of ILEs. No wonder that the ILE research space has recognized the importance of critically examining and analyzing learners characteristics. As a result, 'the learning from ILE is effective for *whoms*?' has been one of the divergent research questions suggested to be taken up by researchers in the recent times (Daniel, 2010). Analyzing learner characteristics and designing ILEs matching to these learner characteristics by recognizing individual differences is one of the solution approaches to be considered for making interactivity deliver its learning potential in ILEs.

Role of domain and learning settings:

ILEs have penetrated as an instructional aid in education right from school level to professional level. The content being covered through ILEs also span across different knowledge types and variety of tasks. It is worth exploring how interactivity in ILEs behave while dealing with such diverse domains. Also, looking at the process of learning in ILEs through the lenses of evolving nature of learning science, may bring in more insight about the role of interactivity in effective learning from ILEs.

Finalizing the solution approach for the study:

After analyzing the above mentioned possible solution approaches and examining their suitability for the motivation and scope set for this thesis work, we finalized the solution approach related to role of user interface interactions and / interactivity in ILEs. Following few paragraphs describe why some of the solution approaches were eliminated for further consideration. Then follows the rationale for the shortlisted solution approach.

We eliminated the approach based on visual design. Use of research based recommendations for visual design instructional strategies is a well-established and prevalent practice in ILE creation. This is basically due to the volume and rigor of the work done in the past in formalizing visual design principles. These principles ensure that visual design aspects do not hinder the process of effective learning from ILEs. Thus, it was considered as an implicit assumption that the ILEs to be used as a part of the proposed research studies would be well-designed as per the recommended visual design and multimedia principles. The research context was set as self-learning mode. Thus, the approach assessing role of human instructor in ILE learning was found to be out of context. Considering the mandatory need to accommodate a diverse learner population and an inability to accommodate customized learning environments in a university affiliated educational set-up, the solution approach focusing on analyzing learners' characteristics was not taken up further. However, the thesis work and research studies were planned with assumptions that all the participants were equivalent in terms of training needed to learn from ILEs and the academic characteristics of learners were considered critically while creating equivalent groups. Due consideration to other characteristics of learners (such as personal, social, affective characteristics) and the role of instructor in influencing learning in ILEs may hold potential for further research.

One of the potential solution approaches considered was to examine & analyze the role of user interface interactions/ interactivity and to give recommendations for its re-designing as needed. All the potential approaches considered so far basically aim at offering the required learning support to learners while learning from ILEs; either internal or external to ILEs. The needed support may take various forms such as visual design features, embedded instructional strategy, human facilitation, learning-conducive interaction features. For this approach, analyzing the contribution of aptly designed interaction features to improve learning in ILEs and the extent to which such features would be able to offer the expected cognitive support to learners was considered as the nature of solution approach. We now revisit the discussion presented in section 2.6 of Chapter 2 regarding the need to redesign the interaction features of ILEs. The synthesis of the literature reviewed indicated that aptly designed features would be able to unleash the learning potential of interactivity in ILEs. In the absence of such apt interaction features, ILEs might remain merely a fascinating learning tool. This implied that the assistance required to the inherent interactive nature of ILEs needed to be offered by designing of apt interactive features. As this approach was also aligned with the motivation, context and scope of the thesis work, we were more inclined towards shortlisting this solution approach for further study. We also considered this as a promising and useful direction for further research as the literature review has highlighted the need for recommendations for interaction design features. Thus, we focus on the apt designing of interaction features in the given research context and learning domain as the selected solution approach.

Organization of the rest of the chapter

In this chapter, moving ahead with this solution approach, we first explore an ILE and its entities to know more about the process of learning from ILEs. Based on this, we then propose the concept of ***'Interactivity Enriching Features (IEFs)'*** that demonstrates how interactivity in ILEs can be enriched with the help of some additional interaction features. The ILEs embedded with these IEFs are being referred to as ***'Interactivity Enriched Learning Environment'***. The process of determining and designing IEFs will be presented in the following subsections. It also elaborates how the measures proposed for enriching interactivity in ILEs offer the required cognitive support to learners while achieving expected learning results.

3.2 Basic elemental blocks of Interactive Learning Environments

The central focus while understanding and analyzing learning impact of ILEs is on the **'Interactivity'** that exists between the **'Learner'** and the **'Interactive Learning Environment'** itself.

The learning process from an ILE is governed by the **'Learning Objectives'** set by an instructor and delivers the process output in the form of **'Learning Outcome'.** Learning outcome can be considered as an outcome of interactions that take place among entities of an ILE. Thus, important stake-holders of the learning process are: i) instructor who defines learning objectives, ii) instructional designer who designs the learning environment and iii) learners, who interact with an ILE through its interactive features. Figure 3.2 depicts these three stakeholders of ILE.

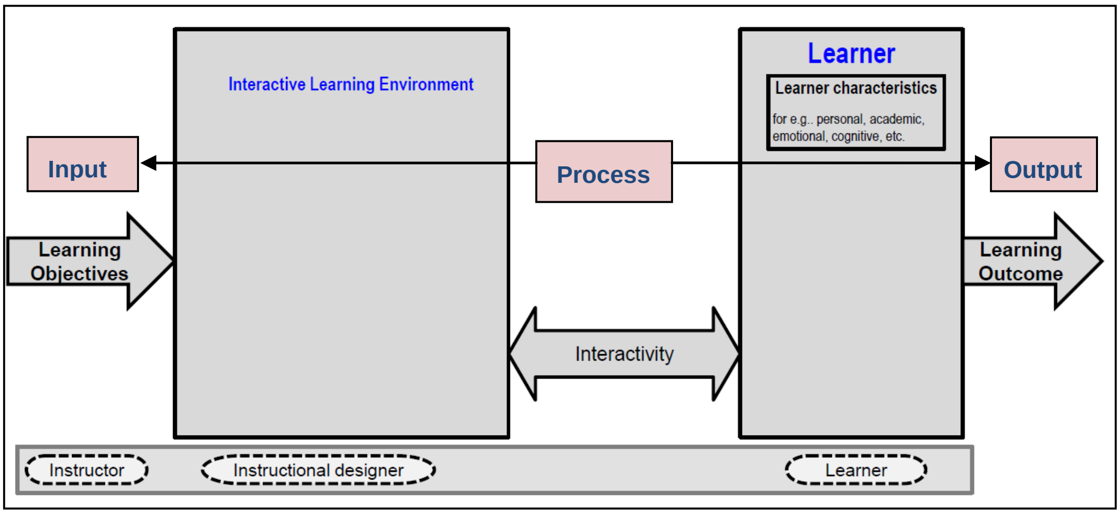


Figure 3.2. Learning process of Interactive Learning Environment and its basic stake-holders

In this thesis, we make following assumptions while analysing learning process in ILEs.

- Students learn from ILEs in self-learning mode. (Instructor support is not being considered as a variable).
- As a result, interactions considered are only those between ILEs and learners. Interactions between an instructor and a 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 well-established multimedia learning principles and are aligned with intended learning objectives.
- Learners have varying characteristics. However, as this research work has been carried out in the context of university affiliated institutions and considering the mandatory requirement of accommodating a diverse range of learners, customization of learning material as per learners is not being considered as variable of this research work. However, the research studies planned were conducted after ensuring equivalence of learners' groups.

3.3 Interaction features and their functionalities in Interactive Learning Environments

The learning process in ILEs is facilitated through interactions between learners and learning environment with the help of 'Interaction Features'. Interaction features are various affordances provided in ILEs so as to allow learners to interact with the learning environment. Based on the level of learner control offered in ILEs, two popular prevalent types of ILEs are; 'interactive animation' and 'interactive simulation'. Interactive animations are dynamic representations which depict changing phenomenon. They offer simple control to learners; such as starting, stopping, forwarding and rewinding the animation (Kombartzky, 2007). As compared to interactive animations, interactive simulations offer higher degree of interactions. They offer additional interactions for exploring the educational content through manipulation of parameters (Gogg & Mott, 1993; Towne, 1995).

The learning process in ILEs expects learners to interact with interaction features to perform various tasks. We reviewed literature to categorize these tasks. Irrespective of domain and content, some tasks are vital in animations and simulations. They include tasks that offer control over certain parameter such as pace, navigation, flow or format. Allowing learners to explore and manipulate educational content is also another vital task in ILEs. Based on the literature reviewed, we came up with following three categories of tasks in animation and simulations.

- **Control task:** Learners use appropriate interactions to control pace, flow, navigation of the content being presented. Sometimes learners also carry out tasks that control visual attention points. The basic purpose of this category task is to customize the pace of learning (Choo, 2005) by learners themselves.

- **Representation task:** Learners carry out representation task through appropriate interactions to view or vary multiple representations of the same educational content. The purpose of this task is basically to select appropriate representation that could meet learning requirement of the content (Reichert & Hartmann, 2004).

- **Manipulation task:** Learners use manipulation interactions to get an opportunity to learn by exploratory learning whereby they can manipulate the content itself. A well designed learning environment allows learners to be engaged in interactive exploration of the content leading to deeper understanding (Choo, 2005).

An interaction between a learner and an ILE is generally initiated to execute any one or more than one of the above mentioned three tasks. Learners select appropriate interactions for executing these tasks. For example, when a learner wants to control the pace of the learning material being presented, s/he will make use of the interaction feature of the ILE that offers control on the information delivery such as pause or stop buttons. Similarly, a learner who wishes to vary certain parameters related to the phenomenon being explored, s/he will make use of the interaction feature in the given ILE that would allow variable manipulation. Based on the above mentioned categories of tasks, we derive corresponding kinds of interactions such as: 'Information Delivery Interaction (IDI)', 'Representation Strategy Interaction (RSI)' and 'Content Manipulation Interaction (CMI)'.

1. **'Information Delivery Interaction (IDI)' for performing Control task:** Interaction features with functions like: to play/pause/ reset animation, to change pace of presentation, to change navigational sequence etc. offer learners opportunities to control how information of content should get delivered to learners. We, thus refer to these kind of interactions as **'Information Delivery Interaction (IDI)'**. The point to be noted here is that, this type of interaction does not have provision to change the educational content of the learning environment; it just controls the manner in which the pre-defined content will get delivered to learners.

2. **'Representation Strategy Interaction (RSI)' for performing Representation task**: These interaction features allow learners to observe the pre-defined educational content in different representation formats. For example, these interaction features allow learners to see zoomed portion of a figure, or to see either 2D or 3D model of the phenomenon, or to observe a particular object from different directions by rotating. We refer to this kind of interactions as '**Representation Strategy Interaction (RSI)'**. Even this interaction does not have provision to change the educational content of the learning environment; it just decides the type of representation in which the pre-defined content will be observed by learners.

3. **'Content Manipulation Interaction (CMI) for performing 'Manipulation task'**: With these interaction features, ILEs allow its educational content to get manipulated dynamically. These features offer different variables for manipulation. Manipulation of variables allow the educational content to get changed according to a range or values of

variables fed in by learners. Thus, by using the feature of variable manipulation learners can dynamically interact with the educational content of ILEs. We refer to this kind of interaction as '**Content Manipulation Interaction (CMI)'**. This type of interaction is different from the first two categories of interaction i.e. IDI and RSI. As compared to them, Content Manipulation Interactions give additional control to learners to manipulate the content in ILEs.

The above mentioned categorization of interactions in ILEs is useful in positioning interactive animation and interactive simulation under the umbrella of ILEs. In the preview of the above mentioned categorization of interactions in ILEs and definitions of interactive animation/ interactive simulation as reported in relevant literature; interactive animation can be considered as a subset of interactive simulation. Interactive animation is equipped with Information Delivery Interaction (IDI) and Representation Strategy Interaction (RSI). As compared to animation, interactive simulations are equipped with one more additional category of interactions i.e. Content Manipulation Interactions (CMI) in addition IDI and RSI.

We wish to make a note that the above mentioned categories were able to accommodate most of the tasks and corresponding interactions that generally take place in ILEs and the ones that have been reported in the relevant literature. However, any additional category, if needed can be added to this in the future to make the literature synthesis richer.

Considering these interaction features as integral components of ILE learning process; they can be positioned as entities within an ILE. Figure 3.3 shows representation of a typical ILE that includes these interaction features. Learners interact with these features through physical behavioural actions. This also leads to learners' cognitive interactions with ILEs. This cognitive interaction as a result of physical behavioural actions bring in the 'Interactivity' in an ILE (denoted by two directional arrow between a learner and an ILE).

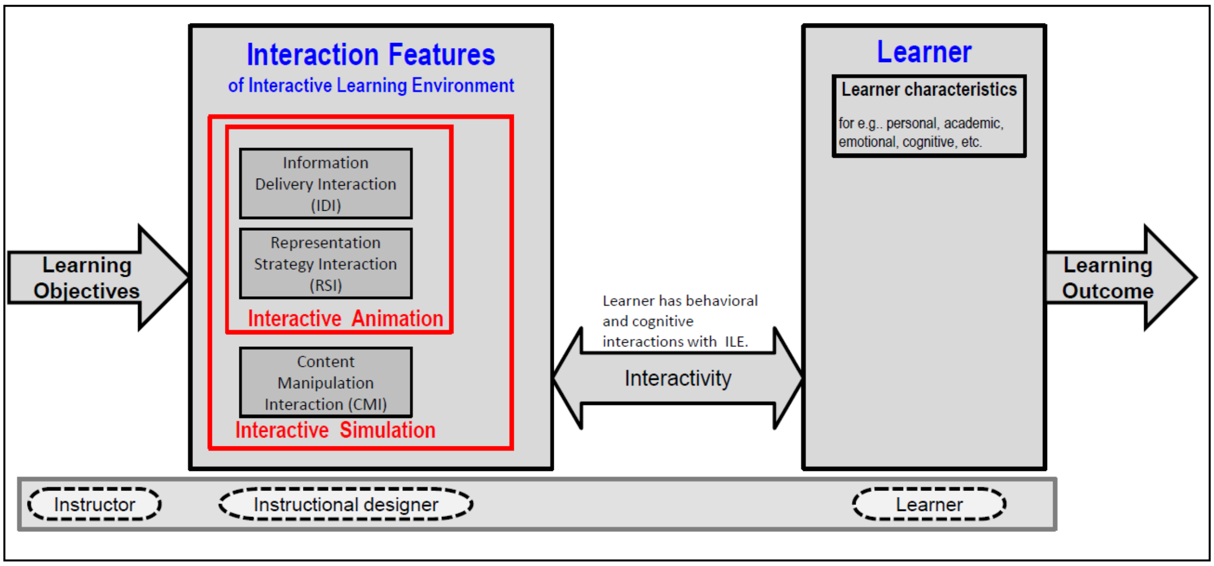


Figure 3.3. Categorization of interactions in an Interactive Learning Environment

Cognitive Processing in ILE Learning

Analysis of the learning process in ILEs is incomplete without considering cognitive processing and cognitive load aspect of learning. The Cognitive load theory recognizes the concept of cognitive load as a crucial factor in learning of complex cognitive tasks in multimedia environments.

DeLeeuw and Mayer (DeLeeuw & Mayer, 2008) theorize that there are three types of cognitive processing (essential, extraneous, and generative) and place them in the *triarchic model of cognitive load*. Mayer (Mayer, 2009) proposed this model for organizing the framework for the Cognitive Theory of Multimedia Learning and stated that a major goal of multimedia learning and instruction is to "*manage essential processing, reduce extraneous processing and foster generative processing*". Cognitive load is not simply considered as a by-product of the learning process, but as the major factor that determines the success of an instructional intervention. Intrinsic cognitive load occurs during the interaction between the nature of the material being learned and expertise of the learner. The second type, extraneous cognitive load, is caused by factors that aren't central to the material to be learned, such as presentation methods or activities that split attention between multiple sources of information, and these should be minimized as much as possible. The third type of cognitive load, germane cognitive load enhances learning and results in task resources being devoted to schema acquisition and automation; germane load is then the consequence of processing information that contributes to learning. The above mentioned three loads and their role in learning is shown in Figure 3.4.

The control of cognitive load is necessary for effective learning in learning environments (Sweller, 1988; Sweller & Chandler, 1994). The relevant theories emphasize on effective instructional design to achieve instructional control of cognitive load. Effective instructional design in ILEs focuses on apt designing of various interaction features as recommended by the relevant instructional design and multimedia principles.

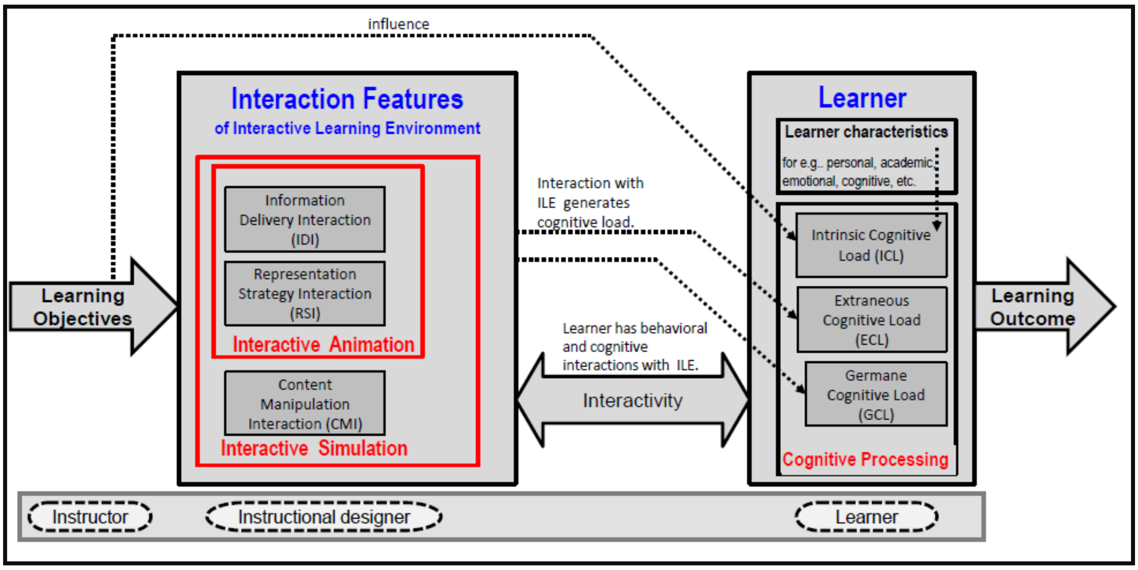


Figure 3.4. Cognitive processing in an Interactive Learning Environment

3.4 Proposing 'Interactivity Enriching Features (IEFs)'

A well-designed ILE offers sufficient affordances and learning support to learners to handle their learning requirements. The science of learning and instruction, a rich body of literature summarizing multimedia principles and results from number of empirical studies offer recommendations for creating educationally effective and meaningful interactions. (Plass, Homer, & Hayward, 2009). The main objective of these recommendations has been to offer guidelines for designing support to learners through meaningful interactions while learning from ILEs. As reported in Chapter 2 of this thesis, these recommendation reported in literature primarily fulfil design requirements for interactions for visual design, information delivery and representation interactions i.e. IDI and RSI.

Learners do need support in ILEs while exploring content using Content Manipulation Interactions. Absence of such support may hold back the learning potential of interactive nature of a simulation. However, there is a dearth of such recommendations for designing Content Manipulation Interactions needed in interactive simulations. It has also been reported that (Guzman, Dormido, & Berenguel, 2010) inappropriately designed content manipulation interactions and insufficient use of such affordances by users can be detrimental to the learning process. Interactive simulation, manipulated in just playful manner does not enable learners to derive full learning benefits from it and fails to achieve expected learning benefits. There have been very few attempts in this direction to offer the required support to learners through properly designed content manipulation interactions.

As reported in Chapter 2, there has been sufficient evidence from results and findings from empirical research studies; that merely providing higher level of interaction in ILEs cannot ensure learning benefits. Desirable learning benefits from ILEs at higher interaction level have been assured only with certain conditions (Hansen, 2002; Liang, 2006; Lin & Atkinson, 2011; Spanjers, Van Gog, Wouters, & Van Merri€enboer, 2012; Tversky, Morrison, & Betrancourt, 2002). This implies that a simulation need not necessarily offer better learning as compared to animation simply because it is designed with higher level of interaction. General impression about higher degree of learner control leading to higher learning gain is questionable and has been challenged in number of findings. Against this backdrop, the mixed results from empirical studies demanded the need for more research to explore, 'what influences learning from ILEs?' (Rey, 2011). The conditional nature of experiments results suggested that, not just the level of interaction, but some additional features must have been pivotal in assisting learners in deriving learning benefits of interactivity in ILEs.

The implications of the above observations are as follows: The fact that, *learning from ILEs has been conditional and the learning benefits were ensured only in the presence of additional conditions* possibly suggest that learners needed support for meaningful learning while dealing with interactive nature of ILEs. These additional features, in a way, augment interactivity in ILEs by offering the much needed cognitive support to learners. We wish to revisit the definitions of interactions and interactivity already cited in this thesis to bring more clarity about the issue.

"Interactivity is not merely an interaction. While interaction refers to various kinds of actions initiated by a learner to interact with the different visualization features, interactivity refers to feel and quality of the learner's action, which is also an indication of the learner's engagement with the content of ILE".

This suggests that learning from ILEs is influenced by quality of interactions. How successful such interactions are in providing required learning support to learners would govern learning outcome from ILEs. Thus, offering learning-conducive interaction features in ILEs can be looked upon as means to improve quality of interactions. Interactivity, being a quality indicator of interactions, such learning-conducive interaction features can enrich interactivity in ILEs. This takes us to the central idea of the solution approach; which would be to firstly determine such 'learning-conducive interactive features', then to design such features as per their attributes and then validate their learning effectiveness in ILEs. We propose to refer to such features as '***Interactivity Enriching Features (IEFs)'***. In the following paragraphs we further elaborate on the concept of IEFs, define the same formally and explain how it will lead to enrichment in ILEs.

We explain the notion of IEF in the following context. Figure 3.5 shows screenshot of an animation. It shows how learners can make use of 'pause' button to control pace of learning. Thus, interaction through this 'pause' button (Information Delivery Interaction) here offers the required cognitive support to learners by controlling the pace of information delivery. Another example can be considered on similar lines to demonstrate how RSI can also assist learners in the learning process. Overall, IDI and RSI interactions will be able to support learners by allowing them to either control pace of the content presentation and or by controlling representation format of the content presented.

While learning from interactive simulations, learners use one more type of interaction feature, which is Content Manipulation Interaction (CMI). With CMI, learners are able to explore the content in order to develop deeper understanding of the content being presented (Chaturvedi & Osman, 2006). Figure 3.6 shows a screenshot of a typical interactive simulation showing a radiation pattern of an antenna. The CMI in it will allow learners to change the educational content by manipulating different variables and will be able to plot a variety of radiation patterns on screen. The action of manipulating different variables will allow learners to further explore the notion of radiation pattern and comprehend interrelated concepts.

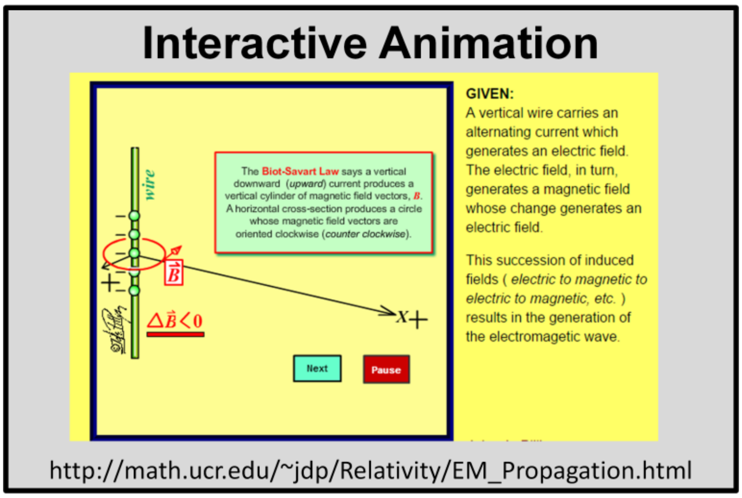


Figure 3.5. Screenshot of an animation with pace control button as cognitive support to learners

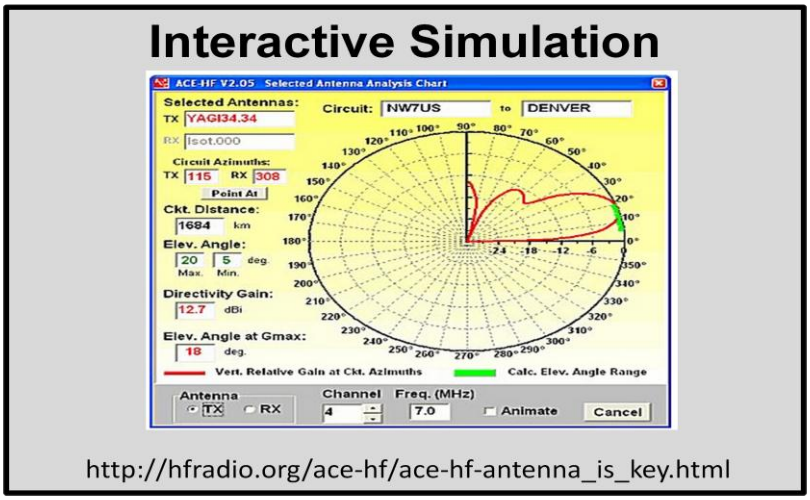


Figure 3.6. Screenshot of an interactive simulation showing features for Content Manipulation Interaction

The interaction level of simulation is higher compared to animation due to content manipulation interaction that allows variable manipulation. Based on this, possible reason for lower learning in simulations as compared to animation in spite of higher level of interaction could have its roots in insufficient learning support made available to learners while dealing with this higher level of interaction. While presence of the 'so-called' higher level interaction facilitates content exploration in ILEs, learners are devoid of any support that will make them use learning potential of this higher level interactions in their favour. Thus, we move ahead to make a claim that interactive nature in a simulation needs to offer learners the necessary learning support while using interaction that allows exploration of educational contents in ILEs. We intend to design this support in the form of '**Interactivity Enriching Features (IEFs)'.** The following section defines and characterizes IEFs.

Defining 'Interactivity Enriching Features (IEFs)'

Interactivity Enriching Features take form of add-on features added to the basic level of interactivity present in ILEs. As seen in Figure 3.7, IEFs are additional interaction features in ILEs. Learners carry out content manipulation interactions in ILEs through these IEFs. Since the presence of IEFs is expected to enrich interactivity in ILEs, we refer to ILEs embedded with IEFs as **'Interactivity Enriched Learning Environments (IELEs)'.**

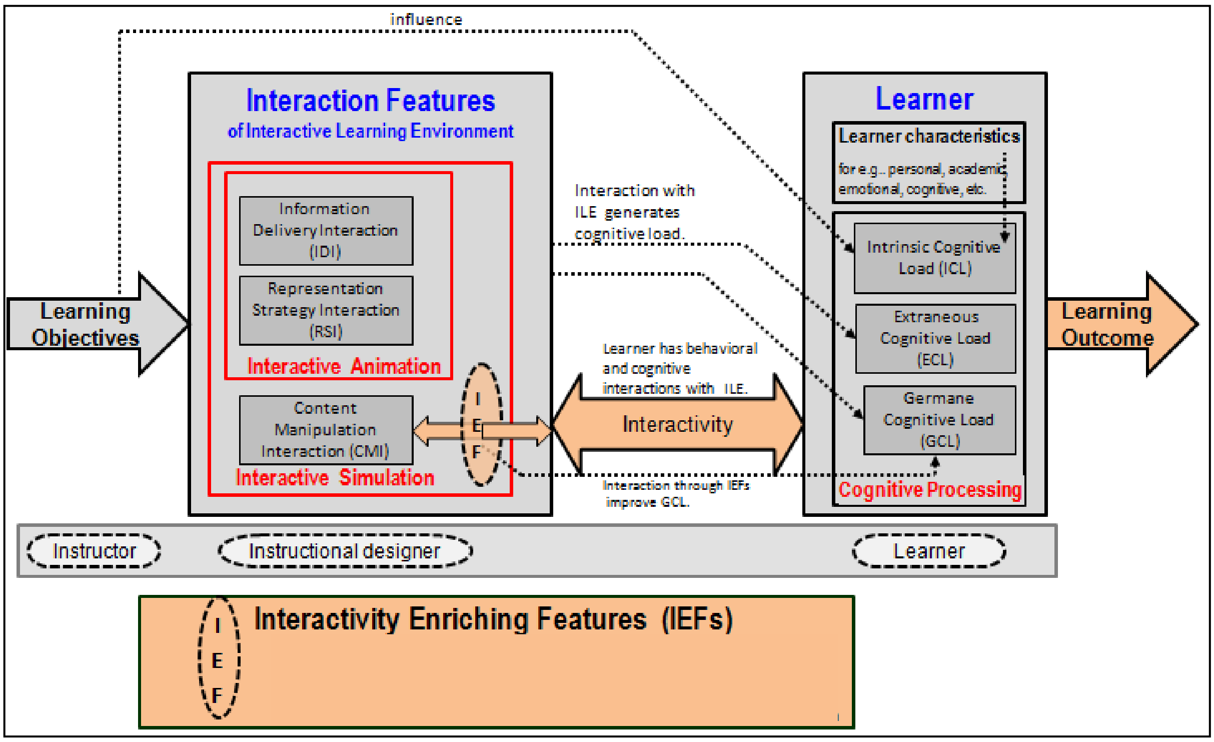


Figure 3.7. Embedding 'Interactivity Enriching Features' (IEFs) in an ILE

What is expected by 'enrichment' in interactive learning environments?

'Enrichment' in learning environments refers to an improvement in learning experience, that ultimately is transformed into improved learning outcome. This process of enrichment entails that learning environments are able to improve learning outcome by fulfilling learning demands of learners during interaction with it.

We refer to those interactions as *'meaningful interactions'*, which support learners' cognitive processing while interacting with ILEs and thus lead to accomplishment of the set learning objectives. It is worth noting that, while we categorize some interactions as meaningful interactions, it will not be incorrect to expect that learners also do experience some interactions as *'non-meaningful interactions'* while interacting with learning environments. Non-meaningful interactions could be those interactions which either do not help learners' cognitive processing, or may even may induce hindrance to learners' cognitive processing while interacting with ILEs. Such non-meaningful interactions may be neutral or even detrimental to the learning process of learners. For example, a variable manipulation in a simulation carried out in a playful manner is an interaction with the learning environment, but cannot qualify as meaningful interaction when it lacks *'goal-directed'* exploration (Page, Thorsteinsson, Lehtonen, & Niculescu, 2008; Guzman, Dormido, & Berenguel, 2010; (Yaman, Nerdel, & Bayrhuber, 2008). Such interactions qualify as non-meaningful interactions. In this backdrop, while designing ILEs for effective learning, it becomes necessary to design apt interactions. Thus, ensuring inclusion of meaningful interactions should be equally important as avoiding non-meaningful interactions. The interaction design strategy for achieving effective learning from ILEs needs to focus on this aspect. Thus, an enrichment in learning environments can be achieved by including meaningful interactions and by avoiding non-meaningful interactions.

Research on cognitive load theory has focused on instructional design intended to decrease extraneous cognitive load. This could be a way of excluding non-meaningful interactions in ILEs. Careful designing of learning environments by excluding such non-meaningful interactions helps learners by eliminating learning hindrances. Many of the multimedia principles are designed to ensure exclusion of such non-meaningful interactions to minimize the extraneous cognitive load. Along with this, instructional design attempts to improve meaningful interactions in learning environments are equally essential. Such meaningful interactions foster germane cognitive processing. Although, there have been a few attempts in designing meaningful interactions that would lead to improvement in the 'good' cognitive processing, still more efforts are required for offering the necessary additional support for learners to generate sufficient 'good' cognitive processing. Thus, it is important to note that fostering germane cognitive processing is also equally crucial for achieving effective learning. This can be achieved by including meaningful interactions. The IEFs are being seen as means of creating such meaningful interactions.

The above discussion and rationale behind IEFs help in identifying its expected attributes as follows.

- IEF is an interaction feature of learning environments.
- IEFs will be an add-on feature i.e. in addition to the basic interactive nature of learning environments.
- Learners should be able to carry out explicit behavioural i.e. physical interactions with learning environments using IEFs.
- Learners' interaction with IEFs should facilitate the learning process by offering the required cognitive support.

On the basis of these attributes, it is hypothesised that inclusion of IEFs in ILEs would lead to fostering of germane cognitive processing of learners. It will offer the required cognitive support to learners by increasing the germane cognitive load. In the following section, the process of designing IEFs and details of the proposed IEFs are given.

3.5 Determining Interactivity Enriching Features (IEFs) in this research study

IEF designing process in ILEs takes into account pedagogical requirements and learning demands on learners in the following manner. Content manipulation interactions in simulations allow learners to explore educational content on their own by manipulating different variables. This interaction feature is useful for fulfilling certain pedagogical requirements from domain; in fact it is essential for learning of certain domain topics. Thus, ILE designers use exploratory nature of interactive simulations for learning to happen through this process of exploration. However, this process of exploring simulation content by manipulating variables puts certain learning demands on learners. As a result, content manipulation interactions need to be designed in such a manner that, they would facilitate content exploration; and at the same time they would also try to assist learners in meeting these learning demands. Overall, these interactions need to create learning-conducive environment. Domain pedagogical requirements and learning demands of learners form important inputs for the proposed IEF design process.

To design such learning-conducive interaction features, we take help of relevant Educational Theories, Learning Theories, Learning Principles. This knowledge database is used in identifying the appropriate theoretical base for learning-conducive interaction features and formalising definition of the proposed IEFs. As depicted in Figure 3.8, the IEF designing process can be explained as follows:

1. Define generalized pedagogical requirements (as specified in the form of Learning Objectives)
2. Identify learning demands on learner in ILEs while meeting these pedagogical requirements.
3. Search the Knowledge Database **(**Educational Theories, Learning Theories, Learning Principles) to establish mapping between learning demands and theoretical recommendations.
4. Define IEFs by establishing mapping between learning demands and theoretical recommendations.

Pedagogical requirements and expected learning demands on learners were analyzed to formalize the need for the specific IEF. These two aspects helped in answering the question, 'why an IEF is needed?' As IEF was perceived as means to fulfill this need, answering the question, 'what an IEF should do?', helped in identifying features that the proposed IEFs should posses. Further, mapping of these features with the recommendations from theoretical database helped in formalizing IEFs. The following sub-sections provide more elaboration on the proposed IEFs.

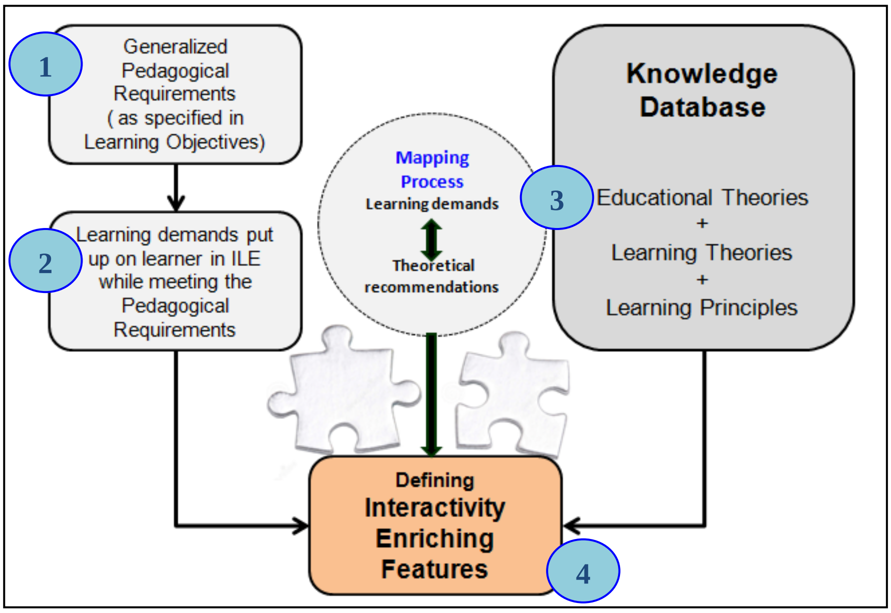


Figure 3.8. Process of designing Interactivity Enriching Features

3.5.1 Productively Constrained Variable Manipulation: PCVM

Learning of certain topics requires building up the whole knowledge by mastering its individual knowledge chunks and interlinked concepts. In a simulation environment, such a pedagogical requirement is often dealt by offering multiple variables for manipulation that allow exploration of individual knowledge pieces and interlinked concepts.

This requirement can put additional burden on cognitive resources of learners, as learners need to manage this manipulation of multiple variables in such a manner that will lead to accomplishment of learning goals. They are expected to carry out manipulation of variables to facilitate the knowledge building process. When not managed appropriately, these demands on learners may result into either simply playful and unintentional manipulation of variables, or some of the variables offered for manipulation may remain unexplored by learners.

What might help in this situation is an additional interaction feature that would offer support for manipulating variables in an intended manner. Thus, what an IEF should do is to offer the variables for manipulation progressively. This can channelize the exploration activity of learners while manipulating multiple variables. This would imply that the number of variables to be offered for manipulation simultaneously are restricted initially, they are released progressively and finally all of them are offered for manipulation for giving unrestricted exploration opportunities to learners.

This design requirement of IEF can be based on the theoretical foundation of Tool-mediated Learning (Paul, Podolefsky, & Perkins, 2012) and partially on model progression (White and Fredriksen, 1990). According to this, learners' interactions with the learning objective (knowledge) are mediated through some tool (for example, an ILE in this case); and the tool is designed keeping in mind the learning objectives. One such feature that can be incorporated in the tool could be 'constraints'. Constraints are features of a tool that restrict actions. The constraints could be productive when the limitations they place increase the likelihood of intended usage or they are able to achieve the expected learning outcome.

In this case, in order to restrict the number of variables to be manipulated, we propose use of a constraint and design the tool (ILE) with such constraint by implementing theoretical recommendation of Tool-mediated learning. This is formalised in the form of additional interactive feature, referred to as IEF- **Productively Constrained Variable Manipulation (PCVM)**. As this constraint is expected to assist learning process in ILEs, this is being perceived as Productive Constraint. It will aid the learning process and will foster learning by aligning instructor's learning objectives with the exploration pattern of learners. Figure 3.12 shows a generic representation of how this productive constraint can be designed. As shown in the Figure, learners can manipulate variables by using additional interactivity offered in the learning environment.

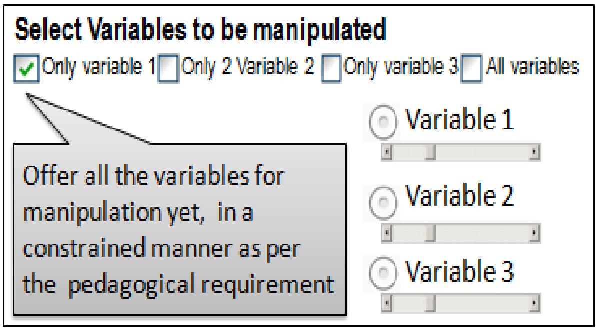


Figure 3.9. Generic representation of IEF-PCVM

3.5.2 Permutative Variable Manipulation: PVM

Some learning goals, especially catering to multi-step procedural knowledge involve performing a task by carrying out its steps in certain sequence. Procedural knowledge is the one that exhibits an ability to flexibly use and apply algorithms and procedures. While dealing with it, decisions about sequencing steps and analyzing its impact on the outcome form an important aspect of its learning. An ability to apply procedures in various ways is useful in improving learning outcome, as it gives more meaning to the process of applying procedural knowledge (Leppävirta, Kettunen, & Sihvola, 2011). It not just trains learners in applying linear procedures, but also in applying multiple discriminations to approach a problem in an algorithmic manner in line with its learning objectives (Goldfinch, Carew, & Mccarthy, 2009). Certain domain topics have this as a specific pedagogical requirement. For such topics, while applying procedures in a flexible manner, learners are required to explore all possible permutations regarding various ways in which a given procedural task could be implemented and their implications on procedure outcome.

Meeting this pedagogical requirement would entail learners to work on such permutations mentally in the absence of appropriate technological affordance. Considering this learning demand, a need for an additional manipulation interaction to vary sequencing of various steps emerges. This interaction can facilitate the needed flexibility in applying procedures. This additional content manipulation interaction can be offered in the form of an IEF that would enable learners to experience various ‘what-if’ scenarios in the simulation environment, which otherwise have to be carried out mentally. The proposed IEF to vary sequencing of various steps in a procedural task should allow number of permutations in which a procedural task can be executed.

This IEF can be based on the theoretical base of Congruence Principle (Tversky, Morrison, & Bétrancourt, 2002). The Congruence Principle in multimedia learning recommends that 'the content presented in a learning environment should be mapped to the conceptual model that learners make to learn'. The Congruence Principle, generally applied in the context of presentation aspect of learning environments, can be extended further to the interaction features of learning environments. This would imply that '*the interactivity designed in learning environments should be mapped to the conceptual model that learners* *make to learn'*. Thus, if learners are expected to develop an in-depth mental model of a procedural knowledge by developing ability to apply procedures in a flexible manner, the interactivity in learning environments must be congruent with these learning expectations. This additional interaction in ILEs can be provided in the form IEF of **'Permutative Variable Manipulation' (PVM)**. Figure 3.10 shows its generic representation.

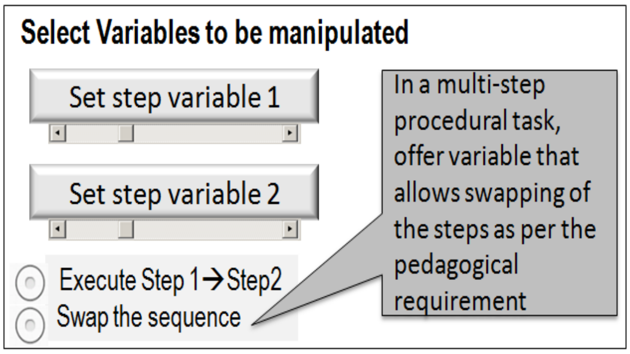


Figure 3.10. Generic representation of IEF-PVM

The additional variable to vary sequencing of multi-steps related to procedural task is being termed as 'Permutative variable' and interaction with it will make the Permutative Variable Manipulation happen in ILEs. This will allow learners to see what change takes place in the outcome due to different permutations, leading to more meaningful understanding and application of procedural knowledge.

3.5.3 Discretized Interactivity Manipulation: DIM

The pedagogical requirement of certain complex procedural topics requires comprehension at the granularity of sub-steps to be followed for its execution. Thus, although, a given procedure may be in continuum, its execution is best understood as a sequence of discretized steps. While such learning tasks are to be executed as a sequence of discretized steps, learners are expected to develop thorough understanding of its sub-steps. This learning demand on learners can be fulfilled if learners are able to develop a discretized mental model of the continuous event/ task to be accomplished. This support for creating a discretized model of a continuous task can be offered by offering additional interaction in learning environments. Such additional interaction feature in learning environments, in the form of IEF, should be able to offer interactivity that facilitates learners to get access to the discrete individual steps of the tasks during its execution. This additional interactive feature is designed as **IEF- Discretized Interactivity Manipulation (DIM).** The Discretized Interactivity Manipulation (DIM) is an IEF that allows learners to execute a given task in the form of discretized steps to strengthen internal mental representation of the task. Figure 3.11 shows its generic representation.

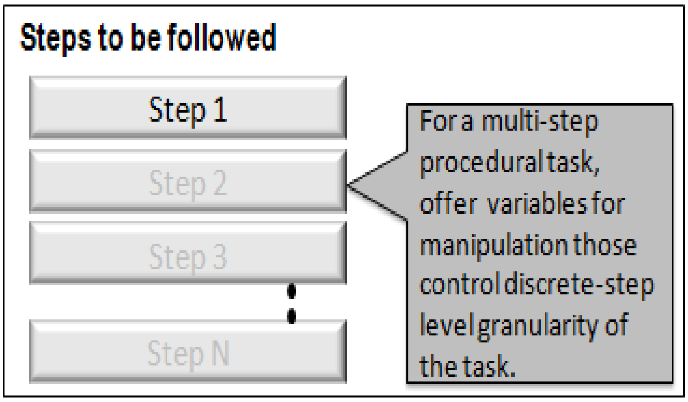


Figure 3.11. Generic representation of IEF-DIM

The design of this IEF is based on the concept of Event Cognition. While learning a given complex procedural task, making sense of continuous procedural tasks by means of meaningful segmented events simplifies learning (Kurby & Zacks, 2007). According to the findings on event cognition, learners should construct an internal representation of the event that is composed of several discrete steps rather than in a smooth and continuous manner (Newtson 1973; Zacks, Tversky & Iyer, 2001). The notion of event cognition suggests that correct segmentation of the given task improves comprehension and saves on cognitive processing resources. Thus, it is beneficial for learners to construct mental representation of events in several discrete steps than in a continuous manner. Extending this concept of Event Cognition and operationalizing it in the form of an interaction feature, the IEF of Discretized Interactivity Manipulation has been designed. From learners' perspective, considering a given procedure as a sequence of discretized step and offering interactivity to have access to such discretized steps through IEF will make learners allocate cognitive resources more effectively.

3.5.4 Reciprocative Dynamic Linking: RDL

Certain course content rely heavily on Multiple External Representations for developing integrated and interlinked knowledge. In ILEs, learners can integrate concepts from different representation formats into one meaningful experience (Moreno & Mayer, 2000) through use of Multiple External Representations. Using Multiple External Representations, learners build abstractions that promotes deeper understanding of the domain (Ainsworth & van Labeke, 2004). The coordination of different representations in a cohesive manner and explicit identification of their relations support students' understanding at a deeper level. However, learning from Multiple External Representations make learners experience more cognitive load due to the requirement of focusing on multiple content of learning environments.

Managing the excessive cognitive load while dealing with Multiple External Representations can be done with the help of additional interactive affordance in ILEs. Considering the need to explore individual representations independently and to strengthen the to-and-fro linkage between representations, an additional interaction in dynamically linked Multiple External Representations is designed in the form of IEF- RDL.

The IEF - 'Reciprocative Dynamic Linking', in interactive simulations will allow learners to select and manipulate each of the multiple external representations individually in a reciprocative manner. This is based on contemporary theories of cognition such as distributed and embodied cognition (Glenberg et al., 2013). These theories postulate that external representations play more roles than merely decreasing cognitive load and can support operations that are difficult to do by imagination alone (Kirsh, 2010). Actions like manipulations could be a way of promoting integration of Multiple External Representations (Chandrasekharan, 2009). The reciprocal interface is two-way manipulative, enabling learners to carry out meaningful switchover among representations. This feature can offload the mental resources while relating, translating and integrating multiple representation to build up whole and integrated knowledge base. Figure 3.12 shows its generic representation.

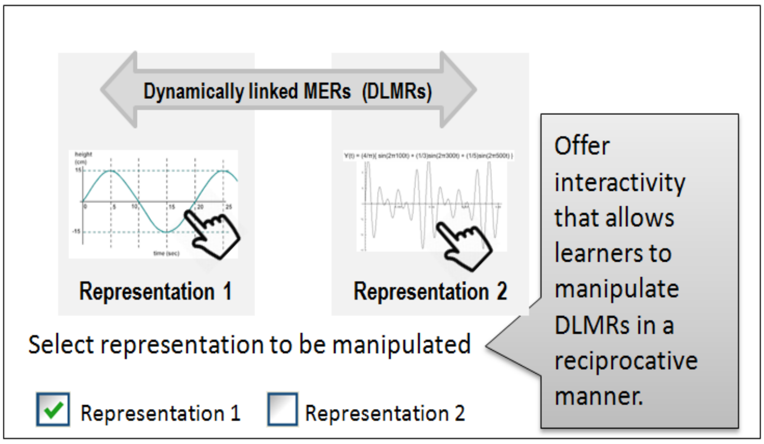


Figure 3.12. Generic representation of IEF-RDL

Table 3.1. Designing of IEFs

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***

Figure 3.13 shows how an overview of the IEFs that are embedded into ILEs.

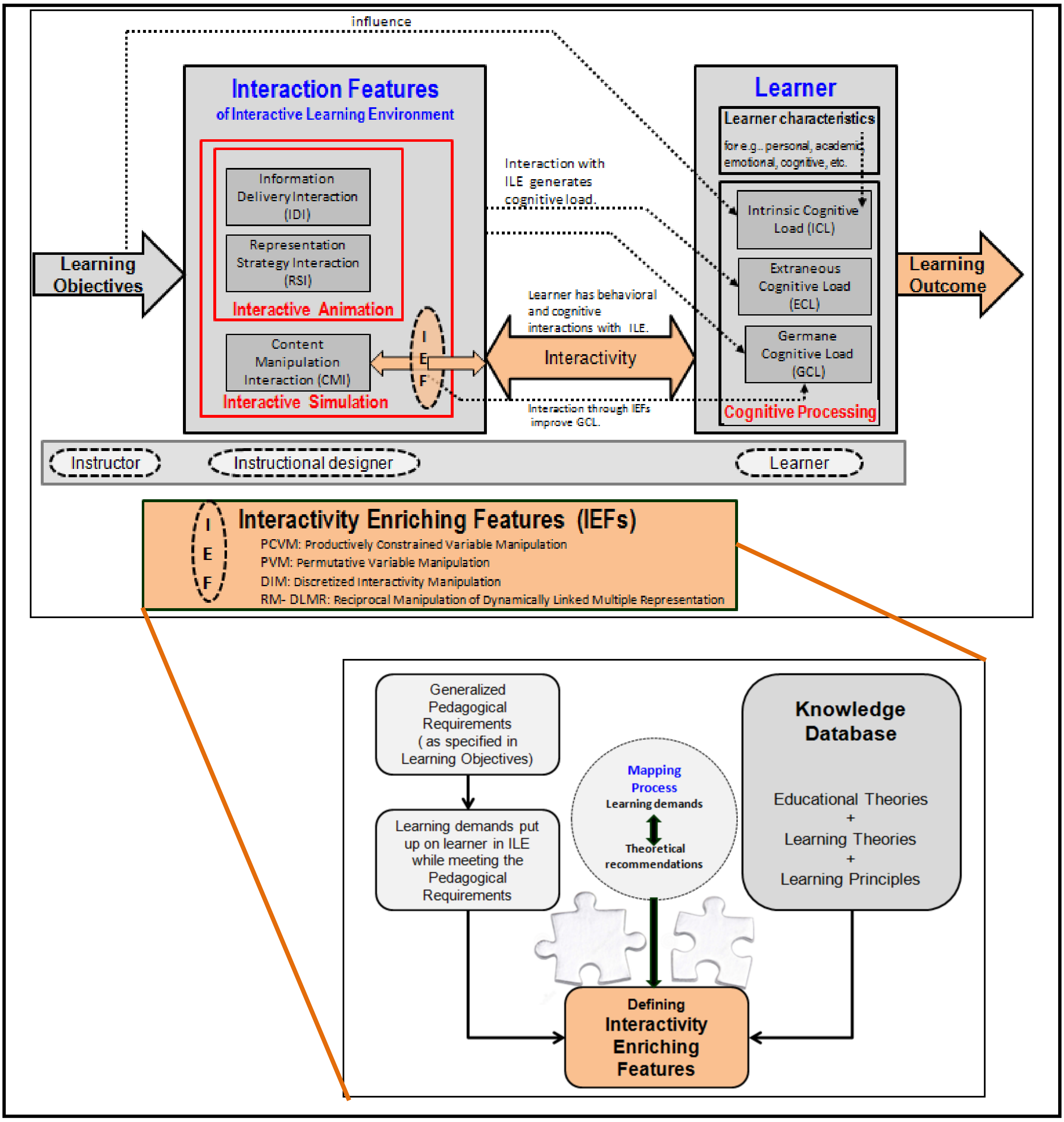


Figure 3.13. Designing of IEFs and embedding them into ILEs

3.6 Research Questions

We started with a broad level research question, "Under what conditions, ILE leads to effective learning?" The research aims are to test the need for IEFs, learning effectiveness of

IEFs and exploring the impact of IEFs on learners' cognitive processing. These aims lead to specific research questions of this thesis work.

The mixed nature of the learning impact of ILEs has been evident from the synthesis of the related work. To begin with, we again wish to evaluate the basic intuitive notion of higher level of interaction leading to higher learning. Evaluating this notion or rather challenging the notion of, 'higher level of interaction leading higher learning' is necessary to prove the basic need of IEFs. The outcome of this evaluation will help further in either supporting or refuting the need of IEFs in ILEs. This forms our first research question.

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

The next follow-up needed would be to investigate the effectiveness of IEFs. As a result, whether the presence of relevant IEFs is able to improve learning in the ILEs as compared to the ILEs without them, is the aim of the next research question. This leads to the second research question that investigates the learning effectiveness of IEFs.

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

Understanding effect of various features of ILEs on students' learning has always been crucial for sound designing strategies. Apart from proving learning effectiveness of such features, investigating how such features help learners in learning is common research thread followed in education research. This not just helps in strongly validating learning effectiveness of such features, but also makes the strong connection to the relevant educational theories and design principles. The research related to learning from multimedia based learning environments is closely associated with cognitive load theory. Thus, in the context of this thesis work, investigating how IEFs affect learners' cognitive demands and looking at the learning effectiveness of IEFs through the lenses of cognitive load theory will further help in strengthening the rationale behind IEFs. This takes us to the third research question of the thesis.

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

The next chapter details out the Research Methodology adopted for addressing the above research questions. The research context being a course on Signals and Systems, the effectiveness of IEFs will be evaluated by planning different research studies for different topics from a course on Signals and Systems. The research studies and their findings are presented in the subsequent Chapters (5, 6, 7).

4. Chapter 4

Research Methodology

4.1 Research Framework

Chapter 2 of the thesis reviewed literature related to the research problem area and presented broad research question related to effective learning conditions in ILEs. Chapter 3 proposed the solution approach in the form of Interactivity Enriching Features embedded into Interactivity Enriched Learning Environment. Chapter 3 also presented the rationale and details of determining and designing IEFs, and presented specific research questions and hypotheses. Thus, the main research aim is now to investigate the effectiveness and learning impact of IEFs.

Keeping in mind the notion of 'fitness for purpose', the research design and overall research methodology was adopted to facilitate the process of answering broad level research question and specific research questions. The thesis was set to address the broad level research question of "Under what conditions, ILE leads to effective learning?" As explained in Chapter 3 of the thesis, the broad level question was addressed with the help of three research questions. The research questions already presented in Chapter 3 are as follows:

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?

The overview of research work is shown in Figure 4.1.

Research Topic →	Interactive Learning Environments
Research Problem →	Inconsistent learning results from Interactive Learning Environments
Broad Research Question →	To investigate, "Under what conditions, Interactive Learning Environment leads to effective learning?"
Research Questions →	1) Does higher level of interaction lead to effective learning in ILE for a given type of knowledge and cognitive level? 2) How do IEFs affect students' learning outcome? 3) What is the effect of including IEFs on students' cognitive load?

Figure 4.1. Overview of the research work

4.2 Research Methodology

Research methodology is plans and procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation (Creswell, 2013). It helps in deciding research design and research methods to be followed to answer research questions. The major steps in Research Methodology were: selecting the philosophical worldview assumptions, looking for research design in accordance with the selected worldview and finalizing specific research methods. The overview of research methodology and interaction between its three steps is shown in Figure 4.2.

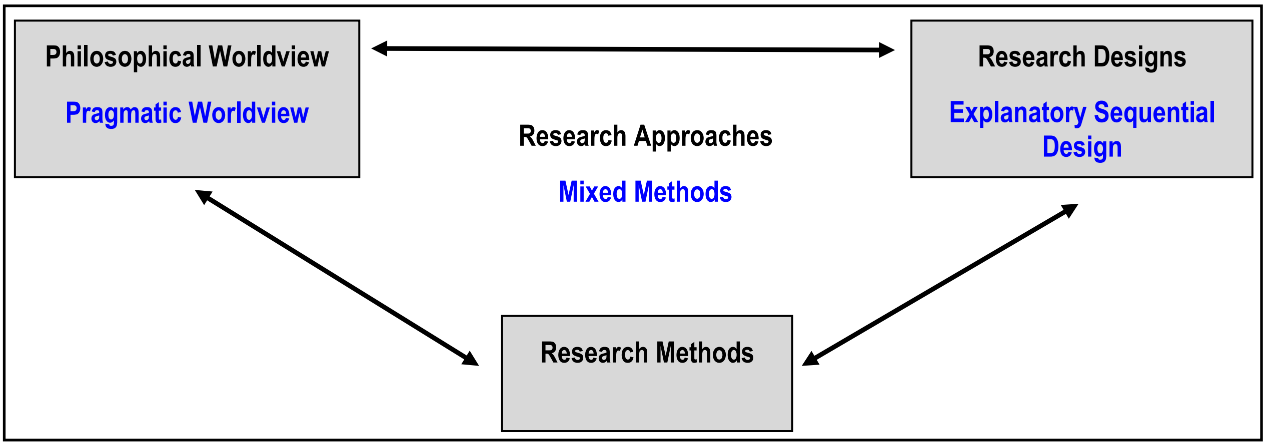


Figure 4.2. Overview of Research Methodology

4.2.1 Selecting the philosophical worldview

Cresswell (Creswell, 2013) proposed four philosophical worldviews for research. The worldviews are assumptions that researchers bring to the study and the basic set of beliefs that guide further actions while planning research. These philosophical worldviews are,

i. Postpositivist worldview, which leads to quantitative research as the research generally focuses on test of a theory
ii. Constructivist worldview, which generates or inductively develops a theory and assumes qualitative research
iii. Transformative Worldview, that focuses on the needs of groups and individuals in the society
iv. Pragmatic worldview, which is real-world practice oriented and allows researchers to draw liberally from qualitative and quantitative assumptions

The thesis work aimed at determining and designing IEFs and to investigate their effectiveness and learning impact in ILEs. The said research problem of the thesis has stemmed up from the real-world teaching learning practices. Thus, to address this issue what was needed was an approach that would analyze relevant existing educational theories, beliefs, principles and would evaluate their practical implementation to improve learning from ILEs. This role was found to be in line with the pragmatic worldview. Thus, the philosophical worldview selected for the research framework was the Pragmatic worldview.

Selecting the Research Approach

The pragmatic worldview allows researchers to use methods that suits the nature of the research problem and thus, generally allows researcher to take benefits from both the research approaches i.e. quantitative and qualitative.

In this thesis work, the research issue demanded both the approaches. The research plan needed: i) quantitative approach to compare how learners perform in a domain knowledge test while learning with IEFs, as compared to while learning without IEFs and ii) qualitative approach to explore how learners use the IEFs while learning from ILEs. Both these approaches were needed to collect evidence-based conclusions regarding impact of IEFs. Thus, the research approach suitable for the thesis research work was Mixed methods research approach.

4.2.2 Selecting the Research Design

Having decided the research approach to be the mixed methods research approach, the next step in the research framework was to finalize the research design. It is a well accepted view that no particular research design is privileged over any other; and rather the choice of design must be driven by the research questions (Creswell, 2002). Thus, the selection of research design was linked to the purpose of the specific research questions. Before evaluating the aptness of a particular design to our research problem, we first reviewed all mixed research designs.

Mixed methods studies generally include at least one quantitative strand and one qualitative strand. A strand is a component of a study that encompasses the basic process of conducting quantitative or qualitative research: posing a question, collecting data, analyzing data, and interpreting results based on that data. Normally, parameters used for choosing a suitable research design for a mixed method for a given study are decisions such as: the level of interaction between the strands, the relative priority of the strands, the timing of the strands, and the procedures for mixing the strands (Creswell & Clark, 2007). Based on these decisions, mixed design research methods have accommodated different types of the research designs; such as convergent parallel, explanatory sequential, exploratory sequential, embedded, transformative and multiphase designs.

The solution approach to answer the thesis research questions expected that the research design should facilitate comparative analysis of the learning impact due to different treatments (for example, learning with and without IEFs) in terms of students' performance scores of domain knowledge tests. Further, the solution approach also expected exploration of how the proposed solution in the form of IEFs is being used by learners. Exploring a learning mechanism merits a qualitative approach (Creswell, 2002). To support findings from quantitative data, what was needed was the qualitative aspect of research design that would include analysing data from sources such as screen capture, semi-structure interviews, open ended questions. Thus, overall research design demanded a quantitative strand of the research design with a follow-up qualitative strand.

Out of the various mixed method research designs, the explanatory sequential design was found to be in line with the above mentioned expectations. The explanatory sequential design occurs in two distinct interactive phases. It starts with the collection and analysis of quantitative data as a first phase. The second, qualitative phase of the study is designed so that it follows from the results of the first quantitative phase. The researcher interprets how the qualitative results help to explain the initial quantitative results. This format of the explanatory sequential design was found to be in accordance with the solution approach, and thus it was finalized as the research design.

Additionally, one of the initial research questions was basically to find out whether students can learn better while learning from learning environments with higher level of interaction. This required comparing students' performance in the given domain while learning from learning environments with lower and higher level of interaction. As mentioned by Creswell (Creswell, 2002), quantitative approach is suitable when the researcher tests a theory by specifying narrow hypotheses and analyses the collected data to support or refute the hypotheses. In other words, this approach is best suited when researcher is interested in finding out whether one type of intervention works better than another type of intervention. Thus, following the principle of 'fitness for purpose', it was decided to answer this research question with pure quantitative approach.

The overall thesis looked at the research questions in an integrated manner and not in isolation. The process of investigating learning effectiveness of IEFs required results from all the three questions. The overview of the research deign is presented in Figure 4.3.

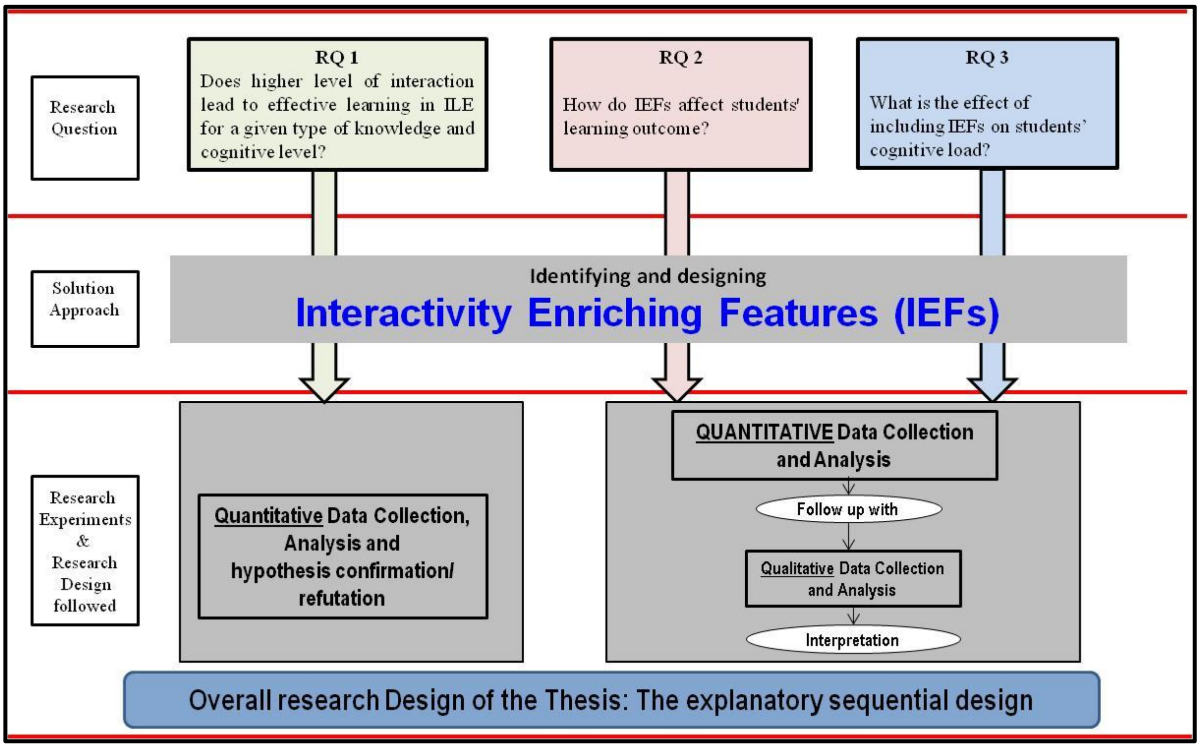


Figure 4.3. Overview of the research design

4.2.3 Research Methods

The following issues were taken into consideration while finalising the research methods and data analysis techniques.

→ Deciding constraints on the research: As the research studies involved participants from engineering colleges, synchronizing research studies with the academic calendar was crucial. The necessary formalities to be carried out for getting permission and consent from the concerned authorities for conducting research studies were chalked out well in advance. The said permissions were obtained using clear official channels after completing the required formalities and written documentation. Various issues related to actual conduction of studies were discussed with the authorities. These issues involved: availability of computer and other laboratory resources for conducting studies, number of participants to be admitted for the study, adjustment of the academic load of the participants, requirement of supporting staff.

→ Planning for resources: Apart from logistics issues, the resources needed for creating computer-based ILEs (in the form of Java applets), experts needed for instrument validation process, research assistants were identified and arranged.

→ Consideration of ethical issues: As the research studies involved human participants, the detailed guidelines were prepared for ethical consideration (Cohen, Manion & Morrison, 2000). These guidelines mainly include:

  - Preparing procedures and documentation for taking informed consent from the participants: Participants were given a consent form before every research study. They were well-informed about the objective and procedure of the study. They were offered clarification by the researches in case they had any queries. After updating the participants with the full information, they were asked about their decision to participate in the study. They were allowed to discontinue participation from the study at any point of time. All the participants were assured that participation in the study would have no bearing on their grades and academic performance.
  - Maintaining anonymity and confidentiality of participants: Anonymity of all the participants was maintained throughout and all the data was given strict confidentiality.
  - Permission for publication: The necessary permissions for publication were sought from the participants.

Research Methods

The main task of research method phase was to operationalize research questions. It included translating a general research aim into specific, concrete questions to which specific, concrete answers can be obtained through research studies. The following were the major steps taken while designing and defining research methods.

- Translating general research purposes and aims operationalized into specific research questions: Specific research question and hypothesis were defined for each experiment to be conducted.
- Finalizing the research design: Looking at the suitability of topic and participants' prior knowledge level, the research designs were finalized. Most of the research experiments followed post test only research design with random matched equivalent groups.

- Addressing the validity and reliability issue: Detailed consideration was given to validity and reliability issues involving content validity, construct validity, reliability of the instruments, group equivalence issues, protocol for conducting interviews and nature of questions to be asked etc.
- Deciding population, sampling method, data collection methods and instruments: As the research context was a course on Signals and Systems, the population was students from second/third year Electrical Engineering (and allied) program, studying the said course. The sampling was convenience sampling. The equivalence of control and experimental groups was verified while conducting experiments. While conducting semi-structured interviews and piloting stage, the subjects were selected by purposive sampling. The purposive sampling was done to avoid certain bias conditions and to ensure participation to be representative in real sense. The research design being 'the exploratory sequential design', it mainly relied of quantitative data collection through domain knowledge tests. For conducting domain knowledge tests, instruments were developed in the selected topics which were validated by domain experts and Educational Technology experts. The piloting was done to look for any possible missing links in the procedures decided for conducting research studies, and to get feedback about usability issues for the learning environments created.

Data Analysis

Appropriate decisions were taken to identify and justify the statistical tests that were used in data analysis. Various factors such as normality, homogeneity of the data etc. were considered for identifying relevant statistical tests and statistical packages to be used. While analyzing qualitative data, appropriate use of rubrics and protocols was done. The research design being 'the exploratory sequential design', the interpretation from quantitative data analysis were inferred and triangulated with the findings from analysis of qualitative data collected.

Writing and reporting the research

Although the interim reporting and analysis were conducted during research experimentation phase, the final reporting of the studies and findings were done after completing the quantitative and qualitative data collection and analysis.

4.3 Overview of the Research Experiments conducted

In order to answer the research questions, five empirical studies were conducted in various topics from a course on Signals & Systems. The details of the research studies are presented in Figure 4.4. The RQ1 was answered by conducting the research studies in the topic of 'Signal transformation', 'Convolution' and 'Fourier Transform Properties' (Experiments E1, E2 and E3 respectively). The RQ2 related to the learning impact of IELEs was answered by conducting research studies in the topic of 'Signal transformation', 'Convolution' and 'Representation of sinusoids in Time and Frequency Domain' (Experiments E1, E4 and E5 respectively). The RQ3 was answered by research experiments E4 and E5, in the topic of 'Convolution' and 'Representation of sinusoids in Time and Frequency Domain'.

Having presented the overview of the research methodology, we now present the research studies and their findings in the following chapters. Chapter 5 presents research experiments E1, E2 and E3 answering RQ1. The experiment E1 presented in Chapter 5 also answers RQ2. Chapter 6 and 7 present experiments E4 and E5 respectively answering the RQ2 and RQ3 of the thesis. Figure 4.4 shows the mapping between the experiments, the research questions and the corresponding chapters.

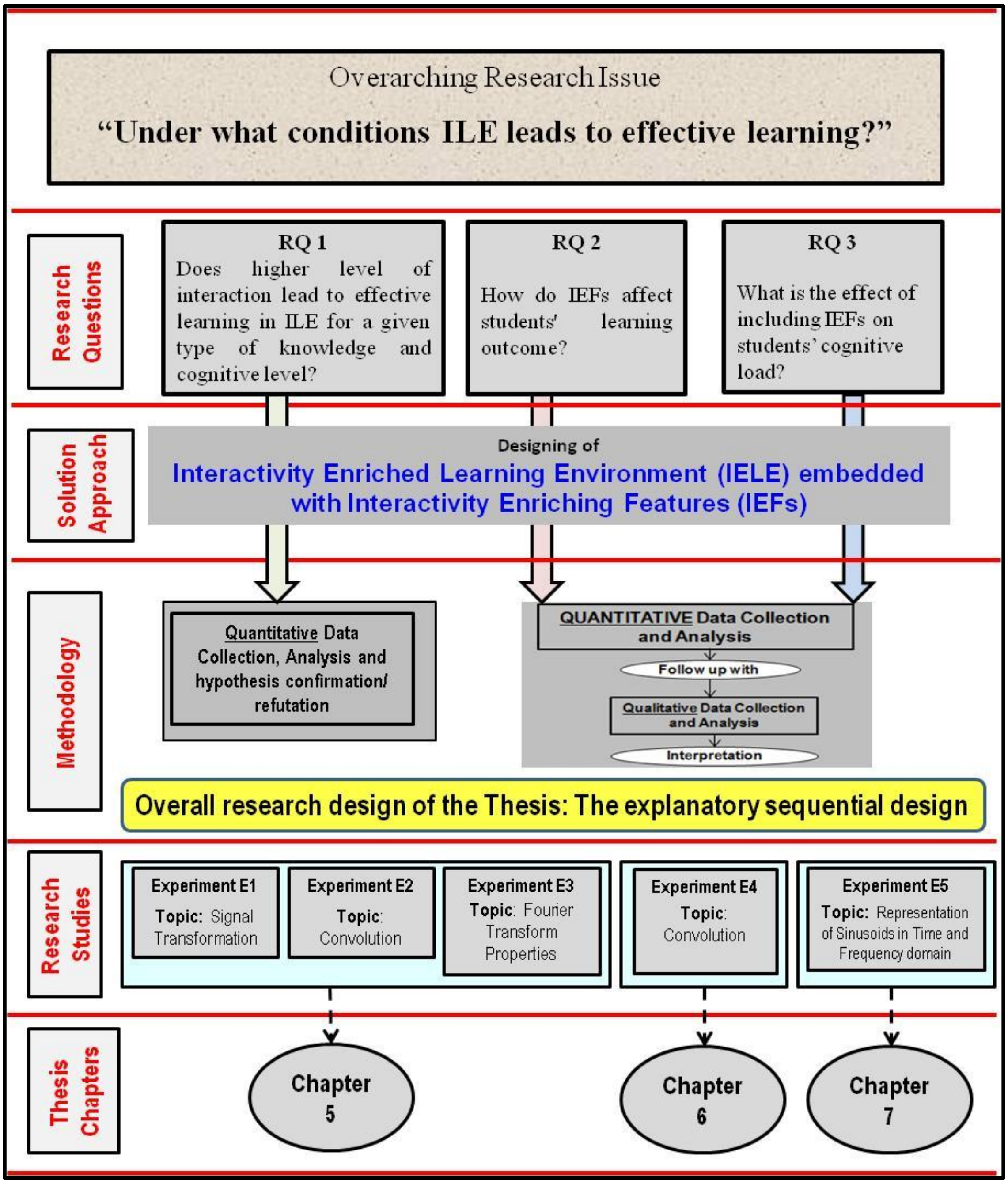


Figure 4.4. Overview of the research

5. Chapter 5

Validating the effectiveness of Interactivity Enriching Features: Experiments E1, E2 and E3

In this chapter, we present detailed methods and findings of research experiments E1, E2 and E3. While findings from E1 answer RQ1 and RQ2, experiments E2 and E3 address RQ1. For reference, the RQ1 and RQ2 (as elaborated in Chapter 3) are reproduced here.

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?

5.1. Research Experiment E1

The research experiment E1 was set to test learning effectiveness of IEFs- 'Productively Constrained Variable Manipulation', and 'Permutative Variable Manipulation' to answer the RQ2. Additionally, E1 was planned to evaluate learning impact of variation in the degree on interaction in line with the RQ1.

5.1.1. Research Questions and Hypotheses specific to E1

With reference to the research questions of the thesis work, the specific research questions for the experiment E1 were formed. To evaluate learning impact of variation in the degree on interaction, the first research question for E1 was :

E1-RQ1*:* Given the type of knowledge and cognitive level, does higher degree of interaction, lead to effective learning?

Our second research question aimed at investigating the learning impact of IEFs embedded in Interactivity Enriched learning Environment (IELE).

E1-RQ2*:* Given the type of knowledge and cognitive level, how do IEFs (Productively Constrained Variable Manipulation and Permutative Variable Manipulation) affect learning in interactive learning environments?

To answer these research questions, the following types of learning environments were used.

(a) a Non-Interactive learning environment (Non-ILE)

(b) an Animation (ANM)

(c) a Simulation (SIM)

(d) IELE embedded with IEFs

The first three learning environments (Non-ILE, ANM, SIM) had different degree of interaction and learning from them was compared to answer E1-RQ1. The SIM and IELE, both had same degree of interaction. However, IELE was designed with IEFs, SIM was designed without IEFs. Learning from these two learning environments was compared to answer E1-RQ2.

The research context was a course on Signals and Systems of Electrical Engineering program. The learning outcomes of Signals and Systems expected students not just to comprehend various concepts from the course, but also to apply them in a meaningful manner while attempting associated procedural tasks. The conceptual and procedural knowledge are two mutually-supportive factors associated with the development of engineering skills (Taraban, Definis, Brown, Anderson, & Sharma, 2007). In order to meet these domain specific requirements, we focussed on ‘Understand’ and ‘Apply’ cognitive levels and ‘Conceptual’ and ‘Procedural’ knowledge types, in conformance with the two-dimensional taxonomy framework as proposed by Anderson (Anderson et al., 2001) to measure learning effectiveness of ILEs. Considering the content to be learnt for the selected topic, we focussed on three categories in this study; 'Understand Conceptual knowledge', 'Understand Procedural knowledge and 'Apply Procedural knowledge'.

Following were the hypotheses for the study. Firstly, based on the premise that giving control to learners while working with learning environments leads to effective learning, it was expected that students, learning from learning environment offering higher degree of interaction would learn better as compared to students learning from learning environment that offered lower degree of interaction.

Thus, the hypotheses for E1-RQ1 were:

E1-H1-A) For Conceptual knowledge at Understand level, students learning with Simulation (SIM) will score higher as compared to students learning with Non-Interactive Learning Environment (Non-ILE) and also, as compared to students learning with Animation (ANM).

E1-H1-B) For Procedural knowledge at Understand level, students learning with Simulation (SIM) will score higher as compared to students learning with Non-Interactive Learning Environment (Non-ILE) and also, as compared to students learning with Animation (ANM).

E1-H1-C) For Procedural knowledge at Apply level, students learning with Simulation (SIM) will score higher as compared to students learning with Non-Interactive Learning Environment (Non-ILE) and also, as compared to students learning with Animation (ANM).

Secondly, we also wanted to assess how the IEFs influence learning from ILEs. Therefore, we hypothesized that at the same degree of interaction, IELE embedded with IEFs would lead to more effective learning when compared with Simulation, the learning environment without IEFs. Thus, we formulated following hypotheses for E2-RQ2.

E2-H2-A) For Conceptual knowledge at Understand level, students learning with IELE score higher than students learning with Simulation (SIM).

E2-H2-B) For Procedural knowledge at Understand level, students learning with IELE score higher than students learning with Simulation (SIM).

E2-H2-C) For Procedural knowledge at Apply level, students learning with IELE score higher than students learning with Simulation (SIM).

5.1.2. Learning Materials

The hypotheses mentioned above were tested with the help of research study focused on the topic 'Signal Transformation'; a topic that deals with basic transformation operations on signals such as time shifting, time scaling, time reversing and amplitude scaling. Details of the learning materials used for the study are as follows.

a) Non-ILE : Non-interactive form of learning material explained signal transformation operations with still images. These operations include single and multiple transformation operations on signals; such as amplitude scaling, time shifting, time scaling and time reversing.
b) ANM: Animation showed the same content in animated form offering only 'play-pause-stop' control to learners. It did not offer any opportunity to learners to change or explore its educational content.
c) SIM: Simulation was an interactive JAVA applet offering dynamic manipulation of variables for interacting, exploring and changing the educational content (Figure 5.1).
d) IELE: The IELE was an applet with IEFs[1]. The IEF- Productively Constrained Variable Manipulation was embedded to control the number of variables offered simultaneously for manipulation (Figure 5.2). By virtue of this IEF, the variables to be manipulated were offered in a controlled manner. Gradual introduction of variables for manipulation was implemented by offering only one single transformation operation initially (Tab 1: any one out of amplitude scaling, time shifting, time scaling and time reversing), then two operations (Tab 2: Commutativity of Transformation) and finally all the four transformation operations from the topic on Signal Transformation. (Tab 3: Multiple Transformation). The other IEF- Permutative Variable Manipulation (in Tab 2:

[1] The downloadable version of IELEs are available at http://www.et.iitb.ac.in/~mrinal/IELESS.html. Due to incompatibility issue of JAVA and browser, the applets need to run with applet viewer. The demo of IELEs are made available at the above mentioned URL.

Commutativity of Transformation) controlled the action sequencing of the procedural task i.e. learners could control the sequence in which transformation operations related to procedural knowledge could be carried out.

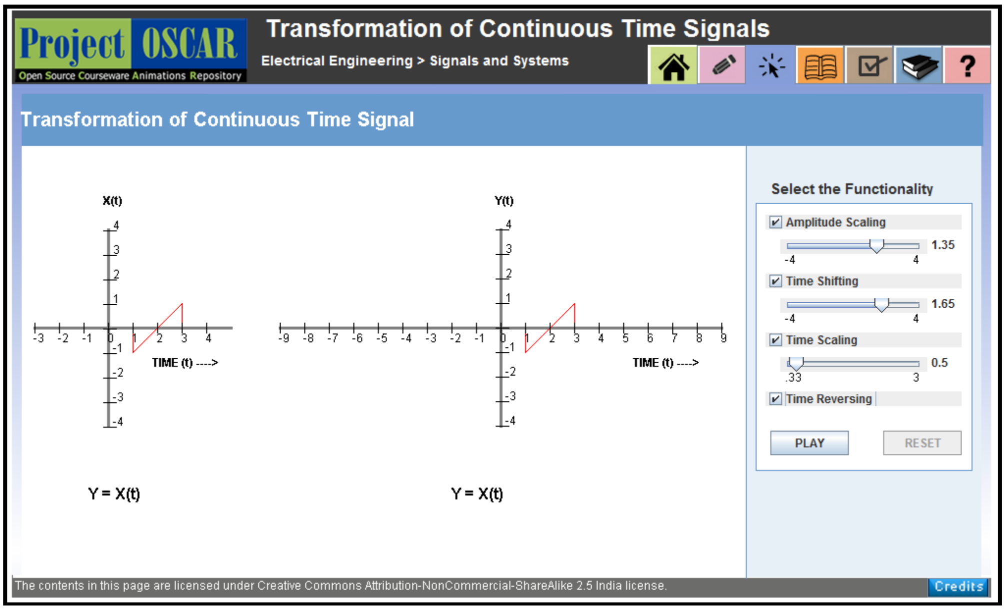


Figure 5.1. Screenshot of the SIM learning environment for a topic on Signal Transformation

To test the equivalence of learning materials in factors other than what was considered in the experiment, such as usability, and look and feel, the materials were tested with students who had already studied the course on Signals and Systems. They were asked to interact with the content and were assessed by the instrument, SUS Scale (Brooke, 1996). SUS is a ten-item Likert scale survey with a score range from 0 to 100, that gives a global view of subjective assessments of usability. All the four types of learning materials were tested to establish equivalence of the learning material and were found to be equivalent. Total 70 students participated in this exercise. The mean SUS scale scores were (Non- ILE (M= 76.39, SD=9.56), ANM (M= 77.22, SD=9.92), SIM (M=81.32, SD=10.83), and IELE (M=80.15, SD=10.59). The one-way ANOVA showed F to be statistically non-significant at $p > 0.05$ (p =0.437). The survey instrument used as SUS scale is given as Appendix A.

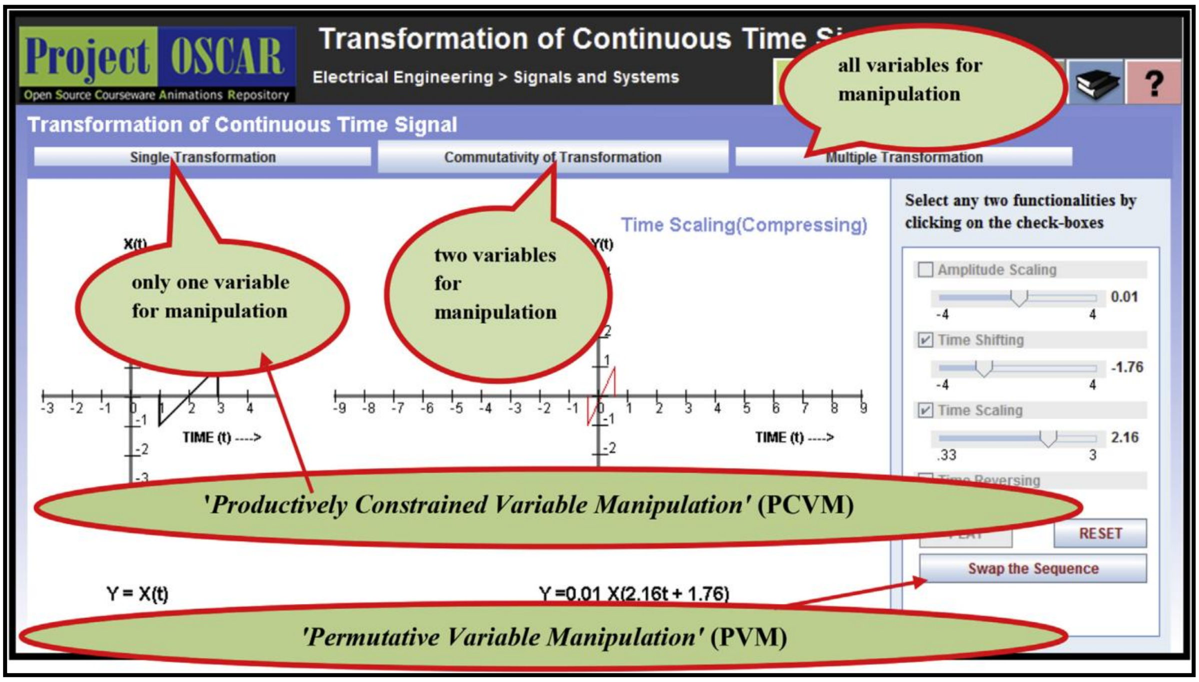


Figure 5.2. Screenshot of the IELE for a topic on Signal Transformation

5.1.3. Participants and Experimental design

Participants were students from second year of engineering from colleges affiliated to University of Mumbai (N= 134; 109 males and 25 females). Generally, students get admitted to engineering institutes on the basis of a common qualifying examination. All semester-end examinations and their assessment pattern are uniform for all students for a particular program from different colleges. These points helped to ensure the homogeneity of population and representativeness of the sample. The convenient sampling was used for selecting students for the study from the list of students.

The participants were distributed into 4 groups corresponding to the four different learning materials developed. While creating matched-random assignment groups, scores of previous semester examination were considered for matching the group equivalence. Non-reporting of some of the participants led to unequal sample size among the groups. There was no statistically significant difference found between the performance scores of the students from each group. An alpha level of 0.05 was used for all statistical tests. The mean examination scores were: Non- IVZ (M= 66.906, SD= 7.25), ANM (M= 66.313, SD= 7.24),

SIM (M= 67.591, SD= 6.48), IELE(M= 63.845, SD=7.95). The one-way ANOVA showed F to be statistically non-significant at $p > 0.05$ ($p = 0.192$).

As discussed in Chapter 4, the overall research design was explanatory sequential design. The quantitative strand of the design was conducted using a 4-group post-test only experimental research design. It assessed students' learning of domain knowledge with the help of domain knowledge test. The post-test scores were used to compare and evaluate the learning effectiveness of the treatment for various groups. A pre-test was not found to be essential, since students did not have any prior knowledge related to the topic and were exposed to the educational content in the topic for the first time. As confirmed from the curriculum and course instructors, none of the previously learnt courses from the curriculum exposed students to the topic on Signal Transformation. The participants were familiar with the use of ICT tools in learning through other courses and laboratory in their curriculum.

Participants were randomly assigned to one of the following four conditions:

(a) a Non-Interactive Learning Environment (Non-ILE group); N=41

(b) Animation (ANM group); N=35 and

(c) Simulation (SIM group); N=23

(d) Interactivity Enriched learning Environment (IELE group); N=35

In addition to investigating the learning effectiveness of IEFs on the basis of students' performance in the domain knowledge test, understanding how students explore ILEs and their perception about need for IEFs in the learning process were another important objectives of the study. The qualitative phase of the explanatory sequential design was designed to focus primarily on this aspect of investigation. The details of the qualitative phase of the explanatory sequential design are explained in section 5.1.8 of this Chapter.

5.1.4. Treatment

The instructional intervention for the four conditions while implementing the quantitative phase of the research design was as follows:

1. The Non-ILE group used non-interactive form of the learning material.
2. The ANM group studied the same content in the form of animation.

3. The SIM group learnt with an interactive JAVA applet that offered dynamic manipulation of variables.
4. The IELE group studied with the applet with Interactivity Enriched Learning Environment with IEFs.

5.1.5. Measures and Instruments

The assessment instrument for the post-test was developed to test students' learning in terms of 'understand', 'apply' cognitive levels and 'conceptual' and 'procedural' types of knowledge. These specific cognitive levels and knowledge types were used in the instrument to meet domain specific pedagogical requirements. Work on the Signals and Systems Concept Inventory (SSCI) (Wage et al., 2005) and the work by Hiebert and Lefevre (Hiebert & Lefevre, 1986) reported the necessity to cover 'conceptual' and 'procedural' knowledge as well as on their co-existence, especially in the engineering curriculum. Also, the Signals and Systems course outcomes expected students to comprehend various concepts from the course and to apply them in a meaningful manner in the new context. Thus, the instrument designed for this study focused on 'understand' and 'apply' cognitive levels as defined in Revised Bloom's Taxonomy (Krathwohl, 2002) and 'conceptual' and 'procedural' types of knowledge. Considering the type of knowledge, along with the cognitive levels of the task to be accomplished helped in assessing engineering curriculum's requirement of developing learners' expertise; not just in the given type of knowledge, but also at the desired cognitive level of that knowledge.

The categorization of assessment questions from the instrument was done considering the basic definitions of different cognitive levels and knowledge types (Mioković, Varvodić, & Radolić, 2012; Krathwohl, 2002) in the context of the selected topic from the domain. In the topic of Signal Transformation, individual transformation operation constituted conceptual knowledge, while multiple transformations to be carried out on a signal in an algorithmic manner was an example of procedural knowledge. With regard to cognitive level of the task, questions related to 'understand' cognitive level were in the form of identifying or interpreting the single or multiple transformation operations, whereas, at 'apply' cognitive level, students were expected to use their comprehension to solve questions by applying their knowledge in the new situation. The ten assessment questions were distributed across these three categories of 'Understand Conceptual knowledge', 'Understand Procedural knowledge and 'Apply

Procedural knowledge'. The normalized scores, out of ten were compared across groups for the above mentioned categories. The questions are provided in Appendix B.

Content validity by experts:

Validating the instrument for correctness of the content, categorization of questions, and alignment of questions with learning objectives was crucial. To establish validity of the instrument developed for post-test, it was peer-reviewed by the researchers of this study in cooperation with five domain experts who had 20+ years of teaching experience each in the domain of Signals and Systems. Two reviewers also had a formal background in Educational Technology research. The review process was carried out in an iterative manner. As mentioned, the major objectives of the review process were to validate the instrument on the basis of correctness of the content, the categorization of questions and their appropriateness in the context of learning objectives. The suggestions given were incorporated in an iterative manner and the revised instrument was further reviewed till all the reviewers were satisfied. One of the suggestions received during review process was to keep signal waveforms simple to avoid students making false mistakes in drawing complicated waveforms while transforming signals. Two of the initial questions from original assessment instrument were dropped on the recommendations of the reviewers as the questions were testing real world applications of signal transformation concepts, while the learning material was not designed to cater to this learning objective.

5.1.6. Procedure

Pilot study

Five students who had already studied Signals and Systems took part in a pilot study whose aim was to determine if the learning materials, assessment instruments and procedure were suitable and aligned. The pilot study was carried out prior to conducting the main study to get feedback about various feasibility and usability related issues regarding the learning material, instrument and experiment procedure. Students gave feedback about the clarity and comprehension of the learning environment and the post-test. The students did not report any flaw in understanding and interpreting the assessment questions, mathematical expressions and graphical representation of the waveforms wherever applicable. The pilot experiment conducted also confirmed sufficiency of the time allotment for the treatment, as well as for the problem solving session.

Main Research Study

The study was performed during lab hours where all participants could use individual computer terminals. Participants were informed that the purpose of this experiment was to investigate the effectiveness of the ILE in teaching relevant concepts from Signal and Systems. Participants had signed consent forms and were also informed that all the collected information would be kept confidential. Detailed directions on how to use the learning environment were given to the participants. All the participants were given 25 minutes of time to interact with the learning material. This was followed by administration of the test for the next 30 minutes. During the test, participants were not allowed access to the learning material. None of the participants demanded more amount of time during learning phase or during test phase. After the experiment, participants were thanked and were given participation certificates.

The semi-structured interviews were conducted after the main study as a part of qualitative phase of the explanatory sequential mixed design using purposive sampling.

5.1.7. Data Analysis Techniques

The research design being 4-group post-test only, students' performance in the post-test was compared to assess effectiveness of the treatment. The instrument was designed for three categories of questions. Thus, the test scores were compared for all these three categories independently. Following steps were taken to carry out statistical analysis of data.

The raw data was processed to get a normalized score, out of ten for each category of questions. The data was further checked for normality and other valid assumptions to decide suitability of parametric statistical tests for comparing means. The statistical analysis involved i) comparison of means for all the four groups to find out statistically significant difference among them using ANOVA or its equivalent non-parametric test, ii) comparison of means to find out statistically significant difference between each pair of groups using independent sample t-test or its equivalent non-parametric test (subject to the ANOVA or its equivalent non-parametric test indicated that the group had statistically significant difference among their means). An alpha level of 0.05 was used for all statistical tests.

The qualitative data received from semi-structured interviews were analyzed using Content Analysis method.

5.1.8. Results

Table 5.1 below shows the means and standard deviations of the post-test scores. Due to the fact that the test scores violated the assumption of normal distribution, the Kruskal-Wallis test, a non-parametric equivalent of a one-way ANOVA, was used to compare the experimental conditions. However, the test scores passed the Levene's test of Homogeneity of Variances, thus confirming equal variances across groups for all the three categories of test scores (Levene statistic: 'Understand Conceptual knowledge' p=0.601, 'Understand Procedural knowledge' p=0.262, and 'Apply Procedural knowledge' p=0.124). Thus, as the homoscedasticity of data was ensured, the statistical tests selected (Kruskal-Wallis test and Mann–Whitney U test) were suitable for the further data analysis for unequal 'n' sample size (Glass & Hopkins, 1970).

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

The Kruskal-Wallis test gave the following results: 'Understand conceptual knowledge' ($\chi^2(3)=3.613$, $p=0.306$), 'Understand procedural knowledge' ($\chi^2(3)=14.062$, $p=0.003$), 'Apply procedural knowledge' ($\chi^2(3)=14.667$, $p=0.002$). For 'Understand conceptual knowledge', there was no statistically significant difference between the test scores. However, as the test score for 'Understand procedural knowledge' and 'Apply procedural knowledge' showed statistically significant difference, the Mann-Whitney U was used for further analysis of the results. The result of Mann-Whitney U test for the groups were found to be as shown in Table 5.2.

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

Result Analysis: E1-RQ1

The E1-RQ1 the study was about impact of degree of interaction on effective learning for the given type of knowledge and cognitive level. In order to answer this research question, average test score of the students studied from Non-ILE, ANM, and SIM groups were compared as these three groups learnt from learning materials that differed in terms of degree of interaction.

Learning impact on 'Understand Conceptual knowledge': The Kruskal-Wallis test on the post-test scores of these three groups demonstrated that there was no statistically significant difference between the scores related to 'Understand Conceptual knowledge' across groups. All the groups; Non-ILE, ANM, and SIM performed equally well for the assessment questions related to 'Understand Conceptual knowledge' category. This was evident from the p value obtained after running Kruskal-Wallis test (p=0.306) and also from the individual comparisons among groups for 'Understand Conceptual knowledge' category test scores (column 3 of Table 5.2 shows individual p values obtained after running Mann-Whitney U test). Thus, hypotheses E1-H1-A was not supported by the results obtained. This established sufficiency of non-interactive Learning Environment (Non-ILE) (the lowest degree of interaction) for tasks of category 'Understand Conceptual knowledge'.

Learning impact on 'Understand Procedural knowledge': The Kruskal-Wallis test on the post-test scores of all the three groups and Mann–Whitney U test reported the following results. While comparing test scores of Non-ILE, ANM and SIM groups; Animation (ANM) and Simulation (SIM) groups performed equally well (p=0.931) on the assessment questions related to 'Understand Procedural knowledge' category. However, there was statistically significant difference between the scores for 'Understand Procedural knowledge' for i) Non-ILE and ANM groups and ii) Non-ILE group and SIM groups (p=0.010 and p=0.004 respectively). These results did not support hypothesis E1-H1-B. Non-interactive Learning Environment was found to be more effective for 'Understand procedural knowledge’ as compared to ANM and SIM.

Learning impact on 'Apply Procedural knowledge': The Kruskal-Wallis test on the post-test scores of all the three groups and Mann–Whitney U test reported the following results. While comparing test scores of Non-ILE, ANM and SIM groups to answer the first research question, though the Simulation (SIM) group had the maximum test score among the three groups, no statistically significant difference was found among the test scores of this category. Thus, comparison of 'Apply Procedural knowledge' scores for Non-ILE, ANM and SIM groups could not support hypothesis E1-H1-C.

Result Analysis: E1-RQ2

The E1-RQ2 of the study was about impact of IEFs on effective learning from learning environment at the same level of interaction for the given type of knowledge and cognitive level. In order to answer this research question, average test score of students who studied from SIM and IELE groups were compared. As explained earlier in the section 5.1.2 of this Chapter, SIM and IELE had same degree of interaction, but IELE was designed with IEFs Productively Constrained Variable Manipulation and Permutative Variable Manipulation.

Learning impact on 'Understand Conceptual knowledge': SIM and IELE performed equally well for the assessment questions related to 'Understand Conceptual knowledge' category. Thus, hypothesis E1-H2-A was not supported by the results obtained. This result, when considered along with the result obtained in the context of hypothesis E1-H1-A established the sufficiency of non-interactive Learning Environment (Non-ILE) for tasks of category 'Understand Conceptual knowledge'.

Learning impact on 'Understand Procedural knowledge': For 'Understand Procedural knowledge' category questions, IELE group was found to be superior and a statistically significant difference was found between the test scores of SIM and IELE group (*p*=0.006). This result supported the hypothesis E1-H2-B. When all the four groups test scores were compared, though IELE group score was the highest among them, we could not find statistically significant difference between Non-ILE and IELE group test scores. The interpretation of results in this context has been discussed in detail in the discussion section of this Chapter.

Learning impact on 'Apply Procedural knowledge': The test scores for 'Apply Procedural knowledge' for IELE group was found to be higher and statistically significant as compared to SIM group score. This result supported the hypothesis E1-H2-C indicating the effectiveness of IEFs on IELE group for 'Apply Procedural knowledge' category. The statistically significant difference found between the test scores of IELE group and each of the Non-ILE, ANM, SIM groups (*p*=0.010, *p*=0.000, *p*=0.013 respectively) confirmed the necessity of IELE for effective learning of tasks catering to 'Apply Procedural knowledge'.

5.1.9. Analyzing students' perception about need for IEFs: Qualitative phase of the research design

The explanatory sequential research design of the study had a quantitative strand that helped in analyzing the learning impact of the treatment for different groups. The qualitative strand in the explanatory sequential mixed design was used for corroborating the findings of the quantitative analysis. In this study, more importantly apart from serving as means for triangulating the quantitative findings, the qualitative phase of the design aimed at gaining insight about the need of IEFs in the learning process. Thus, in order to assess students' perception about; i) appropriateness of the level of interaction in ILEs for a given task, ii) any need of additional means (such as IEFs) while interacting with ILEs, and overall to understand how students explore interactive learning material, the qualitative phase of the design was planned. The knowledge about students' perception regarding appropriateness of the level of interaction in ILEs for a given task was expected to help in answering the E1-RQ1 related to the impact of higher degree of interaction on learning. On the other hand, knowing more about whether students perceive any need for some additional features while exploring the interactive nature of ILEs was important for assessing the role of IEFs in ILE learning. This was expected to support the answering of E1-RQ2. Thus, overall qualitative phase of the explanatory sequential design was planned to answer questions, i) Do students perceive higher level of interaction useful to learn a given task while learning from ILEs? and ii) Does analysis of students' exploration pattern of ILEs indicate need for features like IEFs?

Participants

Twelve students across a range of achievement levels from the target population were interviewed and a screen-capture was recorded while they interacted with the learning environment. These twelve students were selected by purposive sampling, representing high, medium and low achievers' strata of the population. Due to logistical constraints (such as availability of students during the experimental study period), the number of participants in our study was limited to 12.

Procedure

Initially, students were instructed to interact with the learning material without any external instructions or guidance. While they interacted with the interactive learning material (Simulation), the screen capture was recorded using CamStudio™ open source software to observe how students explore the interactive learning material.

Followed by this, semi-structured interviews were conducted of all the students individually. The audio recording of the interviews was done. In the beginning of the interview, students were asked to comment about the similarities and differences that they noted while interacting with the Simulation (SIM) and IELE. Later, students were given three questions from the topic, one each from 'Understand Conceptual knowledge', 'Understand Procedural knowledge', 'Apply Procedural knowledge' category and they were asked to give their comments about their perception about which features would make a given type of learning material appropriate for answering the question from these categories.

Analysis of recorded screen captures

The recorded screen captures were analyzed to find out the manner in which students explore the interactivity offered by interactive learning material. The Simulation offered manipulation of four parameters related to the content presented. Students could select either one of them or multiple variables (maximum up to four) simultaneously. For developing in-depth and complete understanding of the content, it was expected that while exploring, students would not just manipulate all the offered variables individually, but also, different possible combinations of these variables by simultaneous selection. The main objective of the analysis of recorded screen captures was to find out whether students explored all the possible manipulation opportunities offered by the ILE.

The manner in which students explored the simulation, the path they took while carrying out variable manipulation has been represented in a graphical manner in the form of Simulation Exploration Trajectory Representation as shown in Figure 5.3. In this representation, horizontal axis represents every time instance (T1, T2, T3 and so on) at which variable manipulation was carried out by a student, whereas the vertical axis represents the number of variables selected for manipulation at that time instance (for example, 1/2/3/M, wherein 'M' represents multiple, simultaneous selection of all the variables). The typical colour represents trajectory taken by each student while interacting with the simulation by manipulating variables.

As could be seen from Simulation Exploration Trajectory Representation, only three students out of twelve carried out all multiple variable manipulation. Seven students used two variables for exploring content and two students manipulated three variables to explore content. It implied that maximum number of students did not try the multiple transformation options. The higher concentration of trajectories related to single and double variable manipulation as observed from Simulation Exploration Trajectory Representation revealed that most of the students did not try multiple variable manipulation. This indicated that the affordance of variable manipulation offered by the simulation was not fully exploited by learners and thus learning opportunities offered by interactivity in the simulation were under-utilized. This was especially unfavorable for procedural knowledge tasks which involve multiple sequential operations. This observation, in a way, advocated the need for enforced directions and also the need to make available all kinds of exploration opportunities in the form of affordance to learners while manipulating variables.

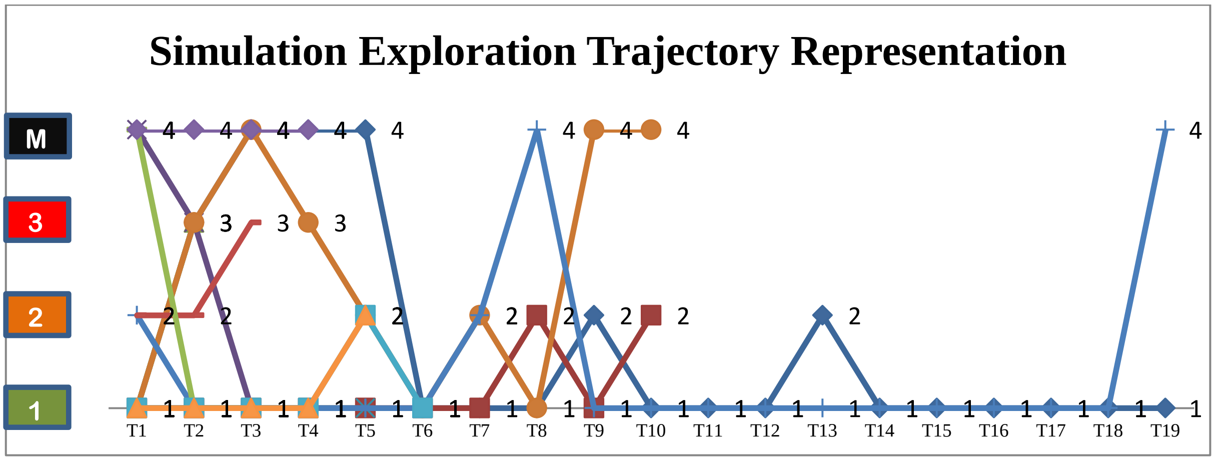


Figure 5.3. Simulation Exploration Trajectory Representation

Analysis of interviews

The face-to-face semi-structured interviews were conducted to get students' interpretation and perception about the following two aspects. Each interview lasted for 10-12 minutes. Students were asked about: firstly, what differences and similarities did they notice while interacting with different interactive learning materials and secondly, which type of learning material they found necessary and sufficient while answering questions pertaining to three different categories; 'Understand Conceptual knowledge', 'Understand Procedural knowledge', 'Apply Procedural knowledge'. The recorded interviews were transcribed and analyzed further using Content Analysis method with a 'sentence' as the 'coding unit'. The coding was done keeping in mind the objectives of questions asked. Accordingly, three categories of the codes emerged from the analysis; 'Feature', 'Reason' and 'Learning impact'. The comments made by the students fell into following three categories: i) the identified features of the learning material, ii) the reasoning why a particular feature they find important, iii) their perception about the learning impact that the feature/s would lead to. The typical verbatim comments classified as per these categories of the code are listed below. The Exploration approach of data analysis (Cohen, Manion & Morrison, 2007) was adopted to follow patterns and trends observed in the data.

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

Following have been the inferences from the data analysis:

1. All students were of the opinion that the non-interactive learning environment was sufficient for answering question of 'Understand Conceptual knowledge' category and none of them found the necessity of interactive learning environment for the same.
2. However, while answering questions related to other two categories, students indicated the necessity of interactive learning environment, especially the IELE, in order to understand sequencing part involved in the multiple transformation. The students also reported that the IELE would help them in visualizing the transformation process and its sequential operation in a better way.
3. When asked about their perception about IELE, the students preferred to study from it, as it could allow them to study impact of every individual operation in a sequential manner. Following are some of the verbatim responses from students that supported this inference. *".....This applet (IELE) is better........it is better to study one operation at a time and then go for all operations together.......it will give better understanding....."*, *"...... this way of dissecting every operation helps in understanding the multiple operations at a later stage......"*.

The interpretations and inferences from this qualitative study were found to be in coherence with the rationale for designing IEFs in ILEs. These features were perceived to be crucial by students, especially, while applying procedural tasks. Students' perception supported the statistical findings for 'Apply Procedural knowledge'. During interviews, students unanimously accepted sufficiency of Non-interactive learning environment for tasks related to 'Understand Conceptual knowledge'. This perception of students has also been confirmed by the results that found average test scores of all the groups to be statistically equivalent while understanding conceptual knowledge. Thus, this qualitative phase of the explanatory sequential research design was found to be useful in supporting the results related to 'the appropriate degree of interaction for the given task' and in supporting the need for IEFs.

5.1.10. Discussion

The goal of this particular research study E1 was twofold: It investigated whether higher level of interaction could lead to better learning and also assessed learning effectiveness of IEFs in ILEs. The results of study E1 showed that, especially for higher levels of learning, ILEs could not deliver their learning benefits unless they were supported with appropriate IEFs. The results also challenged the widely accepted notion that higher degree of learner control always implies effective learning. The summary of results obtained from this study has been as given in Table 5.4.

Effect of degree of interaction on learning from ILE:

Prior work had reported consideration of either, the type of knowledge (Clark & Chopeta, 2004) or the cognitive level (Lahtinen & Ahoniemi, 2005) as criteria for deciding suitable learning environment. However, in this study we have considered both the criteria together to meet engineering curriculum requirement. The same method is being followed while developing instruments for all the research studies of the thesis.

The results obtained from the research study indicated that non-interactive learning environment was sufficient for learning tasks falling into 'Understand Conceptual knowledge' category, as average scores of all the experimental groups were found to be statistically similar. This result highlighted that higher degree of interaction need not necessarily lead to higher learning outcome. It also indicted that type of knowledge and cognitive level of the learning task need to be taken into consideration while assessing effectiveness of ILEs. While attempting a given task at a specified cognitive level, learners are expected to undergo certain amount of cognitive processing. The learning material, that puts additional cognitive overload on learners, instead of assisting them, may hamper the learning process. Previous studies in this context (Low & Sweller, 2005; Moreno & Mayer, 1999) have confirmed the undesirable role of cognitive overload in the learning process. Consideration to this aspect has been given in the research studies E4 and E5.

Table 5.4 Result summary for experiment E1

Research Questions	
Given the type of knowledge and cognitive level, does higher degree of interaction, lead to effective learning? Given the type of knowledge and cognitive level, how do 'Interactivity Enriching Features' affect learning in interactive visualization with the same level of interaction?	
Experimental Results	**Inferences**
'Understand Conceptual knowledge':- No statistically significant difference was found in the average scores of Non-ILE, ANM, SIM and IELE group.	Lower degree of interaction i.e. non-interactive learning environment is sufficient for effective learning of 'Understand Conceptual knowledge'.
'Understand Procedural knowledge': - Non-ILE group average score was statistically higher than the average scores when compared with ANM and SIM group, but IELE group score was found to be higher than Non-ILE score (though statistically insignificant).	Degree of interaction does not solely contribute to effective learning while 'Understanding Procedural knowledge'. Higher degree of learner control does not lead to improved learning unless accompanied by 'Interactivity Enriching Features'.
'Apply Procedural knowledge':- IELE group score was found to be statistically higher than SIM group score and also highest among all the four groups (Non-ILE, ANM, SIM, and IELE), although Non-ILE, ANM, SIM group scores were found to be statistically equivalent.	Higher degree of learner control does not lead to improved learning unless augmented by 'Interactivity Enriching Features'. Thus, degree of interaction or degree of learner control does not solely contribute to effective learning while 'Applying Procedural knowledge'.

Another result from this has been that the Animation (ANM) and Simulation (SIM) were found to be equally effective, but inferior to non-interactive Learning Environment (Non-ILE) for 'Understand Procedural knowledge'. Although the direct inference from this result has been the effectiveness of Non-ILE over Animation (ANM) and Simulation (SIM) for 'Understand Procedural knowledge', it has also thrown light upon the presentation format of interactive learning environment. The animation and simulation followed different presentation format. It should be noted that the usability study conducted for the learning material for Non-ILE, ANM and SIM group had already established their equivalence. Animations and simulations with their inherent ability to animate the educational content, showed various steps of the procedural tasks in a temporally stacked manner. The non-interactive learning environment, lacking the ability of showing content dynamically, displayed various steps involved in the procedural task at the same time on a single integrated screen in a spatially distributed manner, although they were happening at different time instances. Thus, the factor that influenced learning, apart from different degree of interaction in the learning environment could have been, the spatially distributed presentation format of Non-ILE and the temporally stacked presentation format of ANM and SIM. Temporally stacked presentation format might have held back learning from interactive animation and simulation. This could have been due to the burden that it put on learners while retaining previously learnt knowledge. Retaining and using the previously learnt knowledge must have demanded more cognitive processing in addition to the essential cognitive processing and thus, might have contributed to excessive extraneous cognitive load. We looked at this result differently, through the lenses of our second research question. The implications of this result are twofold. Its first contribution is by suggesting that non-interactive learning environment can be boosted by effective presentation format and can be worked to deliver at par, or perhaps better than interactive learning environment, when the interactive nature of learning environment burdens learners with excessive cognitive processing. The second interpretation is more important and thought provoking. In fact, this is a caution, that interactivity offered in interactive learning environments would be 'wasted' if not supported with the appropriate presentation format or other influencing features. Some of the previous studies (Boucheix & Schneider, 2009; Grunwald & Corsbie-Massay, 2006) have discussed the aspect of presentation format. In this study, presentation format demonstrated its ability to override interactivity in the learning environment and to become more influential in the learning process from the ILEs.

While catering to 'Apply Procedural knowledge', the comparative analysis of Non-ILE, ANM and SIM group average scores exhibited that the average score of SIM was higher than the average scores of Non-ILE and ANM, even though statistically non-significant. This finding could have been interpreted as sufficiency of Non-ILE learning material for 'Apply Procedural knowledge'. But, the highest score of IELE among all the four groups needs detailed elaboration. This issue has been discussed in the following subsection.

Effect of 'Interactivity Enriching Features' on learning from ILE:

The second research question of this study investigated what impact IEFs can have on learning from ILEs. The core of interactive simulation is the affordance of variable manipulation. It offers opportunity to learners to interact with the educational content of the learning material. This is one aspect that sets it apart from non-interactive learning environment and even from an animation. While comparing learning from all the four experimental groups, the results have showed the highest learning outcomes from IELE group for 'Understand' and 'Apply' procedural knowledge category. Due to the Productively Constrained Variable Manipulation, while selecting variable for manipulation, IELE allowed students to select only one, then only two and gradually all the variables for manipulation. This gradual progression in the learning environment, from single operation, then two operations and then multiple transformation operation helped learners in developing gradual, yet sound knowledge base necessary for attempting the procedural tasks. This aspect had also got reflected during interviews of students and their perception about different learning materials. Generally, students have a tendency to interact with simulation by clicking or enabling all the possible options they see. Manipulating variables in this manner need not necessarily lead to inquiry based learning, but, may rather end up simply in a playful interaction. The introduction of productive constraint in the learning material in this manner, not just ensured meaningful learning, but, also offered complete exploration freedom to learners. The productive constraint introduced in this manner has the potential to improve learning from simulation environment without compromising the discovery based learning nature of simulation. Additionally, the inclusion of Permutative Variable Manipulation also offered more exploration opportunities to learners, such as swapping action sequence, thus, offering additional opportunities to address the demands of learning objectives. It offered an opportunity to learners to develop expertise in procedural tasks by using procedures flexibly, algorithmically; thus giving more meaning to the process of applying procedural knowledge.

It must be noted that the 'Apply Procedural knowledge' average scores of the three experimental groups, (Non-ILE, ANM and SIM) were found to be at par, but IELE group's 'Apply Procedural knowledge' average score was found to be higher as compared to the other groups with statistical significance. This indicated that the ILE could deliver its learning benefits only after getting augmented by IEFs. Thus, affordance offered by learning environment in the form of Productively Constrained Variable Manipulation and Permutative Variable Manipulation, exhibits the potential to influence learning from ILEs, and has proved itself as 'Interactivity Enriching Features'. For 'Understand Procedural knowledge', IELE group scored highest among all the groups.

To sum up, the results obtained for our second research question, have drawn attention to the aspect that it is not just the feature of variable manipulation, but 'what gets manipulated and how', is more important in ILEs. Introducing learning-conducive interaction features could assist interactivity in ILEs ensuring the expected learning benefits.

5.2 Research Experiment E2 and E3

Research studies E2 and E3 were set with the objective of evaluating learning impact of variation in the degree on interaction in line with the first research question of the thesis work. As both the research studies E2 and E3 followed identical research design, similar treatment and answered the same research question, most of their details and aspects are discussed commonly in the following sub-sections. However, since the research studies were conducted for two different topics in Signals and Systems, the learning material used were different. Therefore, the specific details related to E2 and E3 are presented separately.

5.2.1. Research Questions and Hypotheses specific to E2 and E3

The research question for research experiments E2 and E3 was :

E2-RQ1 and E3-RQ1*:* Given the type of knowledge and cognitive level, does higher degree of interaction, lead to effective learning?

To answer these research questions, the following types of learning environments were used.

a) an Animation (ANM)
b) a Simulation (SIM)

The hypotheses for the studies are presented here. Based on the premise that giving control to learners while working with learning environments leads to effective learning, it was expected that students, learning from learning environment offering higher degree of interaction would learn better as compared to students learning from learning environment that offered lower degree of interaction. Like research study E1, for both the research studies E2 and E3, we focused on 'understand' and 'apply' cognitive levels and 'conceptual' and 'procedural' knowledge, in conformance with the two-dimensional taxonomy framework as proposed by Anderson (Anderson, et al., 2001) to measure learning effectiveness of ILEs. Considering the content to be learnt for the selected topic, we focussed on three categories of questions. While for E2 we focussed on ‘Apply Conceptual knowledge’, ‘Understand Procedural knowledge’ and ‘Apply Procedural knowledge’ categories of questions; for E3 we focussed on 'Understand Conceptual knowledge’ ‘Apply Conceptual knowledge’, and ‘Apply Procedural knowledge’ categories of questions.

Thus, the hypotheses for E2-RQ1for research experiment E2 were:

E2-H1-A) For Conceptual knowledge at Apply level, students learning with Simulation (SIM) will score higher as compared to students learning with Animation (ANM).

E2-H1-B) For Procedural knowledge at Understand level, students learning with Simulation (SIM) will score higher as compared to students learning with Animation (ANM).

E2-H1-C) For Procedural knowledge at Apply level, students learning with Simulation (SIM) will score higher as compared to students learning with Animation (ANM).

The hypotheses for E3-RQ1for research experiment E3 were:

E3-H1-A) For Conceptual knowledge at Understand level, students learning with Simulation (SIM) will score higher as compared to students learning with Animation (ANM).

E3-H1-B) For Conceptual knowledge at Apply level, students learning with Simulation (SIM) will score higher as compared to students learning with Animation (ANM).

E3-H1-C) For Procedural knowledge at Apply level, students learning with Simulation (SIM) will score higher as compared to students learning with Animation (ANM).

The hypotheses mentioned above were tested with the help of a research study focused on the topic 'Convolution' and 'Fourier transform Properties' for research studies E2 and E3 respectively. While 'Convolution' is a topic that forms the base for understanding Linear Time Invariant (LTI) systems and their modeling; the topic 'Fourier transform Properties' is important in understanding various transforms and their uses in different application areas.

5.2.2. Learning Materials

The details of the learning materials used for the studies are as follows.

5.2.2.1. Learning Materials for Research Experiment E2

Figures 5.4 and 5.5 show snapshot of the applet screen interface for ANM group and SIM group respectively in the topic of convolution for research experiment E2. The ANM group studied the content in the form of animation that offered only play-pause-stop control to learners. It did not offer them any opportunity to change educational content.

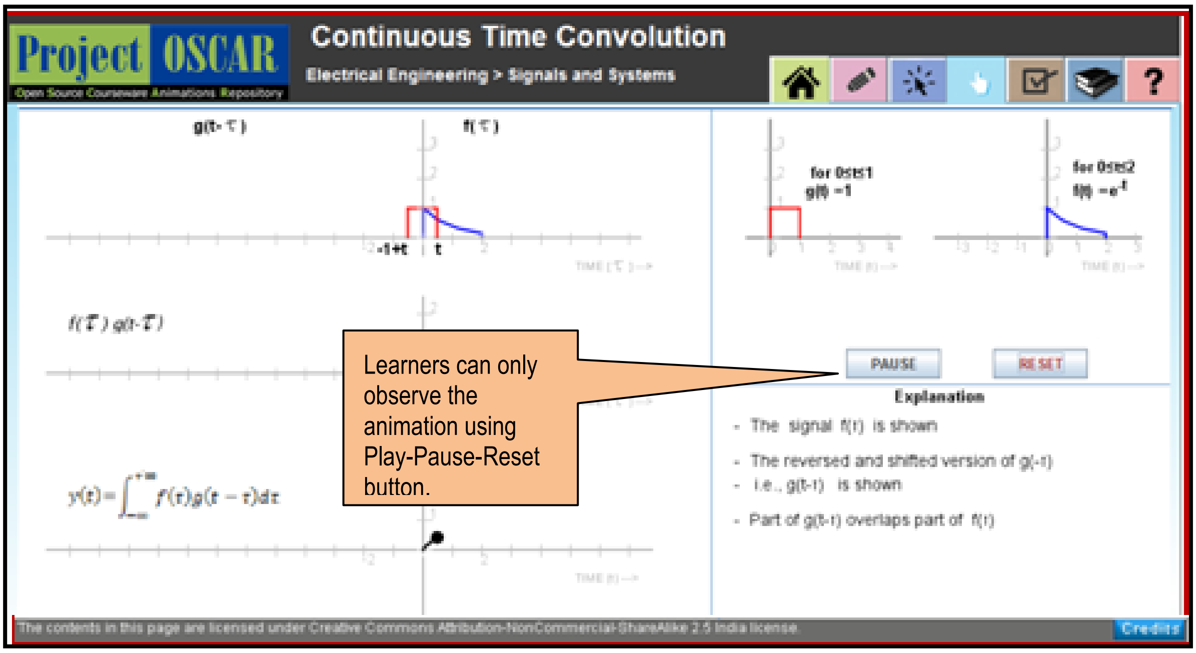


Figure 5.4. Screenshot of the ANM learning Environment for a topic on Convolution

The SIM group learnt with an interactive JAVA applet offering dynamic manipulation of variables for exploring and interacting with the educational content[2]. For research study E2, in case of Convolution, the applet offered opportunity to learners to select signals to be convolved. The convolution process needed two signals to be given as input. Learners could select input signals to be convolved as per their choice.

[2] URL for ANM and SIM
http://oscar.iitb.ac.in/availableProposalsAction1.do?%20title=%20Continuous%20Time%20Convolution%20&id=%20654

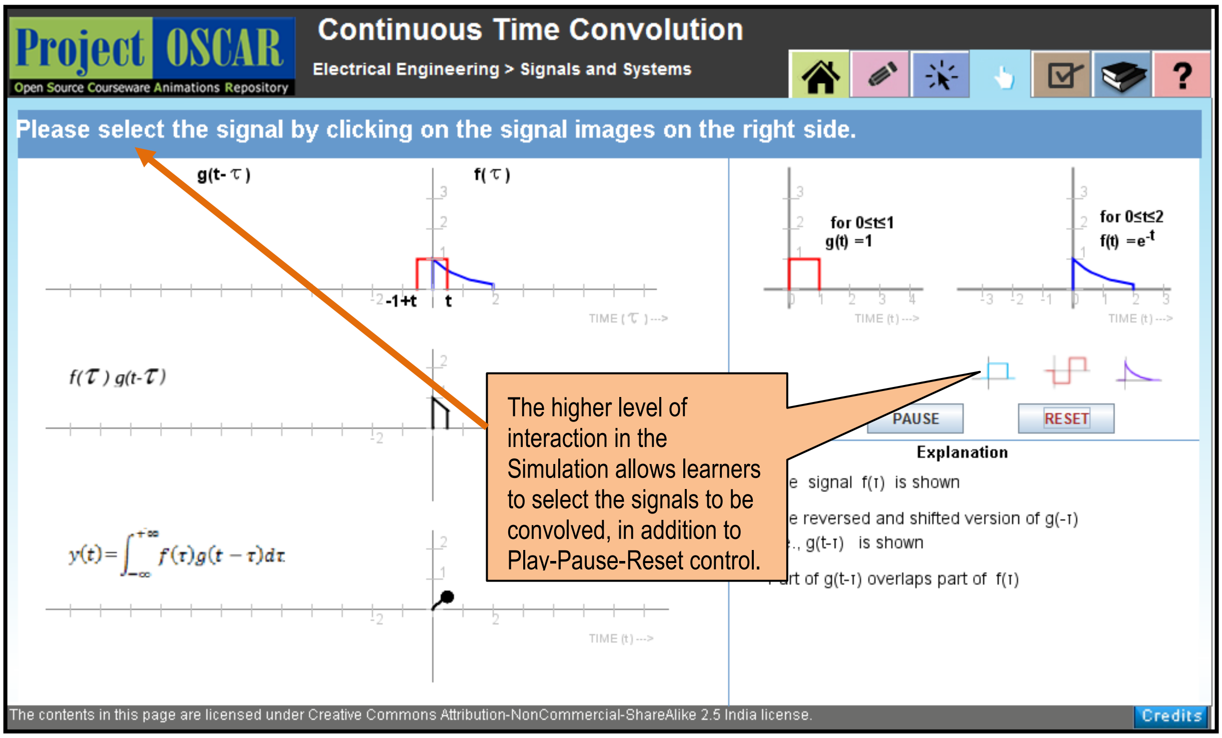


Figure 5.5. Screenshot of the SIM learning Environment for a topic on Convolution

To test equivalence of the learning materials in factors other than what was considered in the experiment, such as usability, and look and feel were tested with students who had already studied the course on Signals and Systems using SUS Scale (Brooke, 1996). Both learning materials were tested to establish equivalence of the learning material and were found to be equivalent. Total 38 students participated in this exercise. The mean SUS scale scores were ANM (M= 75.97, SD=8.79), SIM (M=77.32, SD=9.13). The t test was found to be statistically non-significant at $p > 0.05$ ($p = 0.677$). The survey instrument used as SUS scale is given as Appendix A.

5.2.2.2. Learning Materials for Research Experiment E3

Figures 5.6 and 5.7 show snapshot of the applet screen interface for ANM group and SIM group respectively in the topic of 'Fourier Transform Properties' for research experiment E3. The SIM group learnt with an interactive JAVA applet offering dynamic manipulation of variables for interacting with the educational content. The applet was developed by JH University for exploring the use of the World Wide Web in engineering education in the domain of Signals Systems Controls[3]. The applet offered opportunity to learners to select signals whose Fourier transform properties could be viewed and also students could decide the properties to be applied. The ANM group studied the same content (same properties for the same type of signals) in the form of animation that offered only play-pause-stop control to learners. The content showed how different Fourier Transform properties vary for different input signals. It did not offer any opportunity to learners to select type of signals or select the property to be applied for changing educational content.

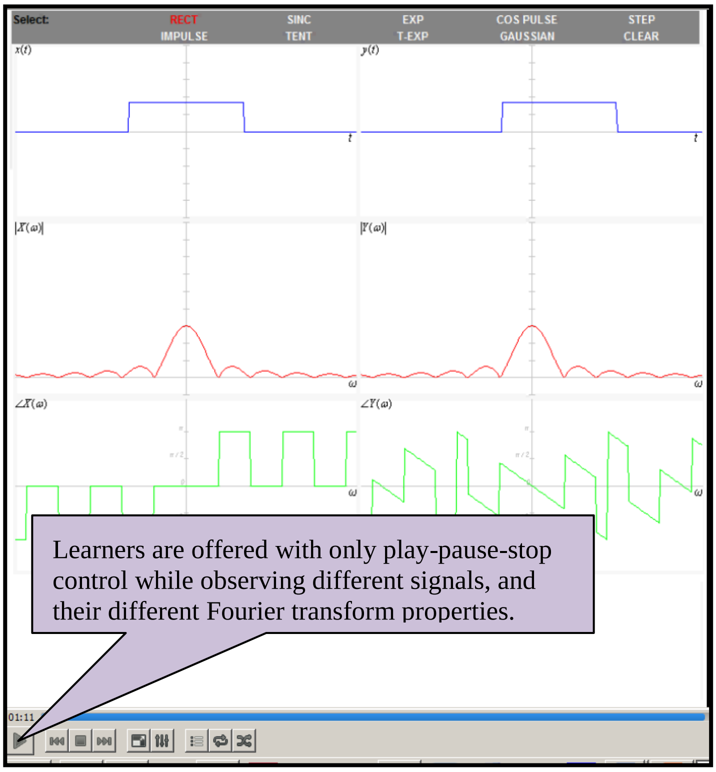


Figure 5.6. Screenshot of the ANM learning Environment in the topic of Fourier Transform Properties

To test equivalence of the learning materials in factors other than what was considered in the experiment, such as usability, and look and feel were tested with students who had already studied the course on Signals and Systems using SUS Scale (Brooke, 1996). Both learning materials were tested to establish equivalence of the learning material and were found to be equivalent. Total 25 students participated in this exercise. The mean SUS scale scores were ANM (M= 78.45, SD=8.15), SIM (M=76.65, SD=9.13). The t test was found to

[3] http://pages.jh.edu/~signals/ctftprops/indexCTFTprops.htm

be statistically non-significant at $p > 0.05$ ($p = 0.566$). The survey instrument used as SUS scale is given as Appendix A.

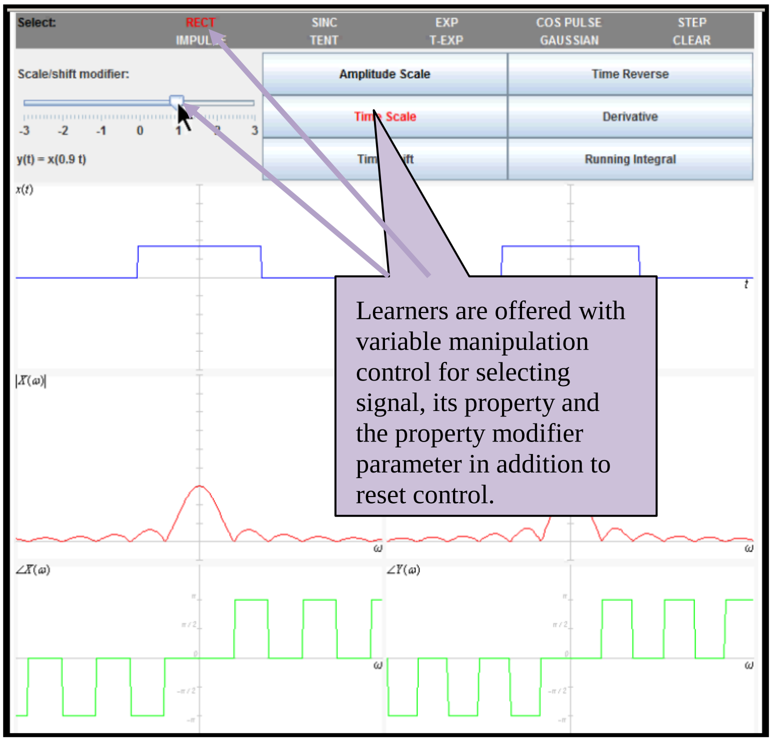


Figure 5.7. Screenshot of the SIM learning Environment in the topic of Fourier Transform Properties

5.2.3. Participants and experimental design for Research Experiment E2 and E3

Participants were students from different batches of the second year of engineering from the college affiliated to University of Mumbai. Entire division of second year engineering students from Electrical Engineering program participated in the study, thus presenting a good representative sample of the students' population. The selection of the college was done on the basis of ease of access and other logistics issues. The students generally admitted to the engineering program qualify a common entrance examination. Also, all the participants were assessed in the first year examination that was common for all the students from the University. These points ensured the representativeness of the sample.

The studies were conducted using a '2-group pre-test post-test' experimental research design. The pre-test was necessary to ensure group equivalence of participants for prior knowledge. The gain i.e. difference between post-test and pre-test was used to evaluate the effectiveness of treatment for various groups. Participants were familiar with the use of ICT tools in learning through other courses and laboratory in their curriculum. While creating matched-random assignment groups, scores of previous semester examination were considered for matching the group equivalence. The semester examination question papers and assessment pattern being uniform for all the students, it ensured that the students participating in the research studies were at par in terms of reference knowledge level.

5.2.3.1. Details of participants and groups for Research Experiment E2

Total 141 participants participated in the study E2 (N= 141; 106 males and 35 females). Participants were randomly assigned to one of the following two conditions:

a) Animation (ANM group); N=71 and
b) Simulation (SIM group); N=70

The mean examination scores considered for creating matched-random groups were: ANM (M= 547.55, SD= 66.81), SIM (M= 549.17, SD= 65.26). The independent sample t-test did not show statistically significant differences between the performance scores of the students from each group $p > 0.05$ ($p = 0.442$). An alpha level of 0.05 was used for all statistical tests.

5.2.3.2. Details of participants and groups for Research Experiment E3

Total 71 participants participated in the study E3 (N= 71; 58 males and 13 females).

Participants were randomly assigned to one of the following two conditions:

a) Animation (ANM group); N=35 and
b) Simulation (SIM group); N=36

The mean examination scores considered for creating matched-random groups were: ANM (M= 558.62, SD= 73.94), SIM (M= 561.62, SD= 67.30). The independent sample t-test showed no statistically significant differences between the performance scores of the students from each group $p > 0.05$ ($p = 0.428$). An alpha level of 0.05 was used for all statistical tests.

5.2.4. Treatment for Research Experiment E2 and E3

The instructional intervention for the two conditions for the research experiment E2 and E3 was identical. The details were was as follows:

a. The ANM group studied the same content in the form of animation that offered only play-pause-stop control to learners.
b. The SIM group learnt with an interactive JAVA applet that offering dynamic manipulation of variables for exploring and interacting with the educational content of the learning environment.

5.2.5. Measures and Instruments

As explained in detail in section 5.1.5, the assessment instrument was developed to test students' learning in terms of 'understand', 'apply' cognitive levels and 'conceptual' and 'procedural' types of knowledge. The instruments focused not only on the types of knowledge, but also simultaneously on the cognitive levels of the task to be accomplished to fulfil engineering curriculum's requirement of developing learners' expertise; not just in the given type of knowledge, but also at the desired cognitive level of that knowledge.

5.2.5.1. Measures and Instruments for Research Experiment E2

In the topic of Convolution, for research study E2, underlying concepts related to signal processing such as signal folding, signal shifting, linearity and time invariance constituted conceptual knowledge. Carrying out requisite signal processing operations in a sequential and meaningful manner as a part of convolution was an example of procedural knowledge. With regard to cognitive level of the task, questions related to ‘understand’ cognitive level were in the form of identifying or interpreting a particular signal processing task, whereas, at ‘apply’ cognitive level, students were expected to use their fundamental understanding of signal processing and linear time-invariant systems to solve questions by applying their knowledge in the new situation. The eight assessment questions were distributed across these three categories of ‘Apply Conceptual knowledge’, ‘Understand Procedural knowledge’ and ‘Apply Procedural knowledge’. The normalized scores were compared across groups for the above mentioned categories. The questions have been provided in Appendix C. Out of eight, answering two questions demanded elaborate working and explanation of the solution approach. The participants were instructed to show detailed working while answering such questions. While assessing the answer sheets, the marking scheme allotted 1 mark each for question number 1 to 4, Q7, and Q8. As question 5 and 6 required elaborate working, the marks were given step wise. For example, marks were allotted for each of the steps such as: changing 't' to 'τ' (Maximum score =0.5), flipping / reversing either of the signals (Maximum score =1), shifting the flipped signal (Maximum score=2), finding out area under the curve for each shift introduced (total 8 such values are to be calculated) (Maximum score =4) and plotting area calculated as a function of shift introduced (Maximum score =1). Within each step, students were graded based on the status of ' not attempted', 'partially attempted' and ' successfully completed'.

5.2.5.2. Measures and Instruments for Research Experiment E3

In the topic of Fourier Transform Properties, underlying concepts related to signal processing such as signal folding, signal shifting constituted the conceptual knowledge, while carrying out requisite signal processing operations in a sequential manner as a part of transform property process was an example of procedural knowledge. With regard to cognitive level of the task, questions related to 'understand' cognitive level were in the form of identifying or interpreting a particular property, whereas, at 'apply' cognitive level, students were expected to use their fundamental understanding of signal processing and transform properties to solve questions by applying their knowledge in the new situation. The eleven assessment questions were distributed across these three categories of 'Understand Conceptual knowledge' 'Apply Conceptual knowledge', and 'Apply Procedural knowledge'. The normalized scores were compared across groups for the above mentioned categories. The questions are provided in Appendix D. Some of the questions demanded elaborate working and explanation of the solution approach. The participants were instructed to show the detailed working while answering such questions.

5.2.5.3. Content validity

To establish validity of the instrument developed for pre-post-test was peer-reviewed by the researchers of this study in cooperation with five domain experts who had 20+ years of teaching experience each in the domain of Signals and Systems. Two reviewers also had a formal background in Educational Technology research. The review process was carried out in an iterative manner. The suggestions given were incorporated and instrument was further reviewed till all the reviewers were satisfied with the accuracy of the content, categorization of questions and their appropriateness in the context of learning objectives.

One of the suggestions received for the instrument on Convolution topic was to reduce the number of assessment questions. As some of the questions required elaborate and stepwise answers, two question were dropped after suggestion from experts to stick to the time of the assessment test. For the instrument on Fourier Transform Properties, the experts recommended rephrasing of questions to simplify language for better comprehension.

5.2.6. Procedure

5.2.6.1. Procedure for Research Experiment E2

Pilot study of E2:

Four students who had already studied Signals and Systems took part in a pilot study whose aim was to determine if the learning materials, assessment instruments and procedure were suitable and aligned. The pilot study was carried out prior to conducting the main study to get feedback about various feasibility and usability related issues regarding the learning material, instrument and experiment procedure. Students gave feedback about the clarity and comprehension of the learning environment and the post-test. The students did not report any flaw in understanding and interpreting the assessment questions, and mathematical expressions and graphical representation of the waveforms wherever applicable.

Main Research Study of E2:

The study was performed during lab hours where all participants could use individual computer terminals. The study was conducted by lab instructors who were given detailed briefing by the researchers about the procedure and protocols to be followed. Participants were informed about the purpose of the experiment. Participants signed consent forms and they were informed that all the collected information would be kept confidential. Detailed directions on how to use the learning environment were given to the participants. As the topic of convolution was already covered by the course instructor, it was necessary to check their prior knowledge in the topic by conducting pre-test. Afterwards the participants were given 30 minutes of time to interact with the learning material. This was followed by administration of the post-test for the next 55 minutes. The post-test had the same questions as that of pre-test, but in scrambled manner with change in the numerical data. During the test, participants were not allowed access to the learning material. None of the participants demanded more amount of time during learning phase or during test phase. After the experiment, participants were thanked and were given participation certificates.

5.2.6.2. Procedure for Research Experiment E3

Pilot study of E3:

Three students who had already studied Signals and Systems took part in a pilot study whose aim was to determine if the learning materials, assessment instruments and procedure were suitable and aligned. The pilot study was carried out prior to conducting the main study to get feedback about various feasibility and usability related issues regarding the learning material, instrument and experiment procedure. Students gave feedback about the clarity and comprehension of the learning environment and the post-test. The students complained about ambiguous nature of some questions and expressed their inability to interpret questions clearly. Such questions were revised; language and associated diagrams were revised as per the feedback received.

Main Research Study of E3:

The study was performed during lab hours where all participants could use individual computer terminals. The study was conducted by lab instructors who were given detailed briefing by the researchers about the procedure and protocols to be followed. Participants were informed about the purpose of the experiment. Participants signed consent forms and they were also informed that all the collected information would be kept confidential. Detailed directions on how to use the learning environment were given to the participants. As the topic of Fourier Transform properties was already covered by the course instructor, it was necessary to check their prior knowledge in the topic by conducting pre-test. The participants were given 30 minutes of time to interact with the learning material. This was followed by administration of the post-test for the next 40 minutes. The post-test had the same questions as that of pre-test, but in scrambled manner with change in the numerical data. During the test, participants were not allowed access to the learning material. None of the participants demanded more amount of time during learning phase or during test phase. After the experiment, participants were thanked and were given participation certificates.

5.2.7. Data Analysis Techniques for E2 and E3

The research design being 2-group pre-test post-test, difference in the post-test and pre-test was compared to assess effectiveness of the treatment. The instrument was designed for three categories of questions. Thus, the test scores were compared for all these three categories independently. Following steps were taken to carry out statistical analysis of data. The raw data as processed to get a normalized score, out of ten for each category of questions. The post-test pre-test difference was calculated to get gain for each category of questions. The data was further checked for normality and other valid assumptions to decide suitability of parametric statistical tests for comparing means. The statistical analysis involved within group and between group comparisons. Initially, within group comparison was carried out with the help of paired sample t-test or its non-parametric equivalent to confirm the statistically significant difference between post-test and pre-test. The means of post-test pre-test difference for both groups were compared to find out statistically significant difference between two groups for all three categories of questions using independent sample t-test or its equivalent non-parametric test. An alpha level of 0.05 was used for all statistical tests.

5.2.8. Results of the Research Study E2

Table 5.5 below shows the mean and standard deviations of test scores conducted for the research study E2. The data was checked for normality using Shapiro-Wilk test and was found to pass the test. As the data was normal, paired sample t-test was used to find out the statistically significant difference between post-test and pre-test within group for each category of questions for both the groups. The paired sample t-test showed statistically significant differences between the performance scores of post-test and pre-test for students from each group $p < 0.05$ ($p = 0.000$), thus confirming the effect of treatment.

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

The participant were randomly allotted to two groups on the basis of their past semester performance score. As shown in the 5.2.3.1 section of this chapter, the group equivalence was proved by the statistically non-significant p value of independent sample t test. However, when the pre-test scores means for all the three categories of questions for both the groups were analyzed using independent sample t-test; the groups were found to be non-equivalent due to the statistically significant difference in their pre-test scores means. The results of t-test indicated that for questions of 'Apply Conceptual knowledge' and 'Apply Procedural knowledge' category, there was statistically significant difference in the pre-test scores of both the groups. Thus, considering this to be a non-equivalent group design for these category of questions, the gain (difference between post-test and pre-test score) for both 'Apply Conceptual knowledge' and 'Apply Procedural knowledge' category of questions for both groups were analyzed with ANCOVA. Before executing ANCOVA, the validity for essential assumption of ANCOCA was verified. ANCOVA was applied with 'pre-test score' as a 'covariate' and the 'post-test score' as 'dependent variable'. The gain score for 'Understand Procedural knowledge' was analyzed using independent sample t-test, as the pre-test score means for this category of questions was found to be statistically equivalent for both the groups.

Learning impact on 'Apply Conceptual knowledge': A one-way ANCOVA was conducted to determine a statistically significant difference between ANM and SIM groups on post-test score after controlling for pre-test score. The necessary ANCOVA test assumptions were verified before running ANCOVA on the data. It demonstrated that there was no statistically significant difference between the post-test scores related to 'Apply Conceptual knowledge' across groups. Both the groups; ANM and SIM performed equally well for the assessment questions related to ‘Apply Conceptual knowledge’ category. This was evident from the *p* value obtained after running ANCOVA test, ($F(1,137)=1.412$, $p=0.237$) after controlling for pre-test score. The R-Squared and Adjusted R-Squared were found to be 0.520 and 0.510 respectively. If the adjusted R-Square value is much lower than the R-Square value, it is an indication that the regression equation may be over-fitted to the sample, and of limited generalizability. These values were found to be very close, anticipating minimal shrinkage based on this indicator. The hypotheses E2-H1-A was not supported by the results obtained. This implied that higher level of interaction could not improve learning for tasks of category ‘Apply Conceptual knowledge’.

Learning impact on 'Understand Procedural knowledge': The individual score on post-test and pre-test for ANM and SIM group indicated that there was no statistically significant difference between the learning gain scores related to Understand Procedural knowledge across groups (Standard deviation for all the samples for both the groups for post-test score was found to be zero). Both the groups, ANM and SIM performed equally well for the assessment questions related to ‘Understand Procedural knowledge’ category. Thus, hypotheses E2-H1-B was not supported by the results obtained. This again implied that higher level of interaction could not improve learning for tasks of category ‘Apply Conceptual knowledge’; or lower level of interaction was found to be sufficient for the desired learning outcome.

Learning impact on 'Apply Procedural knowledge': A one-way ANCOVA was conducted to determine a statistically significant difference between ANM and SIM groups on post-test score after controlling for pre-test score. It demonstrated that there was no statistically significant difference between the post-test scores related to 'Apply Procedural knowledge' across groups. Both the groups; ANM and SIM performed equally well for the assessment questions related to ‘Apply Procedural knowledge’ category. This was evident from the *p* value obtained after running ANCOVA test, ($F(1,137)=2.091$, $p=0.150$) after controlling for pre-test score. The R-Squared and Adjusted R-Squared were found to be 0.780 and 0.763 respectively. If the adjusted R-Square value is much lower than the R-Square value, it is an indication that the regression equation may be over-fitted to the sample, and of limited generalizability. These values were found to be very close, anticipating minimal shrinkage based on this indicator. The hypotheses E2-H1-C was not supported by the results obtained. This implied that higher level of interaction could not improve learning for tasks of category ‘Apply Procedural knowledge'.

5.2.9. Discussion of Research Study E2

The main objective of this research study was to collect evidence to answer the first research question of the thesis. The research experiment E1 already indicated that higher level of interaction need not necessarily lead to higher learning. The results of E1 proved that animation and simulation as learning environments were found to be at par. These results got replicated in the research study E2. For all the three categories of the tasks, animation and simulation groups (ANM and SIM) were found to be at par.

The implications of the results of research experiment E2 were twofold. It would not be inappropriate to simply conclude that animation as an ILE was found to be sufficient for getting the desired learning outcome. However, the other aspect of the result was more crucial and required thoughtful consideration. This results also implied that simulation as an ILE had failed in improving learning in spite of its higher interaction level. This again took us back to the summary and synthesis of the literature presented in Chapter 2 of this thesis. We wished to make the claim based on the results obtained so far from research experiments E1 and E2 that, *'Unless carefully designed, interactivity in ILEs was unable to release its learning potential'*. This finding strongly supported the need for taking up the research problem, 'Under what conditions ILE leads to effective learning?' and also the need to formulate the recommendations to address the problem.

5.2.10. Results of Research Study E3

Table 5.6 below shows the mean and standard deviations of test scores conducted for the research study. The data was checked for normality using Shapiro-Wilk test and was found to pass the test. As the data was normal, paired sample t-test was used to find out the statistically significant difference between post-test and pre-test within group for each category of questions for both the groups. The paired sample t-test showed statistically significant differences between the performance scores of post-test and pre-test for students from each group $p < 0.05$ (p =0.000), thus confirming the effect of treatment.

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

	Animation (ANM) N=35						Simulation (SIM) N=36					
Question category	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

The participant were randomly allotted to two groups on the basis of their past semester performance score. As shown in the 5.2.3.2 section of this Chapter, the group equivalence was proved by the statistically non-significant p value of independent sample t-test. The prior knowledge equivalence was also verified by conducting independent sample t-test on student's pre-test score for all the three categories of the question. For the pre-test, students from both the groups were found to be statistically equivalent for all the three categories (independent sample t test p value: 'Understand Conceptual knowledge' p= 0.651, 'Apply Conceptual knowledge' p= 0.573, 'Apply Procedural knowledge' p=0.976). The learning gain (difference between post-test score and pre-test score) was used to assess the effect of treatment given for both the groups on all the three categories of the tasks.

Learning impact on 'Understand Conceptual knowledge': The independent sample t-test was conducted to determine a statistically significant difference between ANM and SIM groups' learning gain. For 'Understand Conceptual knowledge', the test indicated that there was no statistically significant difference between the learning gain scores. Both the groups, ANM and SIM performed equally well for the assessment questions related to ‘Understand Conceptual knowledge’ category (p=0.214). Thus, hypotheses E3-H1-A was not supported by the results obtained. This implied that higher level of interaction could not improve learning for tasks of category ‘Understand Conceptual knowledge’.

Learning impact on 'Apply Conceptual knowledge': The independent sample t-test was conducted to determine a statistically significant difference between ANM and SIM groups' learning gain. For 'Apply Conceptual knowledge', the test indicated that there was statistically significant difference between the learning gain scores. The ANM group performed better than SIM group for the assessment questions related to ‘Apply Conceptual knowledge’ category (p=0.002). The hypotheses E3-H1-B was not supported by the results obtained as the lower level of interaction led to better learning. In other words, the higher level of interaction was found to be detrimental to the learning and had negative impact on learning of ‘Apply Conceptual knowledge’ category of task.

Learning impact on 'Apply Procedural knowledge': The independent sample t-test was conducted to determine a statistically significant difference between ANM and SIM groups' learning gain. For 'Apply Conceptual knowledge', the test indicated that there was no statistically significant difference between the learning gain scores. Both the groups, ANM and SIM performed equally well for the assessment questions related to ‘Apply Procedural knowledge’ category (p=0.360). The hypotheses E3-H1-C was not supported by the results obtained. This implied that higher level of interaction could not improve learning for tasks of category ‘Apply Procedural knowledge’.

5.2.11. Discussion of Research Study E3

The main objective of this research study was to collect evidence to answer the RQ1 of the thesis. The research experiment E1 and E2 already indicated that higher level of interaction need not necessarily lead to higher learning. The implications of the results of research experiment E3 were in line with the findings of E1 and E2. One interpretation of results could be that an animation was found to be sufficient for getting the desired learning outcome. For 'Understand Conceptual knowledge' and 'Apply Procedural knowledge', animation was at par with simulation, whereas for 'Apply Conceptual knowledge' the animation was found to be more effective than simulation. We analyzed the findings from these three experiments (E1, E2 and E3) collectively. The other interpretation of these results has been that a simulation as an ILE had failed in improving learning in spite of its higher interaction level. This again confirmed the inconsistent and mixed nature of the learning impact in ILEs and demanded for a careful consideration to the role of interactivity in ILEs.

5.3. Limitations of the studies

As with all research, we acknowledge some limitations in these studies that should be considered. In these studies, we have excluded learners' characteristics from the scope of the work. Learner characteristics play a crucial role in the effectiveness of learning from ILEs (Barak et al., 2011; Park et al., 2009; Yaman, Nerdel, & Bayrhuber, 2008). However, due to the need to accommodate a variety of learners in the same educational set-up, our research did not consider specific learner characteristics as a variable of the study.

The studies E1, E2 and E3 were conducted in different topics from Signals and Systems. Variation in the topic might be considered as a confounding variable in the studies. However, as the studies were conducted with students learning the course on Signals and Systems, conducting different studies in the same topic would have severely affected learners' prior knowledge levels; and maturity of learners would have become a serious validly threat. Also, the need to synchronize the studies with academic calendar of institutions was a major challenge. Thus, the studies had to be conducted in different topics. Irrespective of the topic, as the instruments were developed on the basis of Anderson's two-dimensional taxonomy framework of educational objectives, we felt that the variation in topics need not dilute the findings from the studies. Another limitation of the study E1 could be the fact that the two IEFs had to be put into the same learning environment due to pedagogical requirement of the topic and thus, further investigations are needed to evaluate learning impact of an individual IEF.

Development of conceptual and procedural knowledge sometimes is expected to be mutually supportive. This aspect was kept out of the scope. A more detailed and rigorous study would be needed to investigate the aspect of how ILEs and IEFs contribute to the mutual and simultaneous development of conceptual and procedural knowledge.

5.4. Summary

Considering the research questions set for the thesis work, its main research aim was to investigate the effectiveness of IEFs in ILEs. This involves a three-step IEF validation process.

- The first step will be to establish the need for IEFs.

- The second step aims at investigating the learning effectiveness of IEFs in ILEs.
- The step three should offer explanation for effect of IEFs on learners' cognitive load in ILEs.

The research experiments presented in this Chapter helped towards the first and the second step of IEF validation process. The results from research experiments E1, E2 and E3 answering RQ1 confirmed the inconsistent and mixed nature of the learning impact in ILEs and demanded for a careful consideration to the role of higher level of interaction in ILEs. The fact that higher level of interaction could not improve learning in ILEs, justified the need for some additional learning-conducive features in the form of IEFs to ensure the expected learning.

The results from research experiment E1 also proved that inclusion of IEFs (Permutative Variable Manipulation and Productively Constrained Variable Manipulation) improved learning. These results are supportive to the second step. In spite of the interaction level being the same, IELE could offer better learning as compared to SIM. The IEFs were expected to augment interactivity and improve learning in ILEs. The results from E1, answering RQ2 have achieved this for specific tasks. Thus, the overall contribution of the research experiments E1, E2 and E3 was to re-emphasis the need for IEFs, and to offer evidences that showed positive learning impact of IEFs.

6. Chapter 6

Validating the effectiveness of Interactivity Enriching Features: Experiment E4

Before presenting next research study, the research questions are reproduced here to understand positioning and objective of this research study E4. Following are the research questions of the thesis.

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?

The findings from experiments E1, E2 and E3 presented in Chapter 5 answered RQ1. The results demonstrated that higher level of interaction could not necessarily lead to higher learning always. The mere presence of interactivity in interactive simulation could not guarantee expected learning outcome as seen from the results of E1. It further demonstrated that strategically designed IEFs were needed for better learning.

Apart from investigating improvement in learning due to IEFs (RQ2), the research work also aimed at understanding how students learn with IEFs in Interactivity Enriched Learning Environments and what effect IEFs have on students' cognitive load (RQ3). Thus, Chapters 6 and 7, present research studies that addressed RQ2 and RQ3. In Chapter 6, details of research study on a topic 'Convolution' from Signals and Systems are presented.

Research Experiment E4

The main objectives of E4 were to investigate contribution of Discretized Interactivity Manipulation (DIM) as an IEF in ILE learning, and its impact on cognitive load of learners.

6.1 Research Questions and Hypotheses for E4

The research questions specific to this study were:

E4-RQ1: Given the type of knowledge and cognitive level, how does 'Discretized Interactivity Manipulation' as an IEF affect learning in interactive learning environments?

E4-RQ2: How is learners' cognitive load influenced by the presence of IEFs in an Interactivity Enriched Learning Environment?

To answer these research questions, we used the following types of learning environment:

(a) a Simulation (SIM)

(b) Interactivity Enriched learning Environment (IELE) embedded with IEF

The SIM and IELE, both had the same degree of interaction. However, IELE was designed with IEF and SIM was designed without IEF. Learning from these two learning environments was compared to answer E4-RQ1. The inclusion of additional interaction feature operationalized in the form of 'Discretized Interactivity Manipulation' was foreseen as an additional learning support for learners that would help generate germane cognitive load while interacting with learning environment. This aspect was investigated to answer E4-RQ2.

To measure learning effectiveness of ILEs, we focused on ‘understand’ and ‘apply’ cognitive levels and ‘conceptual’ and ‘procedural’ knowledge types in conformance with the two-dimensional taxonomy framework as proposed by Anderson (Anderson et al., 2001). This was done keeping in mind the need of engineering curriculum to develop conceptual and procedural knowledge as mutually-supportive factors (Taraban, Definis, Brown, Anderson, & Sharma, 2007) and learning requirements of a course on Signals and Systems.

The hypotheses for the study were as follows: Firstly, it was expected that students learning with IELE would learn better as compared to students learning with SIM due to the presence of IEF in IELE. Considering the content to be learnt for the selected topic, we focused on three categories of learning objectives in this study; 'Understand Procedural knowledge, 'Apply Conceptual knowledge' and 'Apply Procedural knowledge'. The hypotheses for E4-RQ1 were:

E4-H1-A) For Procedural knowledge at Understand level, students learning with IELE will score higher as compared to students learning with Simulation (SIM).

E4-H1-B) For Conceptual knowledge at Apply level, students learning with IELE will score higher as compared to students learning with Simulation (SIM).

E4-H1-C) For Procedural knowledge at Apply level, students learning with IELE will score higher as compared to students learning with Simulation (SIM).

It was further hypothesized that IEFs would improve learning in Interactivity Enriched Learning Environments due to an increase in germane cognitive load of learners, assuming all other cognitive loads experienced by learners remained equivalent across treatment groups. While introducing the concept of IEFs, it was mentioned that IEFs were expected to offer meaningful interactions to support germane cognitive processing of learners. Thus, inclusion of IEFs was expected to increase germane cognitive load. As explained in Chapter 3, in addition to germane cognitive load, learners experience intrinsic and extrinsic cognitive loads while learning from ILEs. The assumption of equivalence of these two cognitive loads (i.e. intrinsic load and extrinsic load) across treatment groups was verified by controlling certain factors.

The main factors considered for controlling intrinsic cognitive load were; prior knowledge of learners, difficulty level and content of the topic to be studied, academic characteristics of learners. Additionally, self-reported mental effort rating was used as a measure of intrinsic cognitive load to confirm the equivalence of intrinsic cognitive load in both the groups (DeLeeuw & Mayer, 2008).

The learning materials for both the groups were designed as per recommended instructional design practices to avoid extrinsic cognitive load. Also, their equivalence of learning materials in terms of instructional design aspects, except presence or absence of IEF was verified. These points supported extrinsic cognitive load equivalence across groups.

Based on this, the following hypotheses were formulated for E4-RQ2.

E4-H2-A) For Procedural knowledge at 'Understand' level, students learning with IELE experience higher germane cognitive load as compared to students learning with Simulation (SIM).

E4-H2-B) For Conceptual knowledge at 'Apply' level, students learning with IELE experience higher germane cognitive load as compared to students learning with Simulation (SIM).

E4-H2-C) For Procedural knowledge at 'Apply' level, students learning with IELE experience higher germane cognitive load as compared to students learning with Simulation (SIM).

6.2 Learning Materials

The hypotheses mentioned above were tested with the help of a research study focused on the topic Convolution; a topic that deals with an important aspect of Linear Time Invariant (LTI) systems in Signals and Systems. It deals with finding out response of an LTI system for an arbitrary input. The details of the learning materials used for the study are as follows.

(a) SIM: The SIM group learnt with an interactive JAVA applet. This applet allowed students to select signals to be used as input signals for convolution. After selecting the signals to be convolved, students could see the process of convolution and the output of convolution by means of graphical representation along with the dynamic explanation of the process. Fig. 6.1 shows a snapshot of SIM applet screen interface.

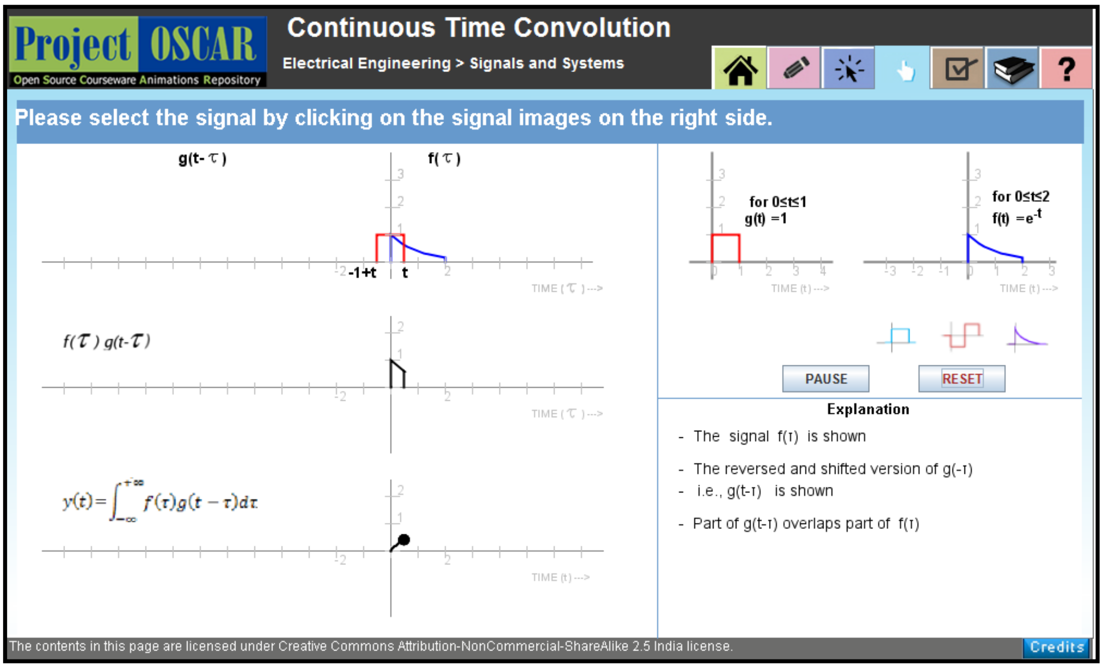


Figure 6.1. Screenshot of the SIM learning environment for a topic on Convolution

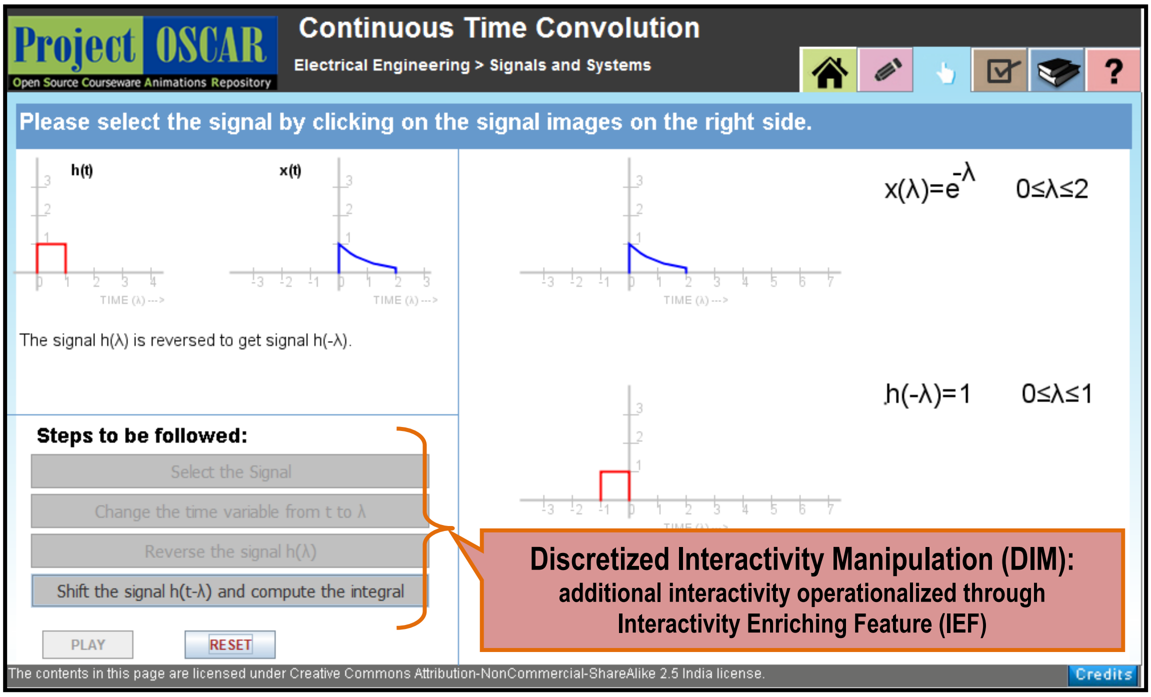


Figure 6.2. Screenshot of the IELE for a topic on Convolution

(b) IELE: The IELE was an applet with IEF[4]. The IEF of ‘Discretized Interactivity Manipulation' was embedded to offer additional interaction while convolving the selected input signals. The IEF- Discretized Interactivity Manipulation offered interactivity in the form of discretized step selection. The steps were designed to have meaningful segmented events of the given procedural task. Fig. 6.2 shows a snapshot of the IELE screen interface.

6.3 Participants and experimental design

Participants were students from second year of engineering college affiliated to University of Mumbai (N= 67; 38 males and 29 females). The selection of the college was done on the basis of ease of access and other logistics issues. The students are generally admitted to the engineering program after qualifying a common entrance examination. Also all the participants were assessed commonly for their first year university examination. This ensured the representativeness of the sample. While convenient sampling was used for selecting students for the study from the list of students, the group creation was done using randomizer.

The study was conducted using a 2-group post-test only experimental research design. Participants were randomly assigned to one of the following two conditions: (a) Simulation (SIM group); N=33 and (b) Interactivity Enriched learning Environment (IELE group); N=34. Although the participants had some prior knowledge about content of simulation, they were found to equivalent in terms of their prior knowledge. Their prior knowledge was judged on the basis of a class test focusing on the topic of Convolution, conducted as a part of academic activity. The questions covered in the class test were verified by the domain experts for their aptness for assessing learners' prior knowledge level. The groups means in the class test were out of twenty and were found be statistically equivalent as there was no statistically significant difference in the scores. The test scores were as follows: SIM ($M=13.43$, $SD=3.92$) and IELE ($M=13.86$, $SD=3.91$) groups test scores; $t(65)=0.703$, $p=0.483$. An alpha level of 0.05 was used for all statistical tests. Participants were familiar with the use of ICT tools in learning through other courses and laboratory in their curriculum.

[4] The downloadable version of IELEs are available at http://www.et.iitb.ac.in/~mrinal/IELESS.html. Due to incompatibility issue of JAVA and browser, the applets need to run with applet viewer. The demo of IELEs are made available at the above mentioned URL.

As discussed in Chapter 4, the overall research design was explanatory sequential design. The quantitative strand of the design was conducted using a 2-group post-test only experimental research design. It assessed students' learning of domain knowledge with the help of domain knowledge test. The post-test scores were used to compare and evaluate the learning effectiveness of the treatment for both the groups.

In addition to investigating the learning effectiveness of IEFs on the basis of students' performance in the domain knowledge test, understanding how students use IEFs was another important objective of the study. The qualitative phase of the explanatory sequential design was designed to focus primarily on this aspect of investigation. The details of the qualitative phase of the explanatory sequential design are explained in Section 6.9 of this Chapter.

6.4 Treatment

The instructional intervention while implementing the quantitative phase of the research design was as follows:

1. The SIM group learnt with an interactive JAVA applet offering dynamic selection of the input signals offered in the applet.
2. The IELE group studied with Interactivity Enriched Learning Environment with IEF of Discretized Interactivity Manipulation.

6.5 Measures and Instruments

6.5.1 Instrument for measuring domain knowledge performance for hypotheses E4-H1-A, E4-H1-B and E4-H1-C

The assessment instrument for post-test was developed to test students' learning in terms of ‘understand’, ‘apply’ cognitive levels and ‘conceptual’ and ‘procedural’ types of knowledge. These specific cognitive levels and knowledge types were focused in the instrument to meet domain specific pedagogical requirements. Work on the Signals and Systems Concept Inventory (SSCI) (Wage et al., 2005) and the work by Hiebert and Lefevre (Hiebert & Lefevre, 1986) reported the necessity to cover 'conceptual' and 'procedural' knowledge as well as on their co-existence, especially in the engineering curriculum. Also, the Signals and Systems course outcomes expected students to comprehend various concepts from the course and to apply them in a meaningful manner in the new context. Thus, the instrument designed for this study focused on 'understand' and 'apply' cognitive levels as defined in Revised Bloom's Taxonomy (Krathwohl, 2002) and 'conceptual' and 'procedural' types of knowledge. Considering the type of knowledge along with cognitive levels of the task to be accomplished, helped in assessing engineering curriculum's requirement of developing learners' expertise; not just in the given type of knowledge, but also at the desired cognitive level of that knowledge.

The categorization of assessment questions from the instrument was done considering the basic definitions of different cognitive levels and knowledge types (Mioković, Varvodić, & Radolić, 2012; Krathwohl, 2002) in the context of selected topic from the domain. In a topic of Convolution, underlying concepts related to signal processing such as signal folding, signal shifting, linearity and time invariance constituted the conceptual knowledge. Carrying out requisite signal processing operations in a sequential and meaningful manner as a part of convolution was an example of procedural knowledge. With regard to cognitive level of the task, questions related to ‘understand’ cognitive level were in the form of identifying or interpreting a particular signal processing task, whereas, at ‘apply’ cognitive level, students were expected to use their fundamental understanding of signal processing and linear time-invariant systems to solve questions by applying their knowledge in the new situation. The seven assessment questions were distributed across these three categories of ‘Understand Conceptual knowledge’, ‘Understand Procedural knowledge’ and ‘Apply Procedural knowledge’. The normalized scores were compared across groups for the above mentioned categories. The questions are provided in Appendix E. Out of seven, answering four questions demanded elaborate working and explanation of the solution approach. The participants were instructed to show the detailed working while answering such questions.

Content validity by experts

To establish validity of the instrument developed for post-test, it was peer-reviewed by the researchers of this study in cooperation with five domain experts who had 20+ years of teaching experience each in the domain of Signals and Systems. Two reviewers also had a formal background in Educational Technology research. The review process was carried out in an iterative manner. The suggestions given were incorporated and the instrument was further reviewed till all the reviewers were satisfied with the correctness of content, categorization of questions and their appropriateness in the context of learning objectives. One of the suggestions received during review process was with respect to time required for solving the assessment questions. Thus, the number of questions were reduced accordingly without compromising the content coverage. Apart from this instrument, the other two instruments used for measuring cognitive load and motivational aspect were well established self-reported scales.

6.5.2 Instrument for measuring learners' cognitive load for hypotheses E4-H2-A, E4-H2-B and E4-H2-C

For testing E4-H2-A, B and C hypotheses, an instrument was needed that could measure learners' germane cognitive load. Cognitive load is a multidimensional construct representing the load that gets imposed on learners' cognitive system while performing a particular task. In an attempt to separately measure the three cognitive loads, it has been reported that mental effort ratings were most sensitive to manipulations of intrinsic processing (created by topic complexity), and mental difficulty ratings were most sensitive to indications of germane processing (reflected by transfer test performance) (DeLeeuw & Mayer, 2008). These results were found to be consistent with a triarchic theory of cognitive load, according to which different aspects of cognitive load could be tapped by different measures of cognitive load. Learners have the ability to reflect on their cognitive processes and provide their responses on numerical scales (Gopher & Braune,1984; Paas, Tuovinen, Tabbers, & Van Gerven, 2003). Therefore, self-reported measures were used to measure participants' cognitive load and intrinsic motivation. Uni-dimensional scales, such as retrospective difficulty ratings, are a popular subjective cognitive load measurement technique because they are easy to use and do not interfere with the learning task (Paas, van Merrienboer, & Adam, 1994). There are more advanced Psycho physiological techniques such as heart rate variability and pupillary responses techniques available. Secondary task techniques is also another method available for measuring cognitive load. The secondary task technique has been criticised as it can interfere considerably with the primary task, especially if the primary task is complex. The Psycho physiological method could not be adopted due to logistic issues. Thus, self reporting single questionnaire method was used.

To measure intrinsic cognitive load, a subjective rating scale was provided on the first page of the students' answer booklets. The participants were asked, "how much mental effort they invested while learning using the applet?", and rated their subjectively experienced mental effort on a nine-point rating scale ranging from 1 'very very low mental effort' to 9 'very very high mental effort'. Nine-point rating scales have been used successfully in other studies (Kalyuga, Chandler, & Sweller, 1998; Marcus, Cooper, & Sweller, 1996; Tindall-Ford, Chandler, & Sweller, 1997).

To measure mental difficulty, a nine-point Likert-type scale was used as a subjective cognitive load measure. This scale is accepted as a valid method for measuring cognitive load (Kalyuga et al., 1998, 2000; Paas & Van Merrienboer, 1994b; Van Merrienboer, Schuurman, Croock, & Paas, 2002; Yeung, Jin, & Sweller, 1997). In this study, participants were asked after each category of questions, "How easy or difficult was it to work with these questions?" The participants selected one of the nine options: ranging from 1 as 'extremely easy' to 9 as 'extremely difficult'. A mental difficulty rating ranging from 1 to 9 was therefore collected from each participant.

6.5.3 Survey Instrument for self-reported ratings of interest, motivation and helpfulness

The affective domain survey in this study was not for any specific hypothesis, but since the integration of cognitive and affective processes in multimedia interactive learning environment has been a promising new direction of research, we decided to look into it as a secondary issue or to explore further potential research directions.

It has been recommended to investigate the relationships between motivation and cognitive load issues as proposed in the 'cognitive-affective theory of learning with media'. Although, a common tool in Cognitive Load Theory (CLT) research is to collect self-rating measures of cognitive load, in a promising new direction for CLT research, Moreno (Moreno, 2007) examined student attitudes and motivation towards multimedia learning and advocated the importance of including motivational factors as a part of such studies. She proposed an extension of Mayer's cognitive theory of multimedia (Mayer, 2001) called a 'cognitive-affective theory of learning with media' (CATLM; Moreno, 2005).

In order to assess this aspect and to capture motivational aspect of learners, six questions from the eight-item instrument in the form of self-reported questionnaire was used (Moreno,2007). These six questions evaluated student's ratings of interest, motivation and helpfulness. It asked the participants to rate their learning perceptions on a five-point scale. It contained the following questions: (1) 'How interesting was it to learn about graphical convolution today?' (with 1 as boring and 5 as interesting); (2) 'How entertaining was it to learn about graphical convolution today?' (with 1 as tiresome and 5 as entertaining); (3) 'How eager would you be to learn about some different topic from Signals and Systems in the same conditions you learned today? ' (with 1 as not eager and 5 as very eager); (4) 'How motivating was it to learn about graphical convolution today?' (with 1 as not motivating and 5 as very motivating); (5) 'How much did the JAVA applet help you to understand about graphical convolution?' (with 1 as not at all and 5 as very much); (6) 'How helpful was this JAVA applet for learning about Graphical Convolution?' (with 1 as unhelpful and 5 as helpful). The motivational factor and learning perception score were computed for each student by adding the scores from each of the six questionnaire items and dividing by six. These six questions evaluated student's ratings of interest, motivation and helpfulness. The remaining two questions from the eight-questions instrument were eliminated, as they were related to the perceived difficulty, indirectly measuring cognitive load, and were already covered separately in another questionnaire of this study.

6.6 Procedure

Pilot study

A pilot study was carried out to determine if the learning materials, assessment instruments and procedure were suitable and aligned. It also gave feedback about various feasibility, usability and logistics related issues regarding the learning material, instrument and experiment procedure. Four students who had already studied Signals and Systems took part in the pilot study. Students gave feedback about the clarity and comprehension of the visualizations. Based on the feedback given by students and also by the domain experts, the number of questions in the domain knowledge performance test was reduced in order to restrict time of the assessment test. Overall, the pilot experiment helped in eliminating minor flaws and logistics related issues in the experimental procedure. It also confirmed sufficiency of the time allotment for the treatment. To test the equivalence of the learning materials in factors other than what was considered in the experiment, such as usability, and look and feel, the materials were tested with students who had already studied the course on Signals and Systems. Both learning materials were tested to establish equivalence of the learning material and were found to be equivalent.

Main research study

First, all participants were briefed about the study procedure and its objectives. They were assured that their participation had no bearing on their academic performance. After signing consent forms, they were allotted to two treatment conditions created using randomizer. The treatment lasted for 35-40 minutes. After completing learning from the respective learning material, participants were asked to solve the assessment test. The assessment test booklet had the following components i) Self-reported mental effort rating single-question questionnaire, ii) Self-reported motivational factors and learning perception questionnaire, iii) Domain knowledge performance test for three different learning objectives, and iv) Self-reported difficulty rating (mental load) single-question questionnaire. The assessment test format was arranged as follows:

→ Self-reported mental effort rating single-question questionnaire

→ Self-reported motivational factors and learning perception questionnaire

→ Domain knowledge question of 'Understand Procedural knowledge' --> Self-reported difficulty rating (mental load) single-question questionnaire for 'Understand Procedural knowledge'

→ Domain knowledge question of 'Apply Conceptual knowledge'--> Self-reported difficulty rating (mental load) single-question questionnaire for 'Apply Conceptual knowledge'

→ Domain knowledge questions of 'Apply Procedural knowledge'--> Self-reported difficulty rating (mental load) single-question questionnaire for 'Apply Procedural knowledge'

At the end of the research study, students were thanked for their participation and were given participation certificate. After assessing domain knowledge performance test answers, some students from both the treatment groups were called for conducting semi-structured face-to-face interview using purposive sampling. The students selected represented high, medium and low achievers' strata of the subjects. The semi-structured interviews were conducted after the main study as a part of qualitative phase of the explanatory sequential mixed design using purposive sampling.

6.7. Data Analysis Techniques

The quantitative data was collected in the form of domain knowledge performance test score, self-reported mental difficulty score, self-reported mental effort score, self-reported motivational factors and learning perception scores for both the groups. The instrument for domain knowledge performance test score and self-reported mental difficulty score was designed for three categories of questions. Thus, the scores were compared for all these three categories independently. Following steps were taken to carry out statistical analysis of data. The raw data was processed to get a normalized score, out of ten for each category of questions. The data was further checked for normality and other valid assumptions to decide suitability of parametric statistical tests for comparing means. An alpha level of 0.05 was used for all statistical tests. The statistical analysis involved the following.

- comparison of means of domain knowledge performance test score to find out statistically significant difference between both the groups using independent sample t-test or its equivalent non-parametric test to test hypothesis E4-H1-A, B, C
- comparison of means of self-reported mental difficulty score and self-reported mental effort score to find out statistically significant difference between both the groups using independent sample t-test or its equivalent non-parametric test to test hypothesis E4-H2-A, B, C
- evaluation of answer sheets to have comparative analysis in term of percentage of unanswered questions and incomplete answers as additional data for hypothesis E4-H1-A, B, C
- comparison of means of affective domain rating using independent sample t-test or its equivalent non-parametric test and comparative analysis of the percentage of students opted for favorable rating as additional data to investigate affective aspect of learning.

The qualitative data received from semi-structured interviews were analyzed using Content Analysis method.

6.8. Results

Domain knowledge Performance Test and Self-reported Difficulty level ratings

Table 6.1 shows the mean and standard deviations of domain knowledge performance test scores for the research study. Both the treatment groups were compared for three different categories of learning objectives for domain knowledge. These results were interpreted further to answer thesis RQ2.

The data passed Shapiro-Wilk test for normality and other assumptions needed for parametric tests were found to be valid. Thus, parametric tests were selected for further statistical analysis. As per the results obtained from independent sample t-test, the domain knowledge performance test score means had statistically significant difference for 'Understand Procedural knowledge' and 'Apply Procedural knowledge' category of questions ('Understand Procedural knowledge': ($t(65)=-2.344$, $p=0.022$), 'Apply Procedural knowledge' ($t(65)=-2.677$, $p=0.009$). There was no statistically significant difference found in the means of 'Apply Conceptual knowledge' category questions ($t(65)=2.314$, $p=0.758$) scores. The effect size observed was 0.5814, 0.6542 and 0.5655 respectively.

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

Apart from this, answer sheets of the students were analyzed for observing the manner in which the answers were written. Firstly, we analyzed the answer sheets for finding out the number of unanswered questions (for question number 6 and 7, which required elaborate working for answering). While 47% of the questions from SIM treatment group (31 questions out of 66 questions) were un-attempted, for IELE treatment group the percentage of un-attempted questions was 25% of the questions (17 questions out of 68 questions). Figure 6.3 depicts this graphically.

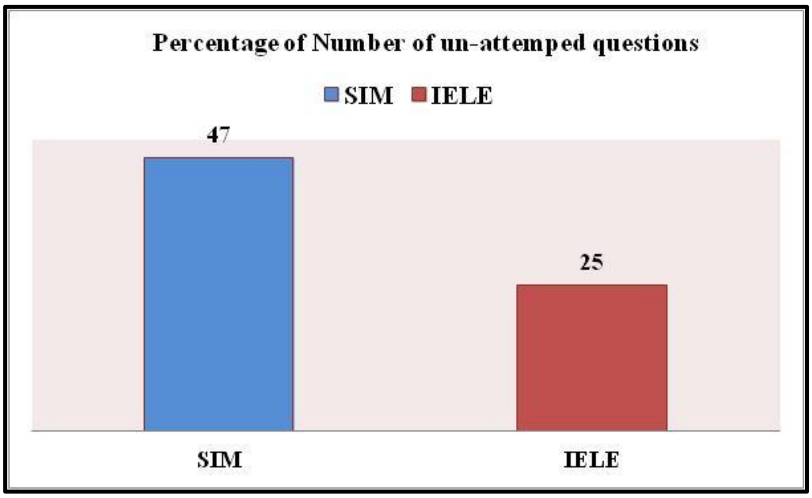


Figure 6.3. Comparative analysis of the percentage of number of un-attempted questions

The experimental group learnt with an IEF that was designed with the intention to improve students' learning while executing a given procedural task in a stepwise manner. Thus, it would have been interesting to investigate up to what level students could succeed in implementing all the steps involved in the given procedural task. Thus, number of steps shown by students from both the groups in the answer of question number 6 and 7 were compared. The answer for question number 6 and 7 had to be given in four steps. With respect to this aspect also, we could see the IELE group outperforming the SIM group. The students who attempted question number 6 and 7, the number of students who could solve the problems with all the four steps was significantly higher for IELE group as compared to SIM group. Table 2 shows the comparative analysis related to this and figure 6.4 depicts this graphically. As evident from Figure 6.4, 51.61% students from IELE could solve all the steps of the answer as against only 9.52 % students form SIM group.

Table 6.2 Comparative analysis of number of steps taken while solving problems

Group	**Number of steps taken while solving problems and number of students**				
	No. of steps	**Four**	**Three**	**Two**	**One**
SIM	**No. of students**	2	3	12	4
	% of number of students	9.52	14.29	57.14	19.05
IELE	**No. of students**	16	5	6	4
	% of number of students	51.61	16.12	19.35	12.90

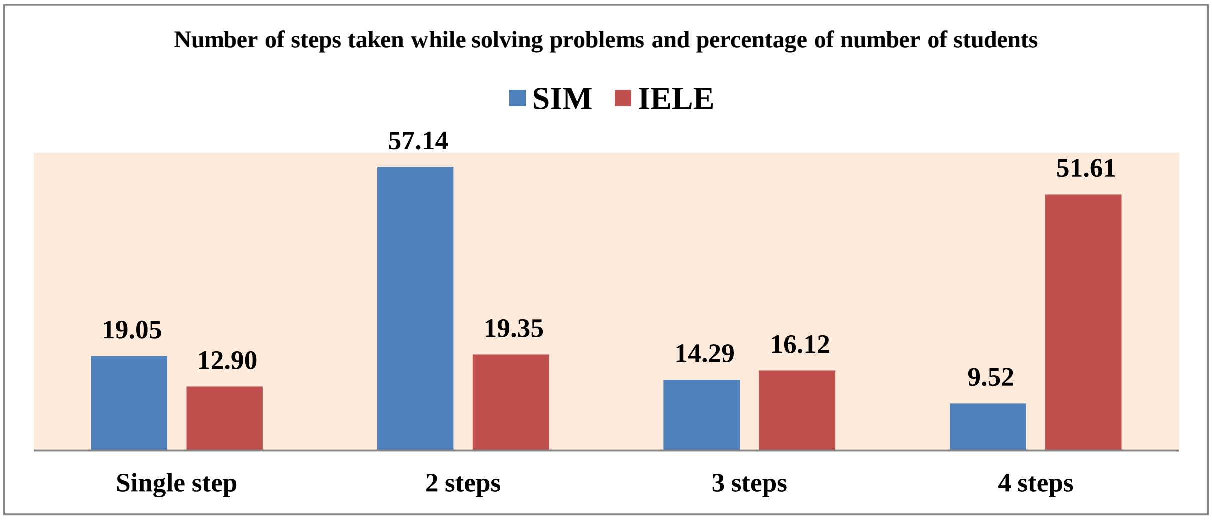


Figure 6.4. Comparative analysis of percentage of number of students and the number of steps shown in the solution

Table 6.3 shows the self-reported difficulty level scores of learners. These scores are a measure of the germane cognitive load as experienced by learners while interacting with the learning environment. The self-reported difficulty level question was asked to learners after they had attempted questions from each of the three categories. The results obtained from independent sample t-test on the self-reported difficulty level scores of learners revealed that the score means were found to be statistically significantly different for difficulty level reported after 'Understand Procedural knowledge' and 'Apply Procedural knowledge' category of questions ('Understand Procedural knowledge': (t(65)=2.605, *p*=0.011); 'Apply Procedural knowledge' (t(65)=2.463, *p* =0.017). There was no statistically significant difference found in the means of difficulty level rating reported for 'Apply Conceptual knowledge' category of questions (t(65)=2.663, *p* =0.510). The effect size was 0.6366, 0.6019 and 0.6507 respectively.

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

To measure intrinsic cognitive load, a self-reported mental effort rating scale was used as an instrument. It measured learner's self-perception of how much mental effort was invested while learning using the applet. The rating was provided on a nine-point rating scale ranging from 1 ‘very very low mental effort’ to 9 ‘very very high mental effort'. The mean and standard deviation of this rating for both groups were: SIM (M=4.52, SD=1.96) and IELE (M=4.70, SD=1.70). There was no statistically significant difference reported in the means based on the findings of independent sample t-test (t(65)=-.387, *p* =0.700).

Self-reported ratings of interest, motivation and helpfulness

The affective aspect of the learning experience of learner was measured by six questions administered from the eight-item validated instrument in the form of self-reported questionnaire (Moreno, 2007). The motivational factor and learning perception score were computed for each student by adding scores from each of the six questionnaire items and dividing by six. These six questions evaluated student's ratings of interest, motivation and helpfulness. The mean and standard deviation obtained for these rating scores are tabulated in Table 6.4.

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

The independent sample t-test conducted on the mean score of each students from both the treatment groups indicated that the means were statistically different with (t(65)=-2.225, *p* =0.030). The ratings given by students were categorized into three categories; 'favorable', 'neutral' and 'unfavorable'. The percentage of the number of students opted for 'favorable' as their rating for each of the questions from the six-question questionnaire for both the treatment groups has been shown in figure 6.5 below.

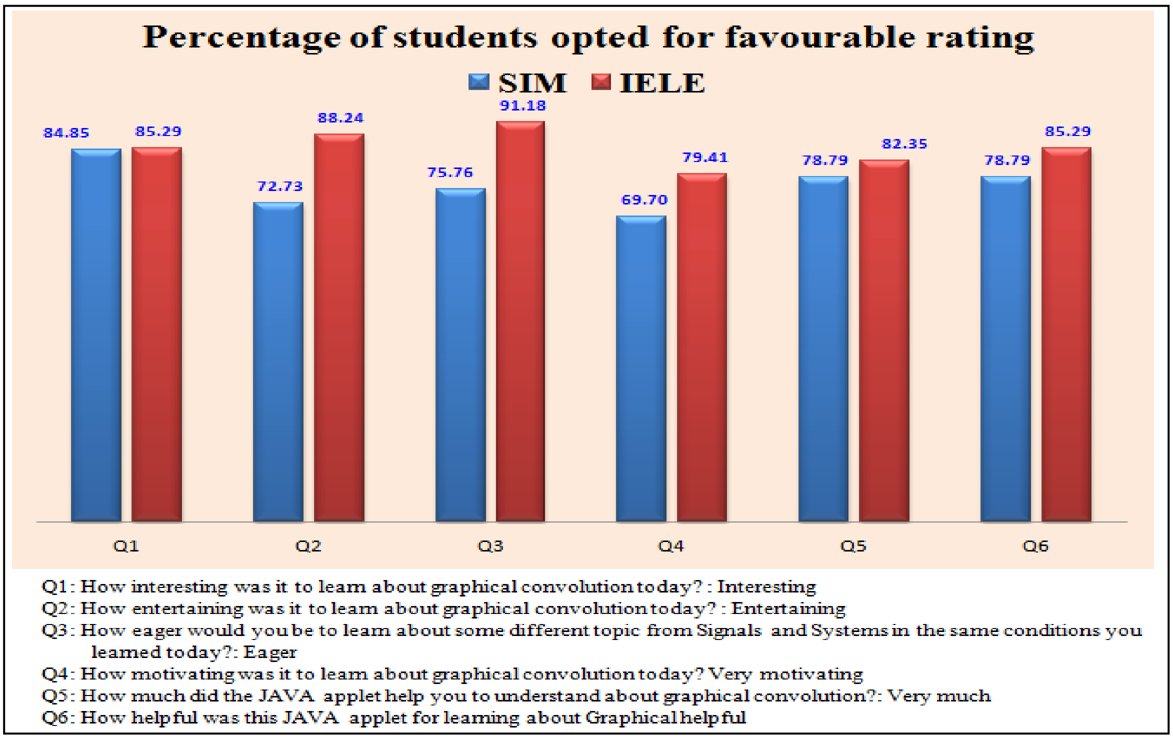


Figure 6.5. Comparative analysis of the percentage of students opted for favourable rating

6.9. Semi-structured Interviews: Qualitative phase of the research design

The explanatory sequential research design of the study had a quantitative strand that helped in analyzing learning impact of the IEF. The qualitative strand in the explanatory sequential mixed design was used for corroborating findings of the quantitative analysis. In this study, the qualitative phase of the design was aimed at gaining insight about how students used IEF in the learning process and what kind of cognitive support IEF offered while learning with IEF. The important objective of conducting interviews was to investigate whether students used the IEF for the same reason for which it was designed in the learning environment. This data collected from interviews were expected to support answering of E4-RQ1 as well as E4-RQ2.

After completing the research study, the answer sheets were evaluated and 7 students from the participants were interviewed face-to-face after a period of two weeks. The scheduling of the interview after two weeks was due to the time needed for assessing the test papers and also due to the availability of students as per their academic calendar. The students were selected by purposive sampling to have representation of the both the treatment groups and also of the students who performed average/ above average in the assessment test. Out of seven, 4 students were from experimental group and 3 students were from control group. The objective of conducting the semi-structured interview was to gather data about student's learning experience and their perception about the learning environment. The researcher and another expert from domain as well as from Educational technology background interviewed students.

Procedure: Students were briefed about the interview objective, protocol and their consent for audio recording of the interview was taken. Then they were asked about their learning experience. They were allowed to interact with the learning environment (belonging to the same group) to ensure that they could recollect their learning experience. The conversation was based on the following open ended questions. 1) Can you brief us about the learning activity that you did with the learning environment? 2) What did you exactly do with the learning environment? 3) How did you try to learn? 4) What were the difficulties that you faced while learning from the said environment? 5) Which typical aspect/ feature of the learning environment you think, must have helped you while learning? 6) In what way, you feel the learning environment features could help you while solving the domain knowledge assessment test? - Did it help for any typical type of questions? 7) What improvement you could propose to improve your learning experience?

The interviews lasted for 15-18 minutes. The recorded interviews were transcribed and analyzed further using Content Analysis method with a ‘sentence’ as the ‘coding unit’. The coding was done keeping in mind the objectives of the questions asked. Accordingly, two categories of the codes emerged strongly from the analysis; ‘Feature’ and ‘Support of the feature for learning'. In the category of 'Feature', students from experimental group commented about the feature that they perceived to be useful. All the four students found the *'step-wise interaction'* as a useful feature. Surprisingly, two students from the control group suggested that *'step-wise interaction'* needed to be provided, when they were asked about the additional feature that could be incorporated in the learning environment to improve learning experience. In the category of 'support of the feature for learning', students tried to give their own reasoning about what support the feature provided them in their learning process. Some of the verbatim responses under this category were,

.................'*moving through the steps,.. mean selecting..... it automatically enters into brain...*', ...'*stepping makes it easy*'..... .

One of the verbatim response from control group student when asked about the learning experience was, ...' *it took time for me to analyze the convolution... I mean where folding* (of signal) *ends, where shifting* (of signal) *starts? I had to do stop, analyze, play.... then look for the next action.'........* A similar comment from one more student from control group in a way suggested that in the absence of Discretized Interactivity Manipulation, students' cognitive resources must have got diverted in discretizing the given procedural task for improving its comprehension and application.

The overall observation from the analysis of interviews was that students who learnt with Discretized Interactivity Manipulation, appreciated its importance while learning. However, in general, it was observed that students were not very open in giving comments about their learning experience. They were not well-versed with the concept of analyzing their own learning. Still, the usefulness of the Discretized Interactivity Manipulation as an additional feature was well captured by the interviews. Some of the additional features suggested by students to improve their learning were provision of audio explanation and adding more variety of signals for demonstration. Thus, although the interviews could not throw light on how students analyze their learning with additional feature in minute details, it definitely proved useful in triangulating the positive learning impact of Discretized Interactivity Manipulation as an IEF.

6.10. Discussion

E4-RQ1: Given the type of knowledge and cognitive level, how does 'Discretized Interactivity Manipulation' as an IEF affect learning in interactive learning environment?

Learning impact of Discretized Interactivity Manipulation: The independent sample t-test on the domain knowledge performance test score demonstrated that hypotheses E4-H1-A and E4-H1-C were supported as evident from the comparisons of the test score means of the SIM and IELE groups. The IELE group performed better as compared to SIM group for 'Understand Procedural knowledge' and 'Apply Procedural knowledge' categories of questions at a statistically significant level. These results indicated that students learnt more effectively from the ILE that used Discretized Interactivity Manipulation as an IEF as compared to the learning environment without Discretized Interactivity Manipulation while catering to 'Understand Procedural knowledge' and 'Apply Procedural knowledge' learning objectives.

The independent sample t-test on the domain knowledge performance test score further showed that both the groups performed equally for the learning objectives of 'Apply Conceptual knowledge' category. The *p* value was found to be statistically non-significant indicating the statistical equivalence of the test score of both the treatment groups. Thus, hypothesis E4-H1-B was not supported.

The statistical analysis and its interpretation confirmed the need of Discretized Interactivity Manipulation IEF for understanding and applying procedural knowledge. As a procedural knowledge, students were expected to carry out the requisite signal processing operations of convolution in a sequential and meaningful manner. The IEF embedded in the ILE was based on the concept of event cognition and was intended to facilitate learners while dealing with a procedural task. The results of the study supported the role of Discretized Interactivity Manipulation IEF in this. Apart from the improvement in the Domain knowledge performance test for IELE group as compared to SIM group, the positive impact of IEF also got reflected in terms of the quality of the answered questions. More number of students attempted questions that needed elaborate application of the procedural knowledge gained. Also the answers given by IELE group demonstrated that students who learnt with IEF were able to incorporate more number of steps in their answers. All these points supported the contribution of Discretized Interactivity Manipulation IEF. The same IEF was found to be redundant while applying conceptual knowledge. The presence of Discretized Interactivity Manipulation could not make significant improvement in students' learning while applying conceptual knowledge. As the IEF mainly focused on supporting learning of procedural knowledge, both the learning environments (SIM and IELE) might have offered similar learning experience to learners while dealing with the content catering to conceptual knowledge. These results were useful in confirming the role of IEF in an ILE. These results further reiterated the need for carefully designing the interactions in ILEs and also demonstrated that mere presence of interactions in ILEs need not necessarily lead to meaningful learning.

E4-RQ2: How is learners' cognitive load influenced by the presence of IEFs in an interactivity enriched learning environment?

Impact of IEF on the cognitive processing of learner: The independent sample t-test on the self-reported difficulty level scores of learners revealed that the score means were found to be statistically significantly different for mental difficulty level reported after 'Understand Procedural knowledge' and 'Apply Procedural knowledge' category of questions ('Understand Procedural knowledge': ($t(65)=2.605$, $p=0.011$); 'Apply Procedural knowledge' ($t(65)=2.463$, $p=0.017$). There was no statistically significant difference found in the means of mental difficulty level rating reported for 'Apply Conceptual knowledge' category of questions ($t(65)=0.663$, $p=0.510$). While hypotheses E4-H2-A and E4-H2-C were supported, hypothesis E4-H2-B was not supported. This indicated that learners experienced improvement in the germane cognitive load while learning with IELE as compared to the SIM group for 'Understand Procedural knowledge' and 'Apply Procedural knowledge' type of task. The statistical equivalence of the difficulty level rating scores for 'Apply Conceptual knowledge' indicated that the inclusion of Discretized Interactivity Manipulation as an IEF offered no additional cognitive support to learners while attempting 'Apply Conceptual knowledge' type of task.

The self-reported difficulty level ratings of learners have been found to be sensitive to indications of germane processing (DeLeeuw & Mayer, 2008) and germane cognitive load is considered to be result of mental activities that are directly relevant to learning. Therefore, lower value of learners' self-reported difficulty levels suggested that learning environment could offer more support to cognitive resources that directly contributed to the improvement in learners' performance . Against this backdrop, interpretation of results obtained from the self-reported difficulty level rating suggested the improvement in the learning performance could be attributed to the improvement in the germane cognitive load.

The above results when considered along with the results interpreted with the domain knowledge performance test score suggested that Discretized Interactivity Manipulation could enhance the interactivity in the ILE and led to improvement in the learning of 'Understand Procedural knowledge' and 'Apply Procedural knowledge' types of tasks. This improvement can be attributed to the improvement in the germane cognitive load; as for these types of tasks, learners reported lower difficulty level rating while learning from IELE. Thus, these results showed that inclusion of appropriate IEF in ILEs improved learning by improving germane processing of learners.

It is worth noting the statistical equivalence of mental effort rating reported for both the groups. The mean and standard deviation of learner's self perception of how much mental effort was invested were : SIM (M=4.52, SD=1.96) and IELE (M=4.70, SD=1.70) and there was no statistically significant difference reported in the means based on the findings of independent sample t-test ($t(65)=-.387$, $p=0.700$). This mental effort reading being a measure of intrinsic cognitive load, it demonstrated that learners experienced same amount of intrinsic cognitive load while learning from two different treatment groups. This finding further strengthened our claim that the IEF led to improvement in learning owing to the support offered by increased germane cognitive load.

Analyzing motivational aspect and cognitive load

The integration of cognitive and affective processes in multimedia interactive learning environment is a promising new direction of research. In this research study, we made an attempt to capture some aspect that could see motivational aspect and cognitive load in an integrated manner. The affective aspect of the learning experience of learners was measured by six questions administered from the eight-item validated instrument in the form of self-reported questionnaire (Moreno,2007). They measured student's ratings of interest, motivation and helpfulness. The mean of the affective scores reported was higher for the IELE group as compared to the SIM treatment group ($t(65)=-2.225$, $p=0.030$). This demonstrated that students reported more favorable affective remarks for IELE group as compared to SIM group. They found the IELE learning environment to be more encouraging and motivating. The frequencies of percentage of students giving more favorable remarks reported in Figure 6.5 indicate that more number of students gave favorable remarks for IELE environment. Although, the difference has been marginal for some questions, the trend of the frequency count suggested the positive affective processes that learners experienced while interacting with the Interactivity Enriched learning environment.

Considering the ratings of the affective domain along with the domain knowledge performance test and mental difficulty level rating of students, the study confirmed the contribution of IEF in improving learning in ILE due to improvement in the germane cognitive load. The IEF could also have led to improvement in the motivational aspect. However, we felt that research studies of longer duration treatments would be needed for confirming the contribution of the affective domain in learners' performance and its linkage with cognitive processing of learners.

We acknowledge some limitations in this study that should be considered. Some of the limitations as mentioned in Section 5.4 of the thesis might be applicable for this study as well. Additionally, we discuss some other points which might be exclusive to this study. The study covered only one topic from Signals and Systems. Investigating the impact of Discretized Interactivity Manipulation in some other relevant topics can make the claims of this study stronger and also deepen our understanding about use of IEFs by learners in learning environments. We have introduced cognitive load aspect in this study. The cognitive science is an evolving science and thus, there is always a scope for revising and modifying means of analyzing or measuring cognitive load. The modern theories from cognitive science might suggest innovative ways of analysing cognitive load. We look at this as a future opportunity to strengthen the theoretical base for understanding how learners learn in ILEs and what kind of supports facilitate learning process.

6.11. Summary

This is one more study that supported the validation of the learning effectiveness of Interactivity Enriching Features as proposed in Chapter 3 of the thesis. As mentioned in the last section of Chapter 5, this study supported the second and third step of the three-step IEF validation approach.

The quantitative results showed improvement in 'Understand and Apply Procedural knowledge' confirming the improvement in learning due to the proposed IEF - Discretized Interactivity Manipulation. This study could also attribute this improvement to the increase in the germane cognitive load of a learner. The interviews gave us insights into the reasons why we saw improvement in 'Understand and Apply Procedural knowledge' from quantitative analysis. There was no improvement observed due to IEF while dealing with 'Apply Conceptual knowledge'. The plausible reason for this was that the IEF could not offer any direct learning assistance to learners for this category of learning objectives. As the IEF of Discretized Variable Manipulation was designed with the intention to improve procedural knowledge, its presence in IELE could not make it different as compared SIM while learning conceptual knowledge.

The results from research experiment E1 and E4 together could confirm improvement in learning due to the IEFs - Permutative Variable Manipulation, Productively Constrained Variable Manipulation and Discretized Interactivity Manipulation. In the next chapter, we present another study that confirm the positive learning impact of another IEF and its association with germane cognitive load.

7. Chapter 7

Validating the effectiveness of Interactivity Enriching Features: Experiments E5

The findings from experiments E1 to E4 presented in Chapters 5 and 6 answered RQ1 and RQ2 of the thesis. Apart from demonstrating that higher level of interaction need not necessarily lead to higher learning always, the main contribution of the research studies has been towards testing effectiveness of IEFs. The findings from research experiments E1and E4 confirmed that strategically designed IEFs could lead to better learning in Interactivity Enriched Learning Environment. It has not been the mere presence of interactivity that could guarantee desired learning in ILEs, but it was the careful design of interactivity that was needed in ILEs to ensure desired learning benefits. Another contribution of research studies has been analyzing the effect of including IEFs on students' cognitive load. The findings from research study E4 showed that the IEF- 'Discretized Interactivity Manipulation' offered the required cognitive support by improving germane cognitive load of learners which resulted in better learning from Interactivity Enriched Learning Environment.

Experiment E5, presented in Chapter 7 aimed at validating effectiveness of IEF- 'Reciprocative Dynamic Linking'. It covered the topic 'Representation of Sinusoids in Time and Frequency Domain' from a course on Signals and Systems. Apart from investigating the improvement in learning due to IEF (RQ2), E5 also aimed at understanding how students learn with IEFs in Interactivity Enriched Learning environments and what effect the IEFs have on students' cognitive load (RQ3). The research design of E5 has been an 'Exploratory Sequential mixed methods'. The IEF- Reciprocative Dynamic Linking was designed for facilitating learning from multiple representations. To investigate how students respond to this IEF, and to judge the required sensitivity of the instrument, we started with an exploratory qualitative study. The quantitative phase of the research design was then used to generalize initial findings (Creswell, 2002). Before we report this study here, we first present research questions, hypotheses to be tested and learning material. Then we present the qualitative strand of the exploratory sequential design followed by the quantitative strand.

Research Experiment E5

The main objectives of the study E5 were to investigate contribution of' Reciprocative Dynamic Linking as an IEF in ILEs and its impact on cognitive load of learners.

7.1. Research Questions and Hypothesis for E5

The research questions specific to this study were:

E5-RQ1: Given the type of knowledge and cognitive level, how does ‘Reciprocative Dynamic Linking' as an IEF affect learning in interactive learning environment?

E5-RQ2: How is learners' cognitive load influenced by the presence of IEFs in an Interactivity Enriched Learning Environment?

To answer these research questions, we used the following types of learning environment:

(a) a Simulation (SIM)

(b) Interactivity Enriched learning Environment (IELE) embedded with IEF

The SIM and IELE, both had same degree of interaction. However, IELE was designed with IEF and SIM was designed without IEF. Learning from these two learning environments was compared to answer E5-RQ1.

To measure learning effectiveness of ILEs, we focused on ‘understand’ ‘apply’ and 'analyze' cognitive levels for ‘conceptual’ and ‘procedural’ knowledge, in conformance with the two-dimensional taxonomy framework as proposed by Anderson (Anderson et al., 2001). This was done keeping in mind the need of engineering curriculum to develop conceptual and procedural knowledge as mutually-supportive factors (Taraban, Definis, Brown, Anderson, & Sharma, 2007) and learning requirements of a course on Signals and Systems. The inclusion of additional interaction feature operationalized in the form of Reciprocative Dynamic Linking was foreseen as an additional learning support to learners that would help generate germane cognitive load while interacting with learning environment.

The hypotheses for the study were as follows: Firstly, it was expected that students learning with IELE would learn better as compared to students learning with SIM. Considering the content to be learnt for the selected topic, we focused on the following categories in this study; 'Understand Conceptual knowledge', 'Apply Conceptual knowledge', 'Apply Procedural knowledge' and 'Analyze Procedural knowledge'. Thus, the hypotheses for E5-RQ1 were:

E5-H1-A) For Conceptual knowledge at Understand level, students learning with IELE will score higher as compared to students learning with Simulation (SIM).

E5-H1-B) For Conceptual knowledge at Apply level, students learning with IELE will score higher as compared to students learning with Simulation (SIM).

E5-H1-C) For Procedural knowledge at Apply/ Analyze level, students learning with IELE will score higher as compared to students learning with Simulation (SIM).

It was further hypothesized that IEFs would improve learning in Interactivity Enriched Learning Environments due to an increase in germane cognitive load of learners, assuming all other cognitive loads experienced by learners remained equivalent across the treatment groups. While introducing the concept of IEFs, it was mentioned that IEFs were expected to offer meaningful interactions to support germane cognitive processing of learners. Thus, inclusion of IEFs was expected to increase germane cognitive load. As explained in Chapter 3, in addition to germane cognitive load, learners experience intrinsic and extrinsic cognitive loads while learning from ILEs. The assumption of equivalence of other two cognitive loads (i.e. intrinsic load and extrinsic load) across the treatment groups was validated by controlling certain factors. The factors influencing intrinsic cognitive load were controlled across both treatment groups. The main factors considered for this were- prior knowledge of learners, difficulty level and content of the topic to be studied, academic characteristics of learners. Additionally, the instrument measuring intrinsic cognitive load was also used to confirm the equivalence of intrinsic cognitive load in both the groups. The self-reported mental effort ratings were used to measure intrinsic cognitive load and learners' mental difficulty ratings were used to measure germane cognitive load (DeLeeuw & Mayer, 2008). The learning materials for both the groups were designed as per recommended instructional design practices to avoid extrinsic cognitive load. Also, their equivalence in terms of instructional design aspects, except presence or absence of IEF was verified. These points supported extrinsic cognitive load equivalence across the groups. Based on this, the following hypotheses were formulated for E5-RQ2.

E5-H2-A) For Conceptual knowledge at ‘understand’ level, students learning with IELE experience higher germane cognitive load as compared to students learning with Simulation (SIM).

E5-H2-B) For Conceptual knowledge at ‘apply’ level, students learning with IELE experience higher germane cognitive load as compared to students learning with Simulation (SIM).

E5-H2-C) For Procedural knowledge at ‘apply'/ 'analyze' levels, students learning with IELE experience higher germane cognitive load as compared to students learning with Simulation (SIM).

7.2. Learning Materials

The hypotheses mentioned above were tested with the help of a research study focused on the topic ‘Representation of Sinusoids in Time and Frequency Domain’; one of the fundamental topics from Signals and Systems. This topic, although very basic in appearance, deals with the core knowledge required for understanding various transforms and representation of signals in multiple domains. Various transforms (such as Fourier, Laplace

Transform) are always regarded as important and difficult topics as reported in Signals and Systems education research literature (Wage, Buck, Wright, &Welch, 2005). The details of the learning materials used for the study are as follows.

(a) SIM: The SIM group learnt with an interactive JAVA applet. This applet allowed students to learn from dynamically linked Multiple External Representations (MERs). Students could manipulate only one of the representations given and accordingly could observe the changes happening in the second representation. Fig.7.1 shows snapshot of the applet screen interface for tab 2, wherein time domain mathematical expression and frequency domain graphical representation are shown. Out of these two representations, only time domain mathematical expression was offered to learners for manipulation.

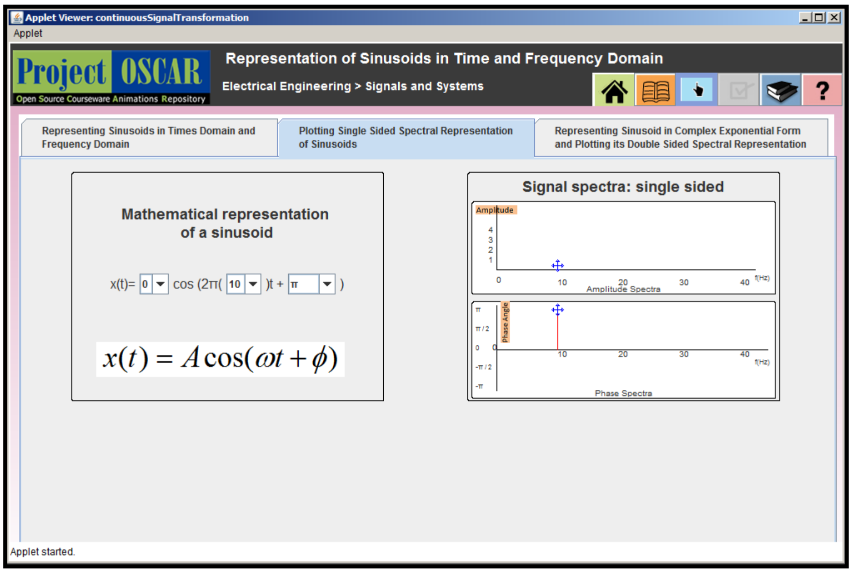


Figure 7.1. Screenshot of the SIM learning environment for a topic on Representation of sinusoids

(b) IELE: The IELE was an applet with IEF[5]. The IEF of 'Reciprocative Dynamic Linking' was embedded to offer additional interaction that allowed learners to select and manipulate each of MERs.

The course on Signals and Systems demands learning from multiple representations. Deeper understanding of time domain and frequency domain representations, as well as

[5] The downloadable version of IELEs are available at http://www.et.iitb.ac.in/~mrinal/IELESS.html. Due to incompatibility issue of JAVA and browser, the applets need to run with applet viewer. The demo of IELEs are made available at the above mentioned URL.

mathematical-graphical translations are essential for understanding various topics from the course. The translation of a signal to its multiple representations has been reported as a key problem in the conceptual learning of this course (Fayyaz, 2014). Thus, designing ILEs with MERs is important in Signals and Systems education, as learners can integrate concepts from different representation formats into one meaningful experience through use of MERs (Moreno & Mayer, 2000). The coordination of different representations in a cohesive manner and explicit identification of their relations support students' understanding at a deeper level. Considering the need to explore individual representation independently and to strengthen the to-and-fro linkage between representations, the IEF of Reciprocative Dynamic Linking was designed. The key features of IEF- Reciprocative Dynamic Linking were:

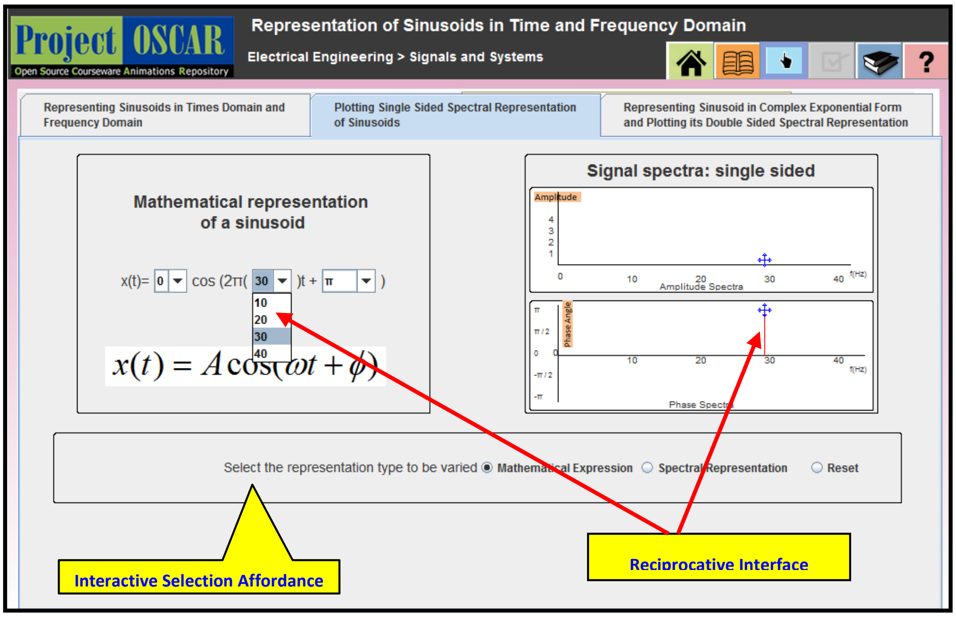


Figure 7.2. Screenshot of the IELE for a topic on Representation of sinusoids

- Reciprocative Interface: The reciprocative interface is two-way manipulative, enabling learners to carry out meaningful switchover among MERs resulting in comprehension of the relations between them. The MERs are not just dynamically linked to each other, but each of them is designed with an interactive manipulating interface. The features derived its base from contemporary theories of cognition such as distributed and embodied cognition (Glenberg et al. 2013). In order to facilitate selection of a particular representation for manipulation interactive selection affordance was provided. Using this feature, learners could select the representation to be manipulated thus, promoting active learning. Figure 7.2 shows key features of Reciprocative Dynamic Linking.

7.3. Measures and Instruments

Instrument for measuring domain knowledge performance for hypotheses E5-H1-A, E5-H1-B and E5-H1-C

The assessment instrument for post-test was developed to test students' domain knowledge in terms of ‘understand’, ‘apply’, 'analyze' cognitive levels and ‘conceptual’ and ‘procedural’ types of knowledge. As explained in detail in Chapter 6- section 6.5, these specific cognitive levels and knowledge types were focused in the instrument to meet domain specific pedagogical requirements.

The assessment instrument consisted of eleven questions, with ten open ended questions and one question in multiple choice format. All questions required students to select, relate and construct multiple representations. The questions from the instrument were related to: i) student's understanding of the individual representation of signals i.e. time domain and frequency domain representation ii) students' ability to translate from one domain to the other i.e. from time domain to frequency domain and vice-versa and iii) students' comprehension of both the representations in an integrated manner.

In the topic of signal representation, underlying concepts related to signal frequency, amplitude, phase, fundamental time period and complementary nature of time and frequency domain constituted the conceptual knowledge. Translating signals from one domain to another or from one representation to another required certain steps to be carried out in a sequential and meaningful manner. This was an example of procedural knowledge. With regard to cognitive level of the task, questions related to ‘understand’ cognitive level expected learners to identify or interpret a particular domain / representation. At ‘apply’ cognitive level, students were expected to use their fundamental understanding of signal attributes in multiple domains, their interrelations in different domains while translating given signals or representations into another. The 'analyze' level questions expected learners to methodically examine the given information, identify the aptness of the information, and then solve the given task using the relevant part of the information. Three out of the ten open-ended questions were from an extended topic; Fourier Transform properties, which was not a direct part of the learning environment. These questions, apart from expecting students to translate from one representation to another, also expected them to analyze and translate their comprehension to an extended topic. The instrument developed is provided in Appendix F.

The questions in the assessment test paper were organized into three categories based on the domain targeted. Due to this, the second category of the questions was a mixed question category as it had questions of 'Understand Conceptual knowledge' and 'Apply Conceptual knowledge' category. The category I questions catered to 'Apply Procedural knowledge' type, Category II questions were from 'Understand + Apply Conceptual knowledge' type and Category III questions aimed at 'Analyze procedural knowledge' type.

Table 7.1 Rubrics for assessing the open ended questions from the instrument

Rubric for assessing learner's competency developed in selecting, constructing and relating appropriate representation Revised and adapted based on https://sites.google.com/site/scientificabilities/rubrics					
Ability		**Missing**	**Inadequate**	**Needs Improvement**	**Adequate**
A2	Is able to construct new representations from previous representations	No attempt is made to construct a different representation.	Representations are attempted, but use incorrect information or the representation does not agree with the information used. For example, showing double sided / single sided spectra in place of single sided/ double sided spectra OR sinusoidal / complex exponential in place of complex exponential	Representations are created without mistakes, but there is information missing, i.e. units, labeling in the graphical representation.	Representations are constructed with all given (or understood) information and contain no major flaws

The answers of domain knowledge assessment test were assessed based on an adopted version of validated rubrics for assessing learner's competency developed in selecting, constructing and relating appropriate representation.[6] The rubric was designed to test six abilities: i) ability to extract information from the given representation correctly, ii) ability to construct new representations from previous representations, iii) ability to evaluate consistency of different representations and modify them, iv) ability to use/ select appropriate representations to solve problems, v) ability to represent mathematical expression (descriptive representation) Sinusoidal / complex exponential and vi) ability to graphically represent (Depictive) the form of signal waveform/ spectra. The students were assessed on four levels

[6] Etkina et al. 2006: Revised and adapted based on https://sites.google.com/site/scientificabilities/rubrics

of performance for these abilities. One of the abilities along with its performance indicators is shown in Table 7.1. The detailed rubrics is given as Appendix G.

Content validity by experts

To establish validity of the instrument developed for post-test was peer-reviewed by the researchers of this study in cooperation with five domain experts who had 20+ years of teaching experience each in the domain of Signals and Systems. Two reviewers also had a formal background in Educational Technology research. The review process was carried out in an iterative manner. The suggestions given were incorporated and instrument was further reviewed till all the reviewers were satisfied with the correctness of content, categorization of the questions and their appropriateness in the context of learning objectives. The instruments were also given to students (other than subjects of this study) to check its usability, language/ diagrams comprehension. The questions were reworded wherever students expressed their difficulty in understanding the questions.

Apart from this instrument, other instruments used for hypotheses E4-H2-A, E4-H2-B and E4-H2-C for measuring cognitive load were a validated self-reported scales. The instrument used to measure intrinsic and germane cognitive load in the form of mental effort and mental difficulty self-rating were the same as the that described in Section 6.5.3 of Chapter 6.

7.4. Qualitative study of the Exploratory Mixed research design

The aim of this study was to obtain insight about how students use Reciprocative Dynamic Linking as an IEF while learning from dynamically linked MERs. This insight was mainly needed to confirm learning benefits of Reciprocative Dynamic Linking. Unlike other IEFs, we wanted to have an early evaluation about the extent to which the IEF would be beneficial for learners. Another objective of this study was to decide how sensitive the instrument should be; rather to find out, up to what cognitive levels the IEF of Reciprocative Dynamic Linking could influence learning. The specific research questions for this qualitative strand were:

Q1. How do students use Reciprocative Dynamic Linking?

Q2.How does Reciprocative Dynamic Linking influence learning from multiple representations?

7.4.1. Participants for the qualitative study

Participants for this study were students from second year Electrical Engineering program studying a course on 'Signals and Systems'. They were selected by purposeful sampling and were in the middle third of their cohort in terms of achievement level (grades). The reason for selecting medium level equivalent achievers was to avoid the potential risk of the research being biased towards either ends. Participants belonged to two engineering colleges affiliated to University of Mumbai. A total of nine students (N=9; female=3, male=6) participated in the study. The average age of students was 20 years. Participants were familiar with the use of ICT tools in learning through other courses and labs in their curriculum.

7.4.2. Procedure of the qualitative study

The overall procedure for the pilot study consisted of the following steps:

- Initial briefing: Initially, students were briefed about the study and its objectives. They were assured that participation in the study would have no bearing on their academic performance. The researcher was different from the course instructor and had no role in assigning course grades.
- Interaction with learning material: After initial briefing, students interacted with IELE which consisted Reciprocative Dynamic Linking. Screen captures of students’ interaction were recorded using CamStudio™ open source software. The screen captures were recorded for the entire time duration while students interacted with the learning material.
- Domain knowledge assessment instrument: After interacting with IELE, students solved open ended questions related to domain knowledge. They were instructed to show the working on the same answer sheet. Students took 30-35 minutes to complete the assessment test (The instrument used here was the preliminary version of the instrument used for quantitative strand of the exploratory design. The findings from this qualitative study further helped in revising the instrument. The details of the final instrument are given in Section 7.3 of thesis Chapter). More than the final answers, the domain knowledge test answers were

evaluated for getting more insight about how Reciprocative Dynamic Linking was used by students while answering.

- Individual semi-structured interview: After the assessment test, semi-structured interviews were conducted using interview protocol. The objective of the interview was to know students' perceptions about major issues like, 'what kind of learning support did students get through Reciprocative Dynamic Linking and 'what aspect of learning could get influenced by Reciprocative Dynamic Linking?' The interviews were recorded for further transcription and analysis.

7.4.3. Observations and Findings from the qualitative study

7.4.3.1. Analysis of screen capture

The screen captures collected from nine students were analyzed to understand trajectory taken by students while exploring the IELE, and how the affordance of Reciprocative Dynamic Linking was used by students. The time for exploring the material ranged from 23 to 30 minutes (average of 27:10 minutes). While analyzing and interpreting the qualitative data using bottom-up approach, initially preliminary exploratory analysis was done to obtain a general sense of the data, and to get an idea about the organization of the data (Creswell, 2002). Three categories emerged from the preliminary exploratory analysis of learners' navigation actions: i) exploring menu icons, ii) linear movement through the content, and iii) selecting MERs for manipulation. The third category focused on learners' navigational actions while using the Reciprocative interface and Interactive Selection Affordance.

Seven of the nine students exhibited a common pattern. While exploring the MERs using Reciprocative Dynamic Linking, students manipulated the first MER, then the second. After this, they again reverted to manipulate the first MER. This pattern was observed for all three different MERs in IELE. Learners' manipulation of the first representation followed by the second was an expected navigation pattern, wherein the main goal would have been to explore the content (Exploratory search). However, coming back to the first representation after having explored both the representations indicated learner's intention of confirming the mental model created during the learning process (Confirmatory search) (Figure 7.3). This observation was significant because it resembled the 'prediction and hypothesis testing phase' of inquiry cycle. Its elaboration follows in the Discussion section.

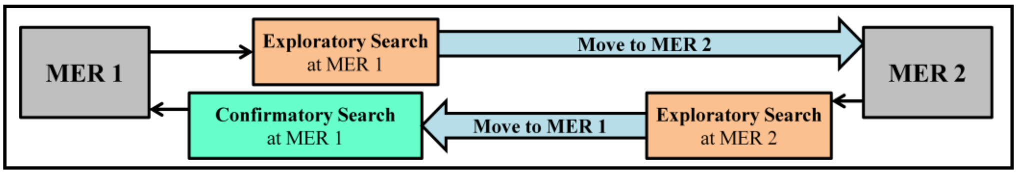


Figure 7.3 Exploration pattern observed from screen capture analysis

7.4.3.2. Analysis of domain knowledge assessment test

Students' answers were assessed to judge their ability in grasping mathematical and graphical representations, extracting relevant information from the given representation, constructing new representations, and integrating multiple representations. Not only the final answers, but also the intermediate steps taken by students were important for obtaining insight into the thought process and mental models students built while relating representations. The following were the results:

i. Students were able to successfully integrate multiple representations: Students showed translation process at a more granular level. They showed transition from the given representation to the translated representation with the help of intermediate representations. Although, only the final translated representation was expected, the intermediate representations showed clear explanatory links in the translation. Learners were not just able to grasp isolated representations, but also exhibited the interim steps of extracting relevant information from the given representation, and constructing new representations and finally integrating MERs. This showcased learners' ability to develop strong cross-representational linkage in multiple representations integration, leading to the development of representational competence. For example, when the question demanded translation from time domain graphical representation to frequency domain graphical representation, students supported this translation additionally with the help of an intermediate state, i.e. a time domain mathematical expression as shown in Figure 7.4. Comprehending translation in MERs at a more granular level indicated learning that could further strengthen the mental model of the phenomenon being learnt.

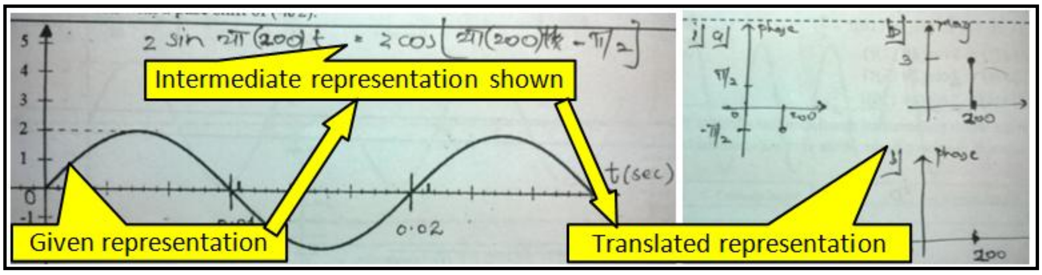


Figure 7.4. Translation process shown in the answer sheet

<u>*ii. Students were able to answer higher level cognitive questions.*</u> Students exhibited their ability to answer questions with higher difficulty level and from less familiar domain. The assessment questions were spanned across three cognitive levels: understand, apply and analyze (Krathwohl, 2002). Students were successful in answering analyze level questions. The topic presented in IELE involved understanding of amplitude, frequency and phase parameters of the signal in time and frequency domain. Typically, students are comfortable with amplitude and frequency aspect, but face difficulty in the phase aspect (Fayyaz, 2014). In this study, students were not only able to draw amplitude spectra correctly, but also drew phase spectra, showing their understanding and comfort of less familiar domain.

<u>*iii. Students were able to answer questions from extended topic*</u>. Students could successfully answer questions even from the extended topics. The instrument had questions from extended topic, related to effect of signal processing on signal representation and its Fourier Transform. The ability to answer these questions indicated students ability not just to understand the actual content of the learning material (signal representation), but also to acquire whole, integrated knowledge promoting further knowledge building process (of analyzing signal processing in time/ frequency domain representation).

7.4.3.3. Analysis of semi-structured interviews

Semi-structured interviews were conducted to get students' perception about the Reciprocative Dynamic Linking affordance. Each interview lasted for 15-17 minutes. Students were asked how they used the learning material to learn the content, and which features they found useful in learning process. Students were also shown their assessment test answer sheets and reasoning behind their answers was investigated. The recorded interviews were transcribed and analyzed further using Content Analysis method with a ‘sentence’ as the 'coding unit' (Cohen et al., 2007). The coding was done keeping in mind the objectives of the questions asked. Accordingly, three categories of the codes emerged from the analysis -i) Feature, ii) Reason, and iii) Learning impact. The details of the coding categories and some corresponding verbatim responses are given below:

i. Features are those aspects of the IELE that learners mentioned as being useful.

"I can change both the graphs", "...both are interrelated, so both should be allowed to vary."

ii. Reasons are learners' perception about why a particular feature is important.

"It [reciprocative interface] will make me comfortable in each domain.", "I can also check how this [second graph] varies."

iii. Learning impact is learners' perception about the impact of feature/s on their domain knowledge.

"... more variation, more learning.", "... now, I will be more comfortable in lecture... I know how they are related.", "Oh, now I know how those vertical lines [spectral line] change... I can understand Fourier series and also how to draw Fourier spectra" [extended topic], "I am now more confident".

All students appreciated reciprocative affordances. When asked whether manipulating only one of the representations was sufficient, all students mentioned it to be insufficient for learning and advocated the need for having two-way reciprocative manipulation affordance. The perceived benefits of the reciprocative affordances as reported by students were: more exploration opportunities, faster grasping, clarity of concepts, increased confidence due to both way manipulation and translation, developing understanding by comparison, ease in learning of advanced / extension of the topic, and the ability to cross-check relations by manipulating both representations.

7.4.4. Discussion of the Qualitative study

The screen capture and interview data helped in understanding how students use the affordance of Reciprocative Dynamic Linking (Q1). Students' navigation through the IELE consisted of two types of search manipulations: exploratory and confirmatory. During the initial exploratory manipulation, students interacted with the first representation in order to comprehend the topic. Due to dynamic linking, they could observe the changes happening in the second representation. The reciprocative nature allowed students to manipulate the second representation as well, giving them the opportunity to relate both representations. Generally, it is a default cognitive action to imagine or visualize the change that the second representation could cause in the first, while observing change in the second representation due to the first one. In our case, learners could use the reciprocative nature of interactivity to offload the burden on working memory while doing so. Thus, the reciprocative affordance could have led to reduction in the cognitive load demand. The opportunity to manipulate the second representation supported an operation that would have been difficult for the learner to do by imagination alone. Thus, the reciprocative interactivity helped learners in comprehending the representations in isolation as well as the relation and translation between representations. The granular translations shown in the assessment test was an evidence of the development of sound learning in students.

Another phenomenon observed in screen capture data was that learners returned again to the first representation after manipulating the second, that is, the confirmatory manipulation. We conjectured that while manipulating both the representations, the learner generated a hypothesis as part of mental inquiry process and returned to the first representation again to test or confirm the hypothesis. We had support for this conjecture via interview data, wherein students reported that they used the feature that allowed variation in both the graphs for checking how representations were related. This data related to students' confirmatory manipulation also helped answering Q2 of how Reciprocative Dynamic Linking influenced learning from MERs. Probably, this affordance was used by students to get support in the learning process that managed their cognitive resources optimally, and also supported their inquiry process thus leading to deeper learning. However, we found it difficult to get direct confirmation for students' formation & testing of mental model from students themselves. Students, not trained to reflect on their own learning process typically do not realize these subtle aspects about their own learning and mostly tend to accept reasons for learning as provided (de la Harpe, et al., 1998).

7.5. Quantitative study of the Exploratory Mixed research design

The first phase of qualitative study was followed by quantitative study. Generally, the follow-up quantitative phase of exploratory design involves experiments with large N. Due to some logistic and technical issues, we could not conduct the qualitative study with large N.

Thus, still more qualitative data was collected during the quantitative phase. The details of the second phase of the exploratory research design are presented below.

7.5.1. Participants and experimental design for Quantitative study

Participants were students from second year of engineering from three different colleges affiliated to University of Mumbai (N= 24; 14 males and 10 females). Although, the selection of colleges was done on the basis of ease of access and other logistics issues, the selected colleges had students from different strata of academic profile. Also, the students admitted to the engineering program had qualified a common entrance examination. All the participants have appeared for the first year examination that was common for all the students from the University. This ensured the representativeness of the sample. While convenient sampling was used for selecting students for the study from the list of students, the group creation was done using randomizer.

The study was conducted using a 2-group post-test only experimental research design. Participants were randomly assigned to one of the following two conditions: (a) Simulation (SIM group); N =12 and (b) Interactivity Enriched learning Environment (IELE group); N = 12. The participant were studying in the third semester of the program. They had no prior knowledge about the content of the simulation and they were at par for their prior knowledge based on their academic structure. Additionally, the prior knowledge was checked by giving some sample questions to solve before the treatment and domain knowledge assessment test. The sample questions expected students to express the given signals into different representations. All participants were found to be at par based on their answers given to the sample questions. The first year performance grade point score (out of ten) was used to confirm group equivalence. The means of grade point were found to be statistically equivalent (SIM (M=8.26, SD=0.86) and IELE (M=8.35, SD=0.85); $t(19)$= 0.217, p=0.415). The average age of students was 20 years. Participants were familiar with the use of ICT tools in learning through other courses and laboratory in their curriculum.

7.5.2. Treatment for Quantitative study

The instructional intervention while implementing the quantitative phase of the research design was as follows:

- The SIM group learnt with an interactive JAVA applet that offered only one representation for manipulation.
- The IELE group studied with the applet- IELE embedded with IEF of Reciprocative Dynamic Linking.

7.5.3. Procedure for Quantitative study

First, all participants were briefed about the study procedure and its objectives. They were assured that their participation had no bearing on their academic performance. After signing consent forms, they were allotted to two treatment conditions created using randomizer. The treatment intervention lasted for 35-40 minutes. After completing learning from the respective learning material developed, participants were asked to solve the assessment test. The assessment test booklet had the following components i) Self-reported mental effort rating single-question questionnaire, ii) Domain knowledge performance test for different learning objectives, and iii) Self-reported difficulty rating (mental load) single-question questionnaire. The assessment test format was arranged as follows:

- → Self-reported mental effort rating single-question questionnaire
- → Domain knowledge question of 'Apply Procedural knowledge' --> Self-reported difficulty rating (mental load) single-question questionnaire for 'Apply Procedural knowledge'
- → Domain knowledge question of 'Understand and Apply Conceptual knowledge'--> Self-reported difficulty rating (mental load) single-question questionnaire for 'Understand and Apply Conceptual knowledge'
- → Domain knowledge question of 'Analyze Procedural knowledge' --> Self-reported difficulty rating (mental load) single-question questionnaire for 'Analyze Procedural knowledge'

At the end of the research study, students were interviewed. After the interview they were thanked for their participation and were given participation certificate.

7.5.4. Data Analysis Techniques for Quantitative study

The quantitative data was collected in the form of domain knowledge performance test score, self-reported mental difficulty score, self-reported mental effort score for both the groups. The instrument for domain knowledge performance test score and self-reported mental effort score was designed for different categories of questions. Thus, the scores were compared for all these three categories independently. The questions in the assessment test paper were organized into three categories; category I questions catered to 'Apply Procedural knowledge' type, Category II questions were from 'Understand + Apply Conceptual knowledge' type and Category III questions aimed at 'Analyze procedural knowledge' type. As mentioned earlier in Section 7.3 of this Chapter, the second category of the questions was a mixed question category with questions of 'Understand Conceptual knowledge' and 'Apply Conceptual knowledge' due to domain (time and frequency domain of a signal) based categorization method adopted. This was done to maintain content coherence in the test.

Following steps were taken to carry out statistical analysis of data. The raw data was processed to get a normalized score, out of ten for each category of questions. The data was further checked for normality and other valid assumptions to decide suitability of parametric statistical tests for comparing means. An alpha level of 0.05 was used for all statistical tests. The statistical analysis involved the following.

- comparison of means of domain knowledge performance test score to find out statistically significant difference between both groups using independent sample t-test or its equivalent non-parametric test to test hypothesis E5-H1-A, B, C
- comparison of means of self-reported mental difficulty score and self-reported mental effort score to find out statistically significant difference between both groups using independent sample t-test or its equivalent non-parametric test to test hypothesis E5-H2-A, B, C

The qualitative data received from semi-structured interviews and screen captures were analyzed using Content Analysis method.

7.5.5. Results for Quantitative study

7.5.5.1. Domain Knowledge Performance Test and Self-reported Difficulty level ratings

Table 7.2 shows the mean and standard deviations of domain knowledge performance test scores for the research study. Both the treatment groups were compared for three different categories of questions. These results were interpreted further to answer the RQ2.

The data passed Shapiro-Wilk test for normality and other assumptions needed for parametric tests were found to be valid. Thus, parametric tests were selected for further statistical analysis. As per the results obtained from independent sample t-test, the domain knowledge performance test score means were found to be statistically significantly different for 'Category I: Apply Procedural knowledge' and 'Category III: Analyze Procedural knowledge': ($t(22)=-2.054$, $p=0.026$), and ($t(22)=-2.65$, $p=0.002$) respectively. There was no statistically significant difference found in the means of 'Understand + Apply Conceptual knowledge' category II questions scores ($t(22)=-1.433$, $p=0.082$).

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

We have presented the results of independent sample t-test here. However, as the sample size was small, we also conducted non-parametric test on the data. The Mann–Whitney U test, non-parametric equivalent test of independent sample t-test was used for comparing means of the domain knowledge performance test scores. As per the results obtained from Mann–Whitney U test, the domain knowledge performance test score means were found to be statistically significantly different for 'Category I: Apply Procedural knowledge' and 'Category III: Analyze Procedural knowledge': ($p=0.043$ and $p=0.001$

respectively). There was no statistically significant difference found in the means of 'Understand + Apply Conceptual knowledge' category II questions scores (*p* =0.072).

Table 7.3 shows the self-reported difficulty level scores of learners. These scores are measure of the germane cognitive load as experienced by learners while interacting with the learning environment.

The data passed Shapiro-Wilk test for normality and other assumptions needed for parametric tests were found to be valid. Thus, parametric tests were selected for further statistical analysis. The independent sample t-test on the self-reported difficulty level scores of learners revealed that the score means were found to be statistically significantly different for difficulty level reported after 'Apply and Analyze Procedural knowledge' category of questions (category I and III: ($t(22)=2.50$, $p=0.010$), and ($t(22)=2.2206$, $p=0.019$) respectively. While there was no statistically significant difference found in the means of difficulty level rating reported for the category II of questions ($t(22)=1.153$, $p=0.131$).

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

As the sample size was small, we also conducted non-parametric test on the data. The Mann–Whitney U test, non-parametric equivalent test of independent sample t-test was used for comparing means of the domain knowledge performance test scores. As per the results obtained from Mann–Whitney U test, the domain knowledge performance test score means were found to be statistically significantly different for 'Category I: Apply Procedural knowledge' and 'Category III: Analyze Procedural knowledge': ($p=0.021$ and $p=0.041$ respectively). There was no statistically significant difference found in the means of 'Understand + Apply Conceptual knowledge' category II questions scores ($p=0.106$).

7.5.5.2. Analysis of recorded screen captures

The recorded screen captures were analyzed to find out the manner in which students explored the IEF of Reciprocative Dynamic Linking offered by ILE. The screen captures were collected for all the participants while they were interacting with the learning environment. As four captures were lost due to technical issue, total 20 screen-captures were analyzed. Out of 20, 9 screen captures were for the control group (SIM) and 11 were for the experimental group (IELE). The time for exploring the material ranged from 7 to 20 minutes (average of 12:10 minutes). The objectives of screen capture analysis were as follows: i) to identify the general approach of students while exploring the ILE, ii) to analyze whether the IEF was used by students and iii) to analyze pattern of exploration by both the groups while using Reciprocative Dynamic Linking.

Considering these objectives, the qualitative analysis of screen capture was done in two phases. The phase I consisted of 'code identification phase', where the possible codes that could emerge were looked for and identified. In phase II, all the screen captures were analyzed again based on the identified codes. An exploration activity by a student was considered as a unit of analysis. For example, selecting a representations for manipulation by clicking on radio button, manipulating the selected representation, selecting the other representation for manipulation, navigating between different tabs of learning material were some of the examples of various activities students did while exploring the content. From Phase I analysis, the codes were identified. The objectives of screen capture analysis were considered for identifying codes. While looking for general approach of exploration, the objective was to assess the exploration for any kind of abruptness in the navigation. Based on this, the first phase of analysis indicated the codes to be 'structured navigation' or 'non-structured navigation'. The other objective for screen capture analysis was to identify if students used the IEF, which was coded under the category 'utilization of affordance'. The third objective of screen capture analysis was to identify exploration pattern. The Explanatory manipulation exploration and Confirmatory manipulation exploration patterns were identified during first strand of qualitative analysis of this study. During this screen capture analysis, all the screen captures were analyzed to find out these exploration patterns.

The following have been the observations and inferences for the above mentioned objectives.

- General approach for exploring learning material: (Structured navigation / Non-structured navigation): All participants exhibited structured navigation. The students moved linearly through home screen--> theory--> learning content (tab wise) introductory text --> learning content interaction. Students’ familiarity with computer-based learning environments/ simulation environments was evident from this exploration approach.
- Use of IEF of Reciprocative Dynamic Linking affordances in IELE: (Used/ Not used): All students from IELE group used Reciprocative Dynamic Linking. i.e. all of them manipulated both the MERs. Tab wise observations are as follows.

  Tab 1: Except two, all students selected time domain for manipulation first. All possible variables were manipulated by students (amplitude, frequency, and phase) for both the MERs.

  Tab 2: All students selected both the MERs and manipulated all possible variables.

  Tab 3: All students selected both the MERs and manipulated all possible variables. Tab 3 also has a graphical representation, which was not offered for manipulation. 5 students attempted to manipulate that, checked whether it was also offered for manipulation.

  SIM: All students from SIM group used the possible variable manipulation opportunities offered for only one representation in all the three tabs.

  Thus, students from both the groups fully utilized respective affordances offered in their learning materials. From domain perspective, time domain representation appears to be the more comfortable and familiar domain of representation and was preferred for manipulation as a first choice by maximum number if students. In general, all possible exploration opportunities and affordances were used by students.
- Exploration pattern (Explanatory manipulation exploration/ Confirmatory manipulation exploration IELE): The qualitative strand of this study revealed many students followed confirmatory manipulation exploration pattern. The similar observation was found in this phase of screen capture analysis. In a given tab, both the representation were manipulated in the form of confirmatory search. While exploring the MERs using Reciprocative Dynamic Linking, students manipulated the first MER, then the second. After this, they again reverted to manipulate the first MER. This pattern was observed for all the three Tabs. This observation, resembling the 'prediction and hypothesis testing phase' of inquiry cycle was confirmed in this screen capture analysis as well. This pattern was prominent in

9 students out of 11. In case of SIM group, students used the offered affordances for more number of times. In an attempt to comprehend the content, students from SIM group probably had to use the only given affordance for many more number of times as compared to IELE group. Still that could not translate into desired learning outcome, as was evident from the test score.

7.5.5.3. Semi-structured Interviews

All the twenty-four participants were interviewed face-to-face immediately after they completed the assessment test. The objective of conducting semi-structured interview was to gather data about students' learning experience and their perception about learning environment / its features.

Procedure: Students were briefed about interview objective, protocol and their consent for audio recording of the interview was taken. Then they were asked about their learning experience. The conversation was based on the following open ended questions. 1) "Can you tell us something about the learning experience you had today?" 2) "Which typical aspect/ feature of the learning environment you think, must have helped you while learning?" 3) "In what way, you feel the learning environment features could help you while solving the domain knowledge assessment test?" After asking about their own learning experience and the manner in which they utilized the learning environment for the purpose of learning, they were shown the learning environment of the other group and their perception about it was asked. (i.e. control group participants were shown the experimental group learning environment and vice versa).

The interviews lasted for 8-10 minutes. The recorded interviews were transcribed and analyzed further using Content Analysis method with a 'sentence' as the 'coding unit'. The coding was done keeping in mind the objectives of the questions asked. Accordingly, following categories of the codes emerged strongly from the analysis.

- Learning pattern: This code elaborated the learning pattern followed by learners while learning the given content from the learning material.
- Feature impact: This code focused on which feature of the learning material was perceived by learners to be useful in learning and how learners derived learning help from it.
- Learning preferences: This code refers to the learning style/ feature preferred by learners.

Following are some of the verbatim responses corresponding to the above mentioned codes.

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.

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".....

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"....

Inferences from the interviews

The overall responses from interviews were in favour of Reciprocative Dynamic Linking. The important keywords/ phrases emerged from the interviews favoring Reciprocative Dynamic Linking were, *"back testing, more flexibility in understanding, good rechecking, predict what can happen, can grasp in easier way, able to find relations, chain of representations, it fits in my mind, clear idea, relate better, help in thinking backwards, time and frequency domain go hand-in-hand"*.

During interviews students demanded some additional features/ content, such as more examples, audio commentary. Regarding learning preference, all the 24 students advocated the need of Reciprocative Dynamic Linking. Students who learnt without Reciprocative Dynamic Linking, when explained what it was, commented that they would have preferred learning from Reciprocative Dynamic Linking learning material. After asking for this preference, they justified the reasons for their preferences using the keywords as mentioned above.

7.5.6 Discussion for Quantitative study

E5-RQ1: Given the type of knowledge and cognitive level, how does Reciprocative dynamic Linking as an 'Interactivity Enriching Feature (IEF) affect learning in interactive learning environment with the same level of interaction?

Learning impact of Reciprocative Dynamic Linking:

The independent sample t-test on the domain knowledge performance test score demonstrated that IELE group scored higher as compared to SIM group for category I and category III questions. The *p* value was found to be 0.026 and 0.002 respectively, thus confirming the effectiveness of IELE group over SIM group. The confirmed that the Reciprocative Dynamic Linking improved learning for ‘Apply and Analyze Procedural task’. This supported hypothesis E5-H1-C.

We did a detailed analysis of questions from category I and III to get more insight. The questions from category I aimed at assessing students’ ability of applying procedural knowledge while translating from one domain representation to another domain representation. Out of the five questions from category I, question number 2, 4 and 5 not just assessed students for the topic explained in the learning material, but the questions also covered the topics that could be treated as an extension of the topic. The better performance of IELE group students, especially in these questions, in a way indicated that the experimental group could develop deeper learning about the topic and was able to apply knowledge in different (unfamiliar) topics as well. The mean score of question number 2, 4 and 5 for IELE group were found to 77.92% higher than the mean score for these questions for SIM group). (The means for these questions (2, 4 and 5) together were found to be statistically significant after running an independent sample t test p=0.012). As far as category III questions were concerned, the question number 10 and 11 were from 'analyze' cognitive level. The score on these questions of IELE group was higher than SIM group by 63.15 % (statistically significant means with p=0.002) and that again has been a supportive result. These findings demonstrated learning effectiveness of IELE as compared to SIM.

Category II had mixed questions; at 'understand conceptual knowledge and 'apply conceptual knowledge'. This category contained questions wherein students have to translate signals to time domain representation from the given frequency domain representation. In order to cater to this domain requirement, this category had to have mixed questions. However, it was found to be at par for 'understand conceptual knowledge' and 'apply conceptual knowledge' task (p=0.082). This indicated that IEF of Reciprocative Dynamic Linking could not offer significant help to learners. The hypotheses E5-H1-A and E5-H1-B were not supported. We discuss about the probable reasons for this while answering E5-RQ2.

The quantitative results when seen along with qualitative data collected from interviews and screen captures, provide more insight to the inferences drawn. The physical interactions with MERs is a necessary part of one's thinking process in the knowledge building process (Kirsh 2009). The feature of Reciprocative Dynamic Linking made this physical interaction with MERs possible. This was supported by the responses that emerged from the interviews of students. We restate some of the responses here; *"more flexibility in understanding", "can grasp in easier way", "able to find relations", "chain of representations", "it fits in my mind", "clear idea", "relate better"*. These responses from students can be considered as an indication of the learning support that they could get from their interaction with Reciprocative Dynamic Linking. Additionally, due to the presence of Reciprocative Dynamic Linking, students could free up their cognitive resources and use them for developing better understanding of MERs; which got reflected in their higher test scores. The results related to cognitive load discussed in the next subsection also support this aspect.

The screen capture analysis revealed and confirmed the pattern followed by students while exploring the content. The students followed exploratory and confirmatory search pattern. The pattern suggested that the students were trying to check the mental model created through their interactions with Reciprocative Dynamic Linking. This again has been captured in some of the responses that emerged from the interviews; *"back testing", "good rechecking", "help in thinking backwards"*. All these and similar responses articulate the process the students followed by interacting with Reciprocative Dynamic Linking. The reciprocative nature of the interaction was used by students first to build up the mental model of the content being learnt, and then it was used to check the mental model created. The responses like "*back testing", "good rechecking", "help in thinking backwards"* support this. The science education literature associates prediction ability as one of the feature of model making. The response, "*I will be able to predict what can happen"* suggests that students could exhibit this ability as an outcome of model formation process. The better performance of students in the questions form extended topic, in a way, indicated that students could predict how the learnt knowledge would get applied in the new situations.

The students were better equipped to "relate, link MERs" with Reciprocative Dynamic Linking. The responses such as "*able to find relations", "chain of representations", "relate better", "time and frequency domain go hand-in-hand"* supported this. For some questions Reciprocative Dynamic Linking could not show any improvement in the learning. To investigate reasons for this, we looked at the questions and the kind of cognitive processing they might have expected from learners while answering them. The very reason of introducing Reciprocative Dynamic Linking in the learning environment has been to support learners' cognitive requirement. It was hypothesized that learners demanded cognitive support while learning some types of tasks and the additional feature such as Reciprocative Dynamic Linking would offer the same, thus allowing some of the cognitive resources to get freed up for using for actually learning the educational content. With this as a premise, it would be also appropriate to conclude that features like Reciprocative Dynamic Linking have more prominent role to play when learners need good level of cross-representational linkage. The questions for which Reciprocative Dynamic Linking could not do any improvement in the learning scores were like identifying a representation and writing down mathematical expressions. These questions did not expect learners to construct new representations and perhaps students could solve these questions without need of additional support.

E5-RQ2: How is learners' cognitive load influenced by the presence of IEFs in an interactivity enriched learning environment?

Impact of IEF on the cognitive processing of learner

The Self-reported Difficulty level ratings collected from learners have been found to be sensitive to indications of germane processing (DeLeeuw et al. 2008). Germane cognitive load, enhances learning and results in task resources being devoted to schema acquisition and automation; it is a result of mental activities that are directly relevant to learning. The lower value of learners' self-reported difficulty levels suggested that learning environment could offer more support to cognitive resources that directly contributed to the improvement in learners' performance. The independent sample t-test on the self-reported difficulty level scores of learners revealed that the score means were found to be statistically significantly different for difficulty level reported after 'Apply and Analyze Procedural knowledge' category of questions (category I and III: ($t(22)=2.50$, $p=0.010$), and ($t(22)=2.2206$, $p=0.019$) respectively. This indicated that learners experienced improvement in the germane cognitive load while learning with IELE as compared to the SIM group for 'Apply and Analyze Procedural knowledge' type of task.

There was no statistically significant difference found in the means of difficulty level rating reported for the category II of questions ($t(22)=1.153$, $p=0.131$). For category II questions, the statistical equivalence of mental difficulty, along with statistically non-significant difference between test scores was analyzed further. We looked at the questions and analyzed the kind of mental efforts needed to put in for solving these questions. The questions from this category involved concepts related to signal frequency, amplitude, phase, fundamental time period and complementary nature of time and frequency domain. The at par performance of students for these questions in a way suggested that, both SIM and IELE offered equal learning support to learners while answering these questions. These being basic concepts from the topic, learners perhaps needed no additional support from the learning environment. Thus, learners might have felt the presence of IEF in IELE redundant while catering to these questions. One of the verbatim responses is supportive of this (.....*"if I understand, I don't need both ways manipulation.....one is also enough and sufficient"...).*

The mean and standard deviation of learner's self perception of how much mental effort was invested while learning from SIM and IELE has been SIM (M=3.92, SD=1.16) and IELE (M=4.20, SD=1.75) and there was no statistically significant difference reported in the means based on the findings of independent sample t-test ($t(22)= -.453$, p =0.32). This mental effort reading being a measure of intrinsic cognitive load, it demonstrated that learners experienced same amount of intrinsic cognitive load while learning from two different treatment groups. This finding further strengthens our claim that the Reciprocative Dynamic Linking led to improvement in learning due to the support offered by increased germane cognitive load.

Small sample size was a limitation of this study. The logistics issues related to availability of students during academic activities and the issue of incompatibility of JAVA applet with browser constrained the sample size. However, a serious attempt was made to triangulate the data from multiple sources. The inferences were drawn from the quantitative analysis, and were supported by detailed qualitative analysis of screen-capture data and interviews.

7.6 Summary

This study was conducted to find out support for the second and third step of the three-step IEF validation approach. It offered evidence for confirming the improvement in learning due to the IEF- Reciprocative Dynamic Linking for 'Apply and Analyze Procedural knowledge' and it could also attribute the said improvement to the increase in the germane cognitive load of learners. There was no improvement observed due to this IEF while dealing with 'Understand and Apply Conceptual knowledge'. The nature of the questions demanded no additional support for learners, which resulted into SIM and IELE being at pat for this category of questions. The findings and inferences from quantitative phase were further supported by screen capture analysis. The screen capture analysis was useful in finding out the reasons for improvement in performance due to IEF. The semi-structured interviews gave us insights into the reasons why we saw improvement in learning and also regarding the ways in which IEF was used by learners. Based on the findings from experiments E1 to E5, we answer research questions of the thesis in the following Chapter.

8. Chapter 8

Discussion

Overview of the research problem and solution approach

Against the backdrop of mixed nature of learning impact of ILEs, the broad level research issue addressed in this thesis is 'under what conditions do ILEs lead to effective learning?’. The main research objective was to design appropriate interactivity in ILEs to deliver expected learning outcomes. The solution approach involved identifying the nature of cognitive support required to learners while dealing with interactive nature of ILE and to design this support in the form of learning-conducive interactive features, referred to as *'Interactivity Enriching Features (IEFs)'*.

8.1. Answering Research Questions

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

The first research question addressed issue related to suitability of interaction level, i.e. hierarchical nature of learner control offered in ILEs, for the given learning task. Research experiments E1, E2 and E3 answered RQ1. The results showed that higher level of interaction does not necessarily lead to higher learning. Additionally, the findings from E1, E2 and E3 also showed that different knowledge types and cognitive levels required different level of interaction for effective learning in ILEs. The results of E1 found animation and simulation to be at par. These results got replicated in the research study E2. In experiment E3, for understand conceptual knowledge and apply procedural knowledge, animation was at par with simulation, whereas for apply conceptual knowledge animation was found to be more effective than simulation. Consolidating findings from these three experiments (E1, E2 and E3), we found that simulation, in spite of its higher interaction level, did not lead to higher learning when compared with ILEs at a lower interaction level. This confirms the inconsistent and mixed nature of learning impact in ILEs and demands a careful consideration to the role of interactivity in Interactive Learning Environment.

The inferences from these findings can be two-sided. One way of looking at these findings would be to suggest that non-interactive learning environment or ILE with lower level of interaction works at par with ILEs with higher level of interactions. The implication of this could be to make learners learn from ILEs with lower level of interactions. The other way of looking at the findings would be to recognize the fact that, in spite of higher level of interaction, ILEs could not necessarily lead to higher learning. Thus, making learners learn from ILEs with lower level of interaction is certainly not a solution; as the problem lies somewhere else. The problem is about an ILE not being able to deliver its learning outcome, in spite of its potential. Thus, the real question is not about which interaction level is more suitable for learning, but whether the given interaction level is capable of delivering its learning potential. This has been the precise problem addressed by this thesis work. Thus, the focus here is on designing ILEs in such a manner that they are able to deliver their learning potential. Findings from the research experiments E1, E2 and E3 draw attention to the point that the issue is not about lower interactivity being sufficient for meeting the learning demands, but it is about higher level of interaction being unable to deliver their inherent learning potential. Thus, an important and a rather cautious interpretation from these findings is that interactivity offered in ILEs would be 'wasted' if not supported with the appropriate features. Some of the previous studies (Boucheix & Schneider, 2009; Grunwald & Corsbie-Massay, 2006) have discussed this aspect. Thus, answers for RQ1 could justify the need for exploring the broad research issue of the thesis, "Under what conditions ILE lead to effective learning?"

The reason for poor performance of higher level of interaction may be due to learning demands on learners. While attempting a given task at a specified cognitive level, learners are expected to perform certain amount of cognitive processing. The learning material that puts additional cognitive overload on the learner instead of assisting learner, may hamper the learning process. Previous studies in this context (Low & Sweller, 2005; Moreno & Mayer, 1999) have confirmed the undesirable role of cognitive overload in the learning process. Consideration to this aspect has been given in the research studies E4 and E5.

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

This research question was answered by research studies E1, E4 and E5. 'Interactivity Enriching Features (IEFs)' are conceptualized as interaction features in ILE offered to user in the form of an affordance. We determined four IEFs for content manipulation interaction in ILE and using them Interactivity Enriched Learning Environments were designed. The IEFs embedded into IELEs were,

i. Productively Constrained Variable Manipulation
ii. Permutative Variable Manipulation
iii. Discretized Interactivity Manipulation
iv. Reciprocative Dynamic Linking

Results from research experiment E1 showed that inclusion of IEFs (Productively Constrained Variable Manipulation and Permutative Variable Manipulation) improved learning. As per the results from Experiment E1 the ‘Apply Procedural knowledge’ average learning scores of the three groups without IEFs (Non-IELE, ANM and SIM) were found to be at par. However, after redesigning the learning environment with appropriate IEFs, ‘Apply

Procedural knowledge' average score was found to be statistically significantly higher as compared to its counter parts. This showed that ILE could deliver its learning benefits only after getting augmented by IEFs. These results are encouraging, as they directly address the issue of the higher level of interactive features being unable to deliver their inherent learning potential. The very reason of including IEFs was to design interactivity in such manner that learners will be able to fully utilize its learning potential. This was achieved after including IEFs in the learning environment.

Results from E4 and E5 were also able to confirm the learning effectiveness of IEFs. Results from E4 indicated that students learnt better from the ILEs that used Discretized Interactivity Manipulation as an IEF as compared to the learning environment without this IEF for 'Understand Procedural knowledge' and 'Apply Procedural knowledge' learning objectives. As designed, the IEF based on the notion of event cognition was embedded in IELE to be effective for improving procedural knowledge. The same IEF was found to be redundant for applying conceptual knowledge. This IEF mainly focused on supporting learning of procedural knowledge, thus, in a way both the learning environments (SIM and IELE) might have offered similar learning experience to learners while dealing with the content catering to conceptual knowledge. The findings from E5 confirmed that the Reciprocative Dynamic Linking as the IEF improved learning for 'Apply Procedural task' and 'Analyze Procedural task'. However, it was found to be at par for 'Understand Conceptual knowledge' and 'Apply Conceptual knowledge' task. The nature of questions for these two categories demanded no additional support for learners, which resulted into the presence of IEF to be redundant in IELE.

To summarize, the objective with which IEFs were embedded into the learning environment was fulfilled and the results confirmed the same. All these results further reiterated the need for carefully designing interactions in ILEs and also demonstrated that mere presence of interactions in ILEs need not necessarily lead to meaningful learning. Based on this three-step approach mentioned in Section 5.4 of Chapter 5, the research experiments E1, E2 and E3 validated the first step of IEF validation process. The research experiments E1, E4 and E5 helped in completing the second step of IEF validation process.

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

This research question was answered by research studies E4 and E5. The self-reported difficulty level ratings collected from learners were found to be sensitive to indications of germane processing. Germane cognitive load enhances learning. It devotes task resources to schema acquisition and automation. Thus germane cognitive load is a result of mental activities that are directly relevant to learning. Thus, lower value of difficulty level rating reported by learners can be interpreted as better learning. This also suggests that learning environment has been able to offer more support in terms of cognitive resources directly contributing to the improvement in performance of learners.

Against this backdrop, interpretation of results obtained from the self-reported difficulty level rating for research experiments E4 and E5 suggested that the improvement in learning performance could be attributed to the improvement in the germane cognitive load. These findings also corroborated the three-step validation process of IEFs. Findings from experiments E4 and E5 showed how inclusion of IEFs in ILEs created Interactivity Enriched Learning Environments by supporting learners' cognitive processing, This completed the third step of the IEF validation process.

8.1.1. Forming 'Interactivity Design Principles'

The results, findings and inferences from the research studies have been formalised in the form of Interactivity Design Principles. These principles will be useful for instructional designers, content creators and also to instructors who wish to play a dual role of instructor-cum-instructional designer. Figure 8.1 shows these principles.

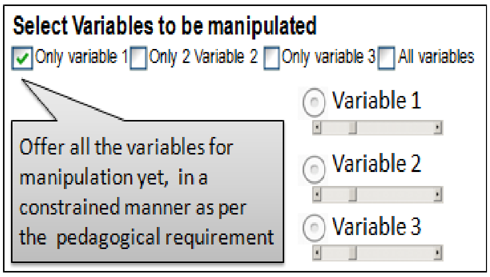
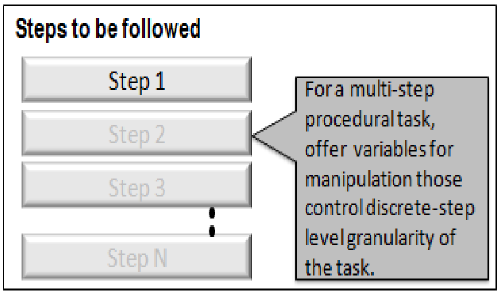
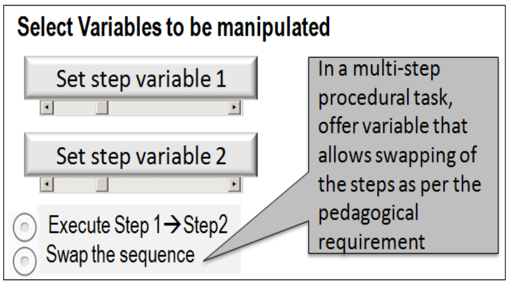
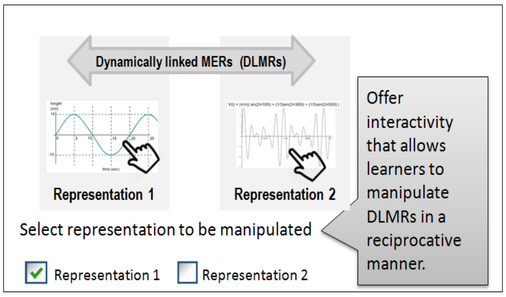
<table>
<tr><th colspan="2">Interactivity Design Principles</th></tr>
<tr><td>
</td><td>While offering more than one variable for manipulation, offer variables for manipulation in a progressive manner. Make use of Productively Constrained Variable Manipulation (PCVM) feature that offers all the variables for manipulation yet, in a constrained manner.</td></tr>
<tr><td>
</td><td>While simulating a multi-step procedural task/ event, offer those variables for manipulation that control discrete-step level granularity of the task. Make use of Discretized Interactivity Manipulation (DIM) feature to offer discretized interactivity to control individual steps in a given procedural task.</td></tr>
<tr><td>
</td><td>When simulating a procedural task that involves steps to be carried out in a sequential order, use Permutative Variable Manipulation (PVM). PVM allows swapping of the steps and offers more flexibility by offering more permutations to explore for a given procedural task.</td></tr>
<tr><td>
</td><td>While learning from Dynamically Linked Multiple Representations (DLMR), offer Reciprocative Dynamic Linking (RDL) interactivity which allows learners to manipulate both (or more) DLMRs in a reciprocative manner.</td></tr>
</table>

Figure 8.1. Interactivity Design Principles

8.2. Proposing Model for Interactivity Enriched Learning Environment (MIELE)

The Chapters presented so far dealt with the research objectives, the solution approach, operationalization of the solution approach and results of the solution approach. Overall thesis work had three main constituents; designing of IEFs, role of IEFs in offering required cognitive support in ILEs and empirical evidence for effectiveness of IEFs. Each of these can be considered as an individual perspective that contributed towards offering enriched learning experience to learners in ILEs. We now present an integrated view in the form of three-layer model that presents these perspectives of IEF designing and its learning impact on ILEs. We propose the **'Model for Interactivity Enriched Learning Environments' (MIELE)**. The model is shown in Figure 8.2. The model aims at integrating elements required for creating Interactivity Enriched Learning Environments; designing of IEFs, effect of IEFs on cognitive processing and designing of ILEs with IEFs.

1. a **descriptive perspective** that describes IEF designing.
2. an **explanatory perspective** that explains the underlying phenomenon related to cognitive processing of learners that makes IEFs improve learning from ILE.
3. a **prescriptive perspective**, that offers recommendations derived from experimental findings for designing enriched interactivity in ILEs.

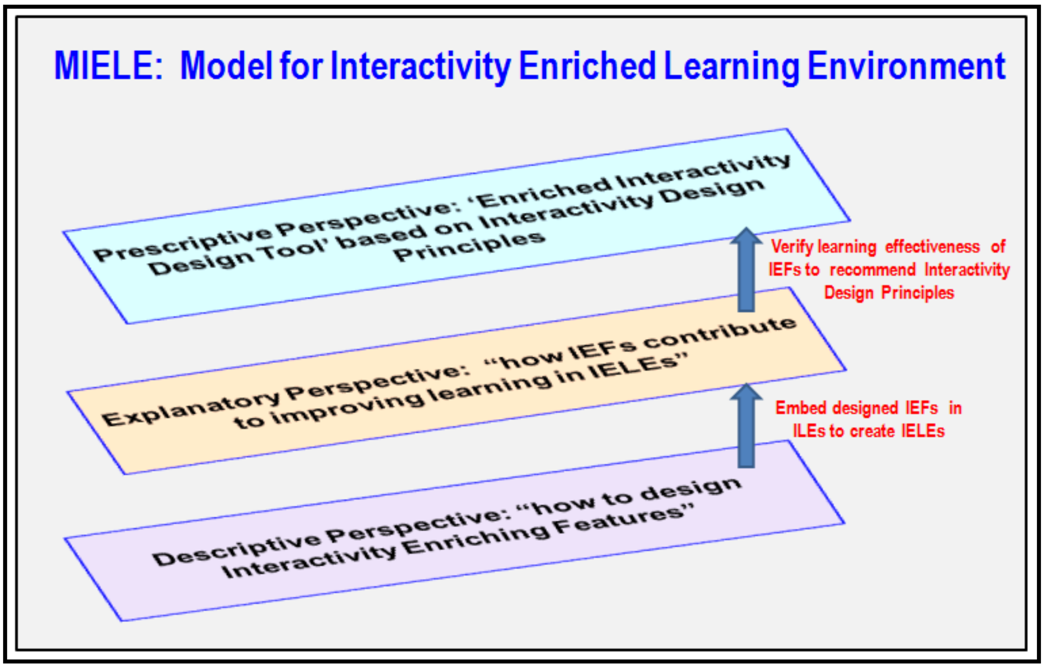
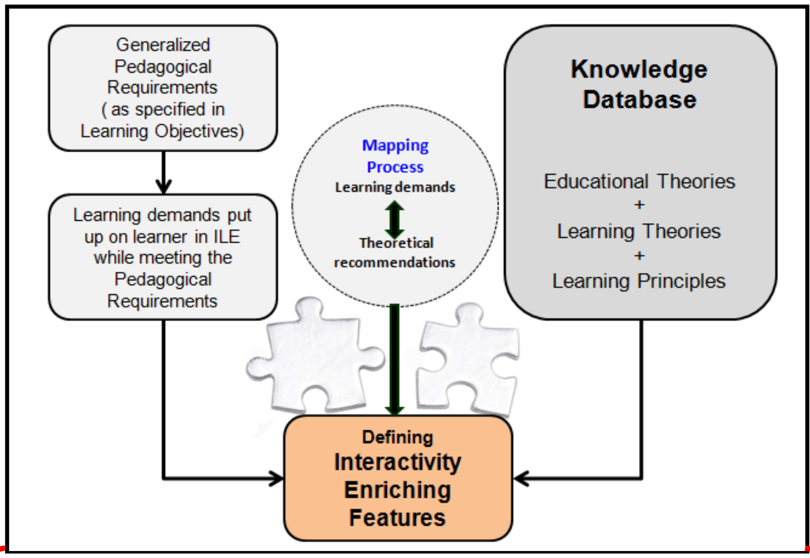


Figure 8.2. Three-layer perspective of the proposed model MIELE

The individual perspectives of the model are presented below.

Descriptive perspective of MIELE: Figure 8.3 presents the descriptive perspective of the model that describes IEF designing. The IEFs are designed on the basis of generalized pedagogical requirement, learning demands and theoretical recommendations. This perspective will help instructional designers/ instructors/ researchers to apply IEF designing process in newer context. Details of this perspective are already explained in Chapter 3.



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***

Figure 8.3. Descriptive perspective of MIELE: designing of Interactivity Enriching Features

Explanatory perspective of MIELE: The explanatory perspective of MIELE explains how IEFs contribute to improve learning in Interactivity Enriched Learning Environments It explains how different interaction features, interactivity, learners and their cognitive processing are inter-related in ILEs and how IEFs enrich interactivity to create Interactivity Enriched Learning Environments. This perspective will help ILE researchers and cognitive scientists in exploring and positioning relevant research issues related to these constituents of ILEs.

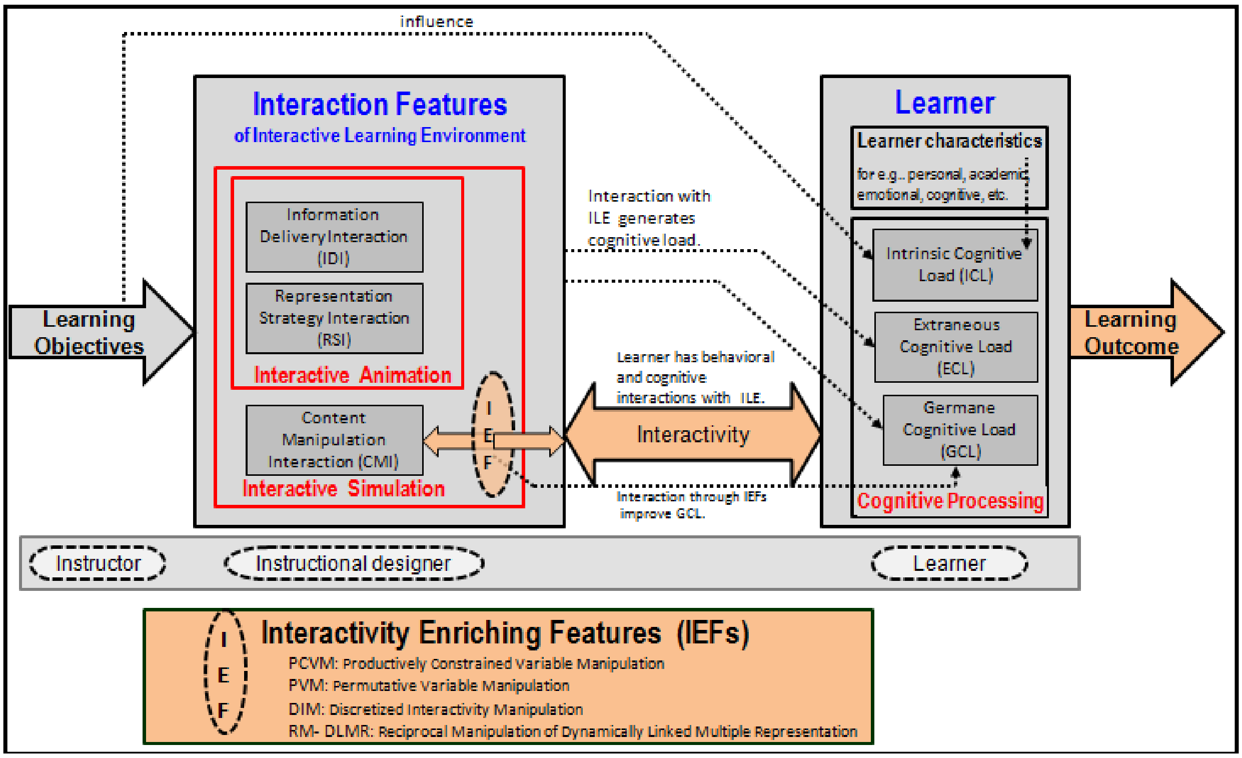


Figure 8.4. Explanatory perspective of MIELE: How IEFs contribute to improving learning in IELEs

Prescriptive perspective of MIELE: This perspective offers recommendations to instructional designers for selection of IEFs. The recommendations have been derived from the findings of empirical studies conducted to test effectiveness of IEFs. The results and findings of experiments E1 to E5, collectively contribute to Prescriptive perspective of MIELE. The objective of these prescriptions is to offer guidelines while selecting appropriate IEFs.

"*e*IDT: *e*nriched Interactivity Design Tool"

The Prescriptive perspective of MIELE has been formalized into a tool that automates the IEF selection process. We propose tool ***e*IDT: *e*nriched Interactivity Design Tool that** offers recommendations to design interactivity by selecting appropriate IEFs. The look and feel of eIDT is available at the URL[7]. Figure 8.5 present the steps followed by eIDT in selecting IEFs. The tool targets content creators and instructional designers to assist them in creating educationally effective interactive learning environments.

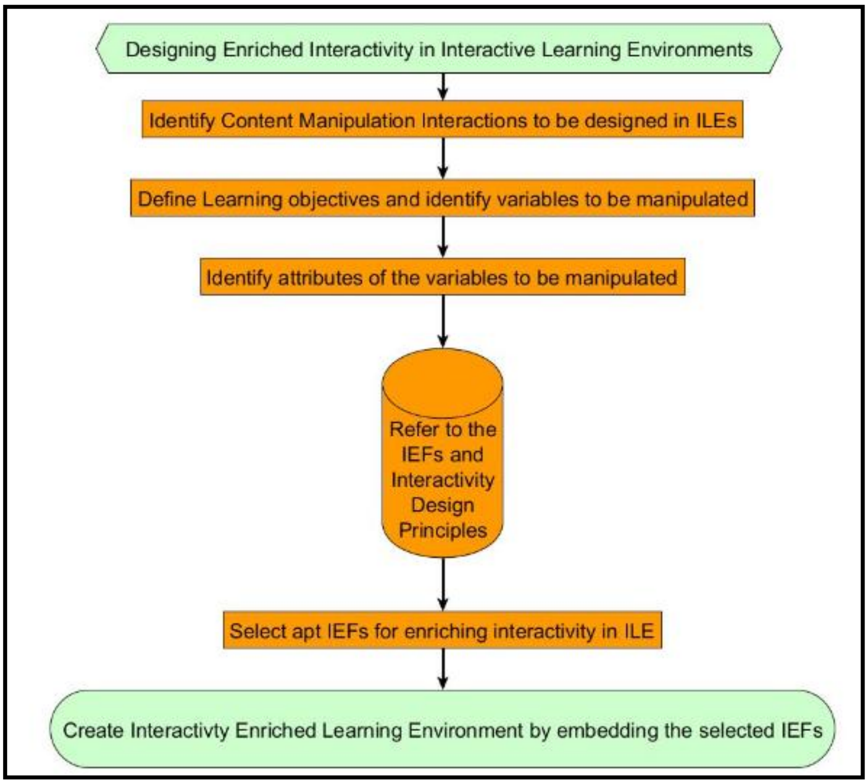


Figure 8.5. Prescriptive perspective of MIELE: Overview of the process of selecting and embedding IEFs to create Interactivity Enriched Learning Environments

The complete overview of the research work is shown in figure 8.6.

[7] http://www.et.iitb.ac.in/~mrinal/IELESS.html

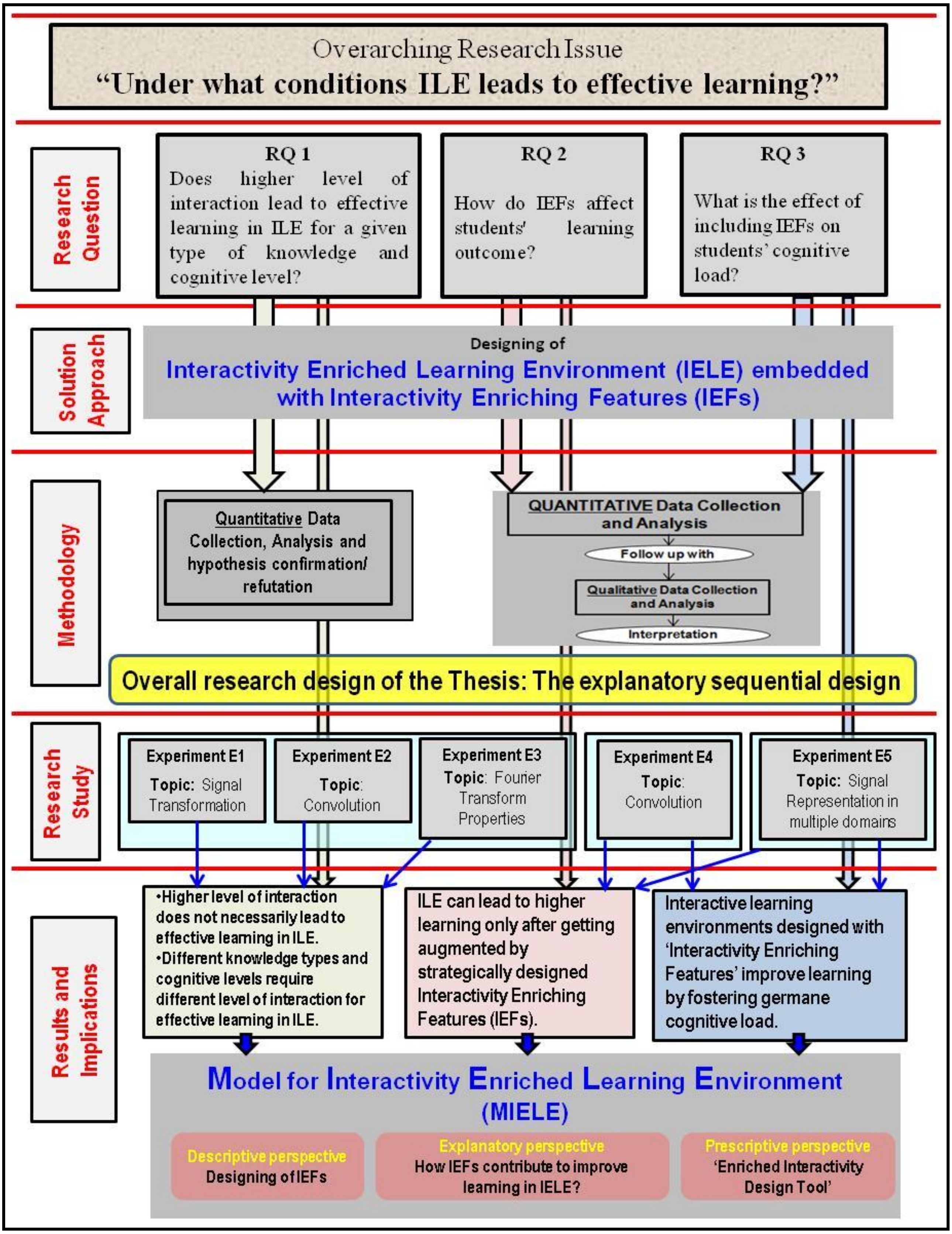


Figure 8.6. Overview of the research work

8.3. Establishing generalizability

The thesis work was set to determine, design IEFs and test their effectiveness in improving learning from interactive learning environments. Thus, the central idea of the thesis has been the four IEFs designed and the claims based on the results of the experiments that tested effectiveness of IEFs. We, thus examine the thesis work for generalizability at these two levels.

Establishing generalizability of the IEFs

The IEFs, as cognitive support were influenced by the role of variable manipulation interaction as per pedagogical requirements and not so much by the domain. In this thesis work, the IEFs were proposed as cognitive support whenever variable manipulation was needed in ILEs while giving learners 'what-if scenario' experience. The experiments to test IEF effectiveness were done in different topics in Signals & Systems. The topics used had specific features with certain pedagogical requirements demanding specific cognitive support. Table 8.1 shows how the specific IEFs designed in this work were related to the features of the topic and its pedagogical requirement.

Table 8.1 Topic features and their pedagogical requirements

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

From table 8.2 above, it appears that the role of domain in the designing of IEFs has been low, while the role of a particular interaction designed for manipulating variables is prominent. Such interactions purely emerged from the kind of cognitive support needed, which in turn were derived from generalised pedagogical requirements. Also, the designing of IEFs derived its basis from relevant educational theories which have pan-domain appicability.

We wish to extend generalizability of the designed IEFs to those ILEs from other domains which have similar pedagogical requirements; such as translating among multiple representations, mastering multi-step procedural tasks, applying procedures in flexible manner, exploring inter-linked parameters. Thus, we investigate which topics from the same and different domain exhibit similar pedagogical requirements. Some such topics demonstrating the potential to use the designed IEFs are given in the Table 8.2. While the learning materials and assessment was from Signals and Systems domain, the generalizability can be extended to the related domains like Discrete Time Signal Processing, Control Systems from engineering curriculum with similar pedagogical requirement.

Table 8.2 Suggested topics to claim generalizability of the designed 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

As an example, we demonstrate how IEFs of Reciprocative Dynamic Linking and Productively Constrained Variable Manipulation can be operationalized in a different topic as shown in Figure 8.7. (a topic from Signals and Systems: mapping between S plane to Z plane). In the said topic of mapping between S plane to Z plane, the topic requires students to manipulate multiple variables to understand how pole and zero locations in S plane can be mapped to Z plane. Each pole in S plane is located with the help of two variables (σ and jω). Thus, here the pedagogical requirement of understanding the pole location as a function of σ and jω demands multiple variables to be offered to learners for manipulation, and thus, the IEF of Productively Constrained Variable Manipulation is apt for designing such interactivity in a typical ILE. Also the pedagogical need of not just mastering the S plane to Z plane mapping, but mastering reciprocal mapping puts forward the need for Reciprocative Dynamic Linking IEF while dealing with such multiple representations. This explanation help is establishing generalizability of the IEFs for different topics that may have similar pedagogical requirement.

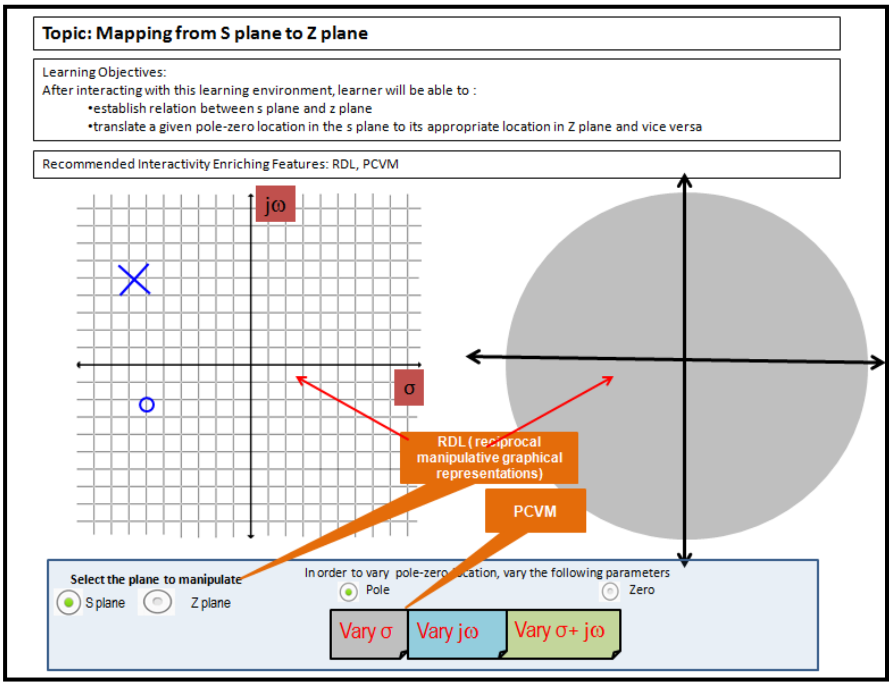


Figure 8.7. Operationalizing IEFs in a topic from Signals and Systems

Establishing generalizability of claims about testing effectiveness of IEFs:

The generalizability of claims about testing effectiveness of IEFs is mainly governed by learners and the instrument. The instrument was very specifically designed to cater to the requirement of assessing conceptual and procedural knowledge in engineering curriculum.

Thus, the claims can be generalized for specific types of knowledge from courses with similar pedagogical requirement for engineering student population.

Apart from this, the generalizability of IEFs for factors such as learner age and learner characteristics would need further investigation and may form as future directions of the thesis research work.

8.4. Limitations of the Thesis

We acknowledge limitations of the thesis work to place the work on more concrete foundation. We believe that reporting limitations will bring in more perspectives of the research issue into discussion and would help in formalizing the future research directions.

Limitations related to learner characteristics: Learners are central to any learning process. While investigating learning effectiveness of any learning environment, learner characteristics play an important role. Various learner characteristics may affect learning. Some of such characteristics may include personal characteristics (demographic information such as age, gender, maturation), social (language, social-economic status, cultural background), emotional characteristics (interest, motivation, attitude), academic characteristics (prior knowledge, education level, education type, computer literacy), cognitive characteristics (cognitive style, mental procedures, attention span, learning traits). In this thesis work, considering the scope of the work and the need to develop a common learning material to accommodate wide range of learners, maximum focus was given to the academic characteristics of learners. All the research studies conducted for this work critically ensured the equivalence of students as far as their academic characteristics were concerned. Thus, findings from this thesis will not be able to accommodate other characteristics of learners other than their academic characteristics. While it is a limitation of the study, it is a strong research avenue that can be taken up further to enrich the MIELE model.

Limitations related to instructor and instructional strategies: In a well-designed learning environment, there still exists a potential to improve learning by supporting learning either by human instructor intervention or by embedding appropriate instructional strategies. As the main focus in this thesis work was on understanding the role of interactive features on learning, and also due to the need of accommodating self-learning mode; the role of instructor and instructional strategies was excluded from the work. Thus, the findings may be different in the presence of these two factors. This again is a limitation from generalizability perspective, however assessing impact of such features will be another interesting direction for the future research work.

Limitations related to topics and domains: This research work was carried out in a course on Signals and Systems; mainly due to the importance of the course in an undergraduate Electrical Engineering program and also due to the personal motivation of the researcher. Thus, the findings may not hold true for school level (other than tertiary level educational setting) or for non-science/technology educational set-up as there would be drastic difference in terms of learner profile, educational setting etc. Any engineering curriculum covers a variety of courses, each catering to a wide range of skills and competencies. Thus, even within engineering curriculum, in order to comment about the generalizability of the findings, one will have to critically evaluate the features of the topics and domain. Thus, we will be cautious in applying generalizability of the research findings in this aspect. It should be noted that, while discussing the research methodology for this thesis work in chapter 4, the pragmatic philosophical worldview was taken. The pragmatist would be more keen on offering solutions for the real-world research issues or practices rather than developing a theory. The findings will become more generalizable only after planning research with constructivism philosophical worldview.

Limitations related to research method: Some aspects from research methods and planning may be improved upon. We discuss some such issues here.

- Due to the constraints of the academic calendar, availability of sample and issues related to infrastructure; the treatments given were of short duration nature. Research studies may be planned that could be more like longitudinal studies during a semester-long period, wherein effect of IELE could be studied for 3-4 different, yet consecutive topics to analyze students learning not just at topic-level learning objectives but at course-level learning objectives.
- Considering the research context, the instrument was designed to assess conceptual and procedural knowledge at different cognitive levels. In engineering curriculum, the higher cognitive levels are of prime importance. Thus, assessing the impact of the IEFs on students learning while dealing with 'evaluate' and 'create' cognitive level tasks will be a valuable study.
- The thesis work investigated the impact of IEFs on students cognitive processing. The cognitive load theory and three types of cognitive loads are crucial while assessing learning impact in ILEs. The instrument used for measuring cognitive load was self-

reported cognitive load subjective rating scale. More advanced research in the field of cognitive science can be referred to find out other ways of measuring these constructs. More recent research in the field of cognitive science and different thought streams can definitely bring in more relevant dimensions of cognitive load in the study and will offer more strong theoretical base to the research methods and subsequent findings. The open questions and the boundaries of cognitive load theory certainly needs further exploration.

In this thesis work, proposing IEFs and designing Interactivity Enriched Learning Environments to meet learners' cognitive demands was one strand taken. There may be other means of achieving this. Thus, as researchers of this work, our view has not been to claim IEFs to be the only solution approach. Any further contribution by research community in this direction will in fact, make the research space more enriched.

Some of the above mentioned limitations do have the potential to become future research topics; and research in these directions will further make the contribution of the thesis stronger.

9. Chapter 9

Contributions

9.1. Thesis Contribution

The thesis makes contribution in the field of Interactive Learning Environments in terms of design guidelines, design process, products and research knowledge based on the empirical studies conducted.

The major contributions of the thesis are:

- 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)

The IEFs were designed for supporting content manipulation interactions in simulations on the basis of generalized pedagogical requirement, learning demands and theoretical recommendations.

- Five empirical studies to test effectiveness of IEFs: To answer the research questions of the thesis work, five research studies using explanatory sequential mixed method approach were carried out that included quasi-experimental studies (N_{total}= 437) and qualitative strand. The studies contribute to the research space in the field of interactive learning environments in terms of its research methodology, replicable research designs and procedures, validated instruments and relevant findings.
- Interactivity Design Principles: The results, findings and inferences from the research studies have been formalised in the form of Interactivity Design Principles. These principles will be useful for instructional designers, content creators and also to instructors who wish to play a dual role of instructor-cum-instructional designer.
- Interactivity Enriched Learning Environments (IELE): The thesis work resulted into creation of Interactivity Enriched Learning Environments embedded with the designed Interactivity Enriching Features. These IELEs were developed for the topics on Signal transformation, Convolution, Time and frequency domain representation of sinusoids in a course on Signals and Systems.

Minor contributions:

- Integrated perspective of IEF designing and its learning impact in ILEs in the form of three-layer Model for Interactivity Enriched Learning Environment (MIELE): The processes of determining and designing IEFs, creating IELEs, and testing effectiveness of IEFs have given three different perspectives to the thesis outcome. The perspectives are useful for instructional designers, ILE creators and education researchers. They are integrated in the form of a three-layer Model for Interactivity Enriched Learning Environment (MIELE). The model offers three-fold contributions;
  - Its descriptive perspective describes IEF designing.
  - Its explanatory perspective explains the underlying phenomenon related to cognitive processing of learners that makes IEFs improve learning from ILE.
  - Its prescriptive perspective offers recommendations derived from experimental findings for designing enriched interactivity in ILEs.
- *e*IDT: Enriched Interactivity Design Tool: The thesis contributes by presenting MIELE based IEF selection guiding tool, eIDT for instructional designers and instructors.

- Validated instruments: The empirical studies conducted for the thesis work offer validated instruments in the topics of Signal transformation, Convolution, Fourier Transform Properties, Time and frequency domain representation of sinusoids.

The thesis discussed and implemented one of the ways of improving learning from ILEs. We have made an attempt to draw attention of the research community towards the need to design content manipulation interaction strategically. The synthesis of the related work has highlighted many important articles which summarized the guidelines for designing educationally effective learning environments (Plass, Homer, & Hayward, 2009; Sorden, 2012; Bétrancourt, 2005; de Jong T, 2010; Domagk, Schwartz, & Plass, 2010; Homer, Jordan, Kalyuga, & South, 2009). While these articles offer sound guidance through various design principles, recommendations and educational theories, they focus more on visual design and information control aspects in interactive learning environments. This thesis showed that in addition to those aspects, content manipulation interaction guidelines are necessary for designing educationally effective ILEs, especially simulations. This thesis work emphasizes that in an interactive simulation based learning environments, not just *'what gets manipulated*?', but *'how it gets manipulated*?' is also equally important.

Overall the thesis provides quantitative and qualitative analysis in the design of interactivity in learning that instructional designers, content creators and domain instructors will need to pay attention to, in order to make their interactions more meaningful and effective. Along with the contributions of the thesis as mentioned herein, another important contribution has been an opportunity to observe positive impact of IELEs on learners' motivational aspects. Although, motivation level of learners to learn from ILEs was not a construct to be measured as a part of this thesis work, close interaction with learners during research studies gave us the opportunity to assess learners' keenness to learn using IELEs. All the participants were very enthusiastic to learn using technology enabled learning environments and their efforts to explore such learning environments while learning were not just obvious, but were commendable. This observations is certainly important and encouraging in deciding scope of the future work.

9.2. Future Work

This thesis derived its motivation from the three major stake-holders; Instructional Designers, Engineering Educators and Cognitive Scientists. These are the three directions in which the thesis can be extended for its future work. Additionally some of the limitations as observed can be taken up as future work.

9.2.1. Validating IEFs for more topics from associated domains

The thesis work carried out experiments in different topics from a course on Signals and Systems. The selected topics were important and difficult topics as highlighted by Signal and Systems Concept Inventory research work. Considering the learning obstacles mentioned in the Signals and Systems education research literature, and from the observations made by domain experts, some more topics can be considered for confirming learning effectiveness of the IEFs. Section 8.3 of this thesis offered details about generalizability of the work. Taking that into consideration, we felt that the designed IEFs would be able to demonstrate effectiveness for the topics with similar features and pedagogical requirements. Some of the topics that can be used for confirming learning effectiveness are give in Table 9.1.

Table 9.1 Potential topics for replicating research studies

Topic	Domain	Recommended IEFs
Signal Transformation	Signals and System	RDL
Fourier Transform properties	Signals and System	PCVM, RDL
Exploring Z plane and S plane (variables: pole location / zero location as a function of coordinates)	Signals and System	PCVM, RDL
Fourier Series Representation of a square wave	Signals and System	PCVM, RDL
Verification of systems for linearity and time invariance properties	Signals and System	PVM
Sampling and reconstruction of signals in time/ frequency domain	Signals and System	PCVM, RDL
Constructing Butterfly diagram	Discrete Time Signal Processing	DIM, PVM
FIR/ IIR filter designing	Discrete Time Signal Processing	DIM, PCVM
Pole-zero plots and frequency response of LTI systems	Discrete Time Signal Processing	PCVM, RDL

In the first few rows, we list topics from Signals and Systems, followed by some topics from another course Discrete Time Signals Processing. The topics have been identified by looking at the pedagogical requirement and the design process of the specific IEF. We demonstrate two examples, one from Signals and Systems and Discrete Time Signal processing each, to show how the IEFs can be applied to other topics. The topic on Signal Transformation expects students to represent transformation in the form of waveform as well as mathematical expression. This pedagogical requirement of learning, integrating and translating both representations (waveform and mathematical equation) exhibit potential for IEF of Reciprocative Dynamic Linking. Similarly, while constructing Butterfly diagram to compute Fast Fourier transform in a course on Discrete Time Signal processing, the pedagogical requirement of understanding the process at discretized level of granularity need to be met. The IEF of Discretized Variable Manipulation can be recommended for this topic.

Thus, identifying the pedagogical requirement for the potential topic and mapping it with the pedagogical requirements of IEFs as specified in Table 3.1 of Chapter 3 will be useful for selecting topics for future research studies.

The research methodology, designs and procedures presented in this thesis are replicable. The thesis provides sufficient details for replicating similar studies in different topics. The additional requirements for conducting such studies will be to develop Interactivity Enriched Learning environments (IELEs) and the validated instrument for the specific topic assessing the required type of knowledge at specified cognitive levels.

The result obtained from these future experiments will be useful; as they will offer additional evidence for testing effectiveness of IEFs and validating MIELE. This will not just benefit ILE researchers and instructional designers, but they will also be valuable for the Signals and Systems/ Signal processing educators due to the developed IELEs in different topics.

9.2.2. Validating IEFs for additional learner characteristics

While validating the IEFs, the thesis work gave due consideration mainly to the academic characteristics of learners. Other characteristics such as learning style and traits, cross-cultural differences, emotional characteristics are also important in teaching-learning process. Especially, the cognitive styles of learners and emotional characteristics may have an important role to play while learning from ILEs. Thus, the important direction to take up in the future will be investigating the effect of such characteristics on the learning effectiveness of IEFs.

A factorial research design can be planned to accommodate more independent variables and to analyze interactions among these variables. Some of the possible independent variables that can be considered are: learners' cognitive styles (visual/ non-visual learners; inductive/ deductive learners), achievement levels (high achiever/ low achiever). Further research studies can also investigate the motivational aspect of learners. This could become one of the constructs to measure the impact of IEFs on learners' motivational level and interest. This will be a very intricate study as learner's performance and motivational level keep on feeding each other.

This thread of further research will be useful for enriching the knowledge about cognitive interactions between learners and the learning environment and will certainly contribute towards refining the process of determining and designing of IEFs and IELEs.

9.2.3. Validating IEFs in the presence of internal/external instructional strategies

Use of appropriate instructional strategy has been one of the moderators considered in ILEs. These strategies could be internal to ILE in the form of embedded features or they could be external to ILE, operationalized through human intervention by an instructors. Literature offers evidence on how learning from animations and simulations can be further improved upon by constructively alignment of instructional strategies. These strategies work as implicit / explicit scaffoldings in the learning process. Such scaffoldings may be in the form of active learning strategies (e.g. Think-pair-Share, Peer instructions) or embedded affordances in the learning environment. Whether such strategies along with IEFs are able to further improve learning outcomes will be an interesting as well as important research question to be answered. The thesis at present scopes down to self-learning mode of learning. The finding from the above mentioned research directions will be useful for widening the use of IELEs in classroom teaching.

9.2.4. Investigating IEFs' effectiveness for higher cognitive levels

As the research context of this study was a course on Signals and Systems, the instruments developed for assessing domain knowledge was designed for understand, apply and analyze cognitive level so as to match the course level objectives. Engineering, being a practising profession, evaluating design abilities of learners is important. Whether the designed IEFs will be able to train learners for higher cognitive levels such as 'evaluate' and 'create' will be a question worth exploring. Future research directions on this line can have two tracks. One track can be to identify the 'boundary conditions' for the designed IEFs. The 'boundary conditions' will refer to the cognitive levels for which the designed IEFs will not be able to demonstrate learning effectiveness. Thus, investigating 'For what kind of higher level cognitive tasks, the designed IEFs can train learners?', will be one of the tracks that can be taken up. This research study should give more weightage to qualitative assessment of the learning process instead of simply comparing the learning scores. A qualitatively rich assessment of such boundary conditions will be extremely useful; as subsequently it can lead towards the second possible track under this thread. The findings from such qualitative study will be able to offer further inputs for refining the design process of IEFs while designing them for higher cognitive levels.

Apart from the above mentioned future directions for this thesis work, identifying more IEFs for different domains can be another possible research path. The IEFs designed in this work stem up from the pedagogical requirement of the domain and the research context. Interactive Learning Environments are being perceived as an important instructional aid for teaching many other science and engineering courses. Thus, depending on the course content, reported learning obstacles and overall pedagogical requirements; the process of determining and designing IEFs can be applied for other courses to come up with domain-specific IEFs. Another important future research thread will be for cognitive scientists to accommodate and implement latest cognitive science research trends for improving learning effectiveness of the learning environments.

The above discussion related to the future research plans is indicative in nature and not exhaustive. Irrespective of the research design, plan, methodology and intervention, all the research paths should lead to achieving the supreme goal of *"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"*.

9.3. Final Reflection

The thesis was a blend of efforts made by an education researcher to meet the research challenges posed, and simultaneously efforts made by an instructor to meet the teaching demands. Both these roles were complementary and were able to complement each other to deliver the best possible outcome of this research work. Irrespective of the role taken, the urge to understand the learner and the learning process in the presence of technology tools was the most decisive driving force for the thesis work. Apart from the thesis contribution, introspecting oneself as a facilitator and maturing more as a teacher has been the most rewarding experience that the thesis brought at a personal level.

Appendix

Appendix A Visualization Usability Scale

1	2	3	4	5
Strongly disagree				Strongly agree

Note: Please put √ in the appropriate place.

1	I think that I would like to use this visualization frequently	1	2	3	4	5
2	I found the visualization unnecessarily complex	1	2	3	4	5
3	I thought the visualization was easy to use	1	2	3	4	5
4	I think that I would need the support of a technical person to be able to use this visualization	1	2	3	4	5
5	. I found the various functions in this visualization were well integrated	1	2	3	4	5
6	I thought there was too much inconsistency in this visualization	1	2	3	4	5
7	I would imagine that most people would learn to use this visualization very quickly	1	2	3	4	5
8	I found the visualization very cumbersome to use	1	2	3	4	5
9	I felt very confident using the visualization	1	2	3	4	5
10	I needed to learn a lot of things before I could get going with this visualization	1	2	3	4	5

Appendix B Assessment Questions from the instrument on Signal Transformation (E1)

Signals & Systems Assessment Questions **Topic: Signal Transformation**

Name: ______________________________________ **Group: IL___** **Date: / /2012**

Test started at :__________________ **Test completed at: _____________**

- Have you used this visualization before? **Y/N**
- Write your choice (a/b/c/d) in the box given.

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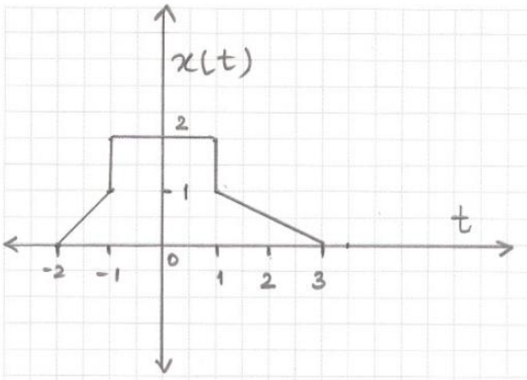
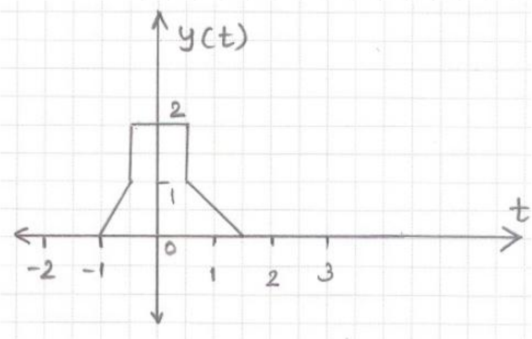
1. x(t) is a signal and y(t) is its transformed version. Identify which transformation operation has been carried out on x(t) so as to get y(t).



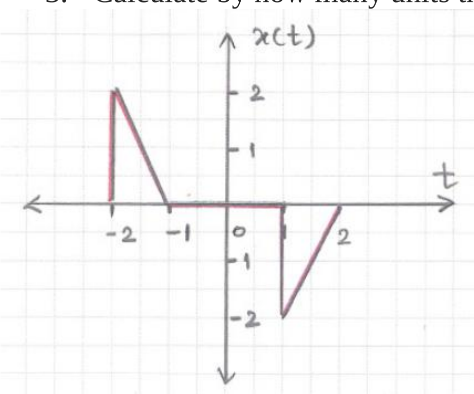


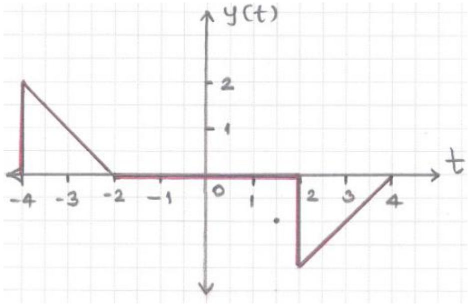
   a. time shifting
   b. time scaling
   c. time reversal
   d. none of the above

2. If x(t) is a given signal, to obtain x(4-2t) from the given signal the following operations should be carried out on the independent variable (time) in the given sequence
   a. Time scaling----Time shifting----time reversing
   b. Time reversing ---time scaling----time shifting
   c. Time scaling--- time reversing ---Time shifting
   d. Time shifting---time scaling---time reversing

3. Calculate by how many units the signal x(t) has been time scaled so as to get signal y(t).

i.e. y(t)=x(__t)



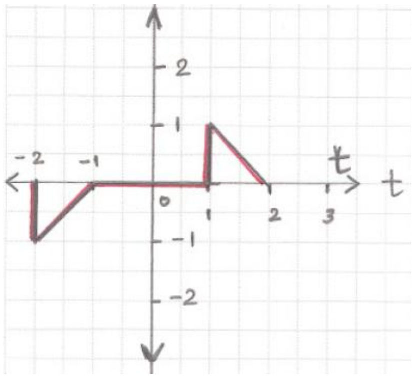


a. $\frac{1}{2}$
b. 1
c. 2
d. None of the above

4. If x(t) is any signal, then the signal reversed across x axis will be represented as ________, and the original signal x(t) reversed across y axis will be _____________.
   a. -x(t) and x(-t)
   b. x(-t) and -x(t)
   c. -x(-t) and x(-t)
   d. x(t) and -x(-t)

5. Signal x(t) shown in question 3 above has been amplitude scaled so as to look like as shown below.

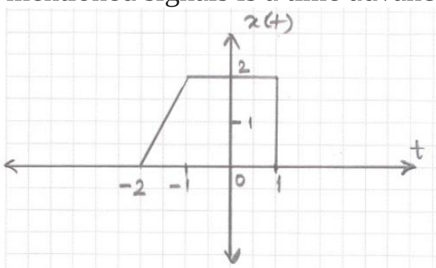
   i.e. y(t)= ___x(t)



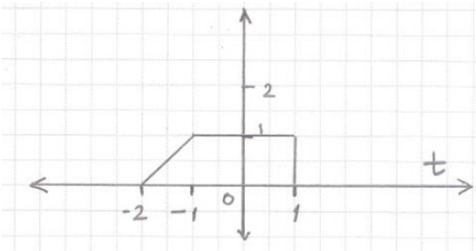
The signal has been amplitude scaled by

   a. 0.5
   b. 2
   c. -2
   d. -0.5

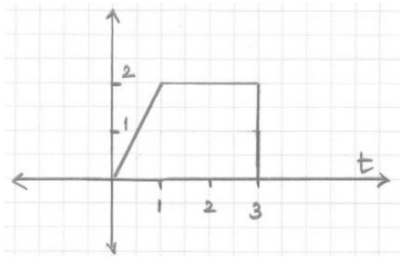
6. Identify which of the below mentioned signals is a time advanced signal of x(t).



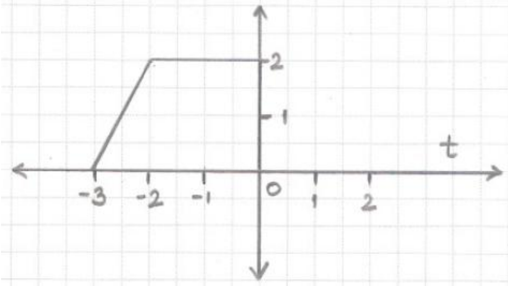
a.



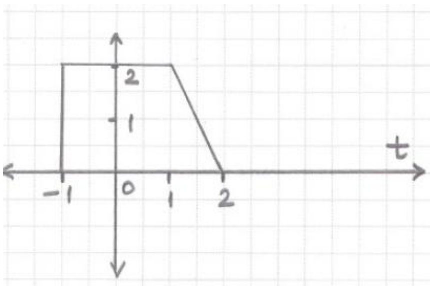
b.



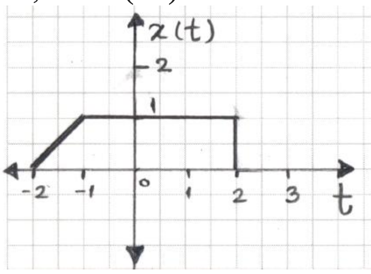
c.



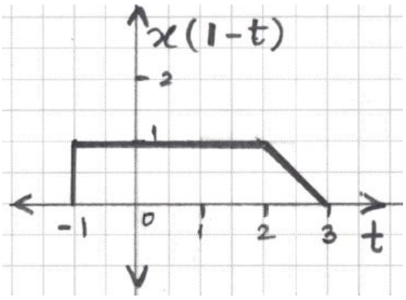
d.



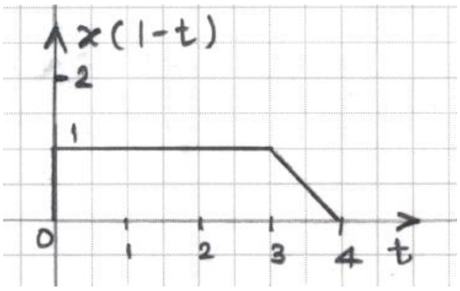
7. If x(t) is a signal as shown below, then x(1-t) will be



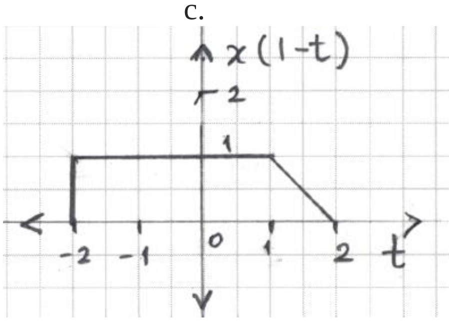
a.



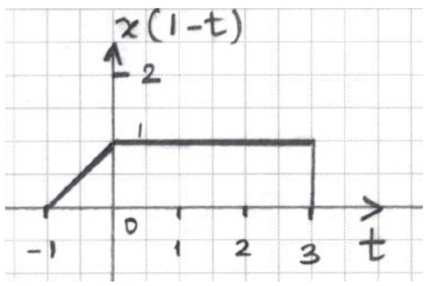
b.



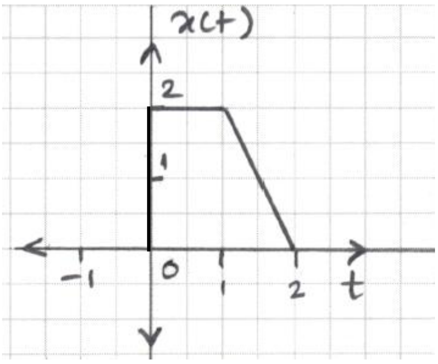
c.

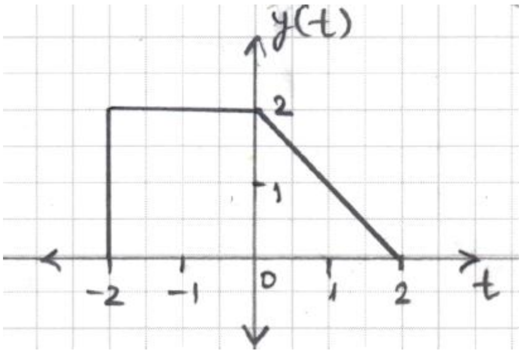


d.



8. Identify which of the following is the correct mathematical representation of the signal transformation on signal x(t) so as to get y(t).





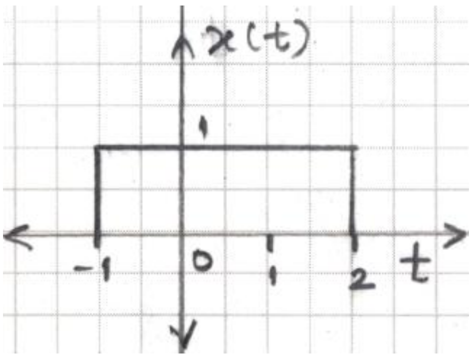
a. $y(t) = x(\frac{t}{2} + 1)$

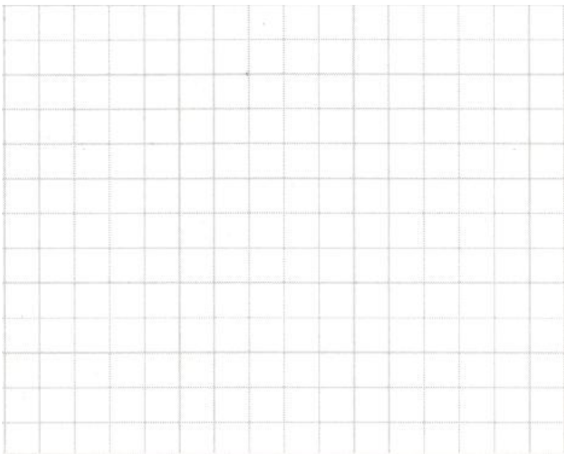
b. $y(t) = x(t + 2)$

c. $y(t) = x(2t + 2)$

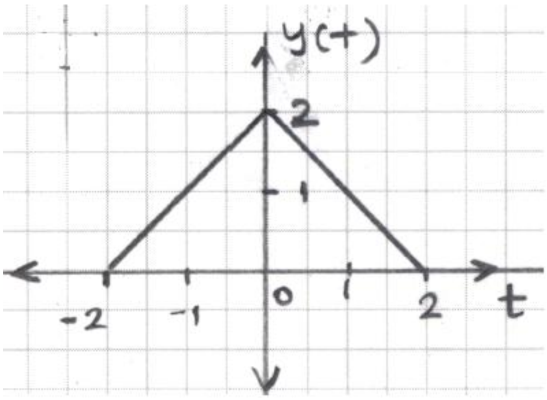
d. $y(t) = x(-\frac{t}{2} + 1)$

9. A continuous time signal x(t) is shown in figure, sketch the signal $x(4 - \frac{t}{2})$





10. If a transformed signal $y(t) = x(2t)$ is as shown below, then sketch x(t)


y(t)
2
1
-2
-1
0
1
2
t

Appendix C Assessment Questions from the instrument on Convolution (E2)

Signals & Systems **Semester: V** **Date ________** **Worksheet No.: ______**

Name: ______________________________ **SAP No.: ______________**

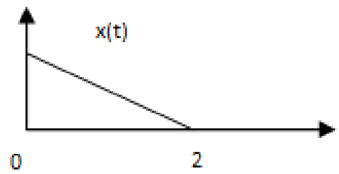
---

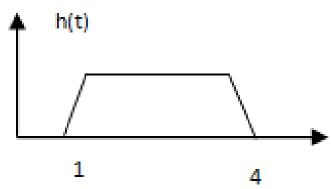
1. If the following expression is convolution integral , for finding out convolution which sequence of mathematical operation you will follow?

$$y(t) = x(t) * h(t) = \int_{-\infty}^{\infty} x(\tau)h(t-\tau)d\tau$$

   a. folding, shifting, multiplication, integration
   b. folding, shifting, integration, multiplication
   c. shifting, multiplication, integration
   d. multiplication, integration shifting

2. If x(t) and h(t) of a systems are as shown, the output of a system is zero everywhere except for





   a. $0<t<4$
   b. $0<t<5$
   c. $1<t<5$
   d. $1<t<6$

3. If is h(t) a unit-step function and x(t) is a unit-ramp function, then the output y(t) will be a
   a. step function
   b. ramp function
   c. triangular pulse
   d. quadratic function

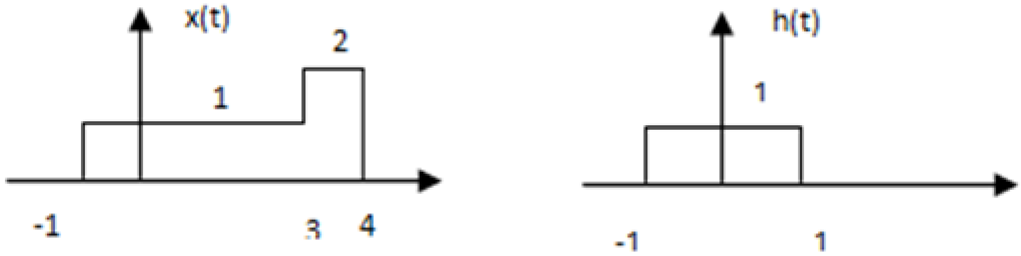
4. If the unit-impulse response of an LTI system and the input signal both are rectangular pulses, then the output will be a
   a. rectangular pulse
   b. triangular pulse
   c. ramp function
   d. step function

Note: While solving the problems given below, please follow the guidelines given below. Plot signals at various stages.

a. Draw x(t),
b. Draw h(t)
c. explain what operation/s you will carry out to get y(t). Please write/ plot waveforms for each of the steps clearly.

5. Let $x(t)= e^{2t}u(-t)$ and $h(t)= u(t-3)$, find out y(t).

6. If x(t) and h(t) of a systems are as shown, plot y(t) by using graphical convolution



method

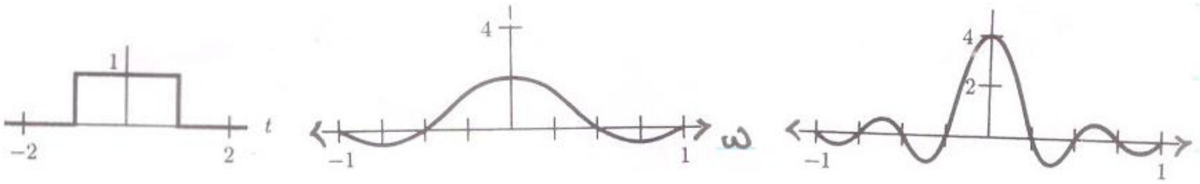
7. If an input signal is applied to two LTI systems with respective unit-impulse responses h(t) and 3h(t-2) , then the response of the second system is the response of the first
   a. amplitude scaled by 3 and delayed by 2
   b. amplitude scaled by 3 and advanced by 2
   c. amplitude scaled by 3
   d. none of the above

8. If a systems with impulse response input $h(t) = e^{-2t} u(t)$ accepts input $x(t)= e^{-4t} u(t)$. However while calculating output, student interchanged the h(t) and x(t).(i.e. h(t) was considered as x(t) and x(t) was considered as h(t)). Predict the change in the answer, the student must have got due to the interchanged values.

Appendix D Assessment Questions from the instrument on Fourier Transform Properties (E3)

Date: ____________ **SAP NO.:** _________________________ **Batch:** ________________

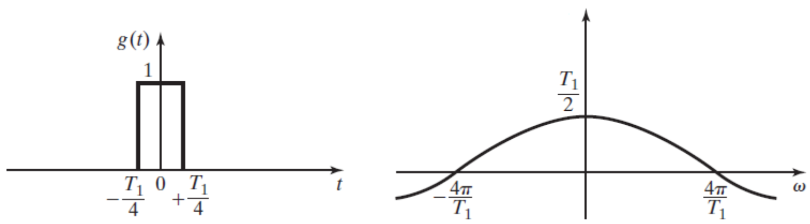
1. A rectangular signal x(t) and its transform X(jω) are shown in Figure 'a' and Figure 'b' respectively. After carrying out some operation on signal x(t), signal y(t) has been obtained. Figure 'c' below shows Y(jω) i.e. Fourier Transform of y(t). Identify which operation has been carried out on signal x(t).



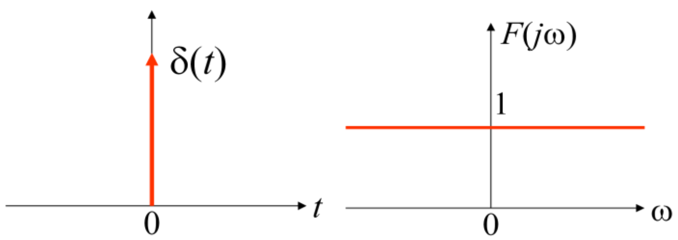
A) Amplitude scaling B) Time scaling

C) Time shifting D) Derivative

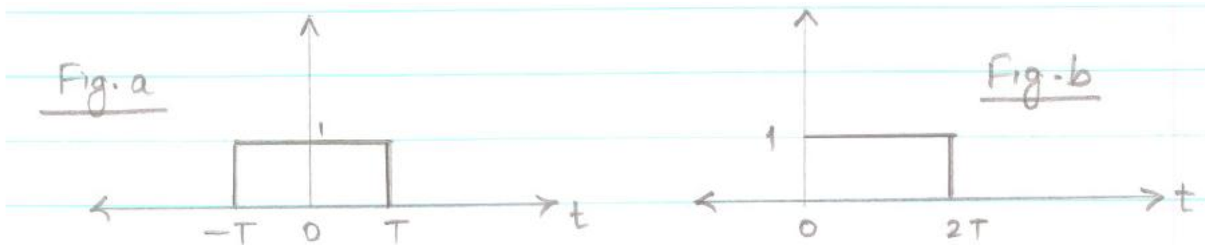
2. The signal g(t) and its transform G(jω) have been shown in figure 'a' and 'b' respectively. Plot Fourier transform of signal f(t)= g(t/2).



3. Let x(t) = δ(t). The signal x(t) and its magnitude spectra F(jω) are shown in figure 'a' and "b' respectively. If y(t) = 3 δ(t) , then plot magnitude spectra of y(t) (i.e. Y(jω)).



4. Which one of the following is the Fourier Transform of the signal given in figure 'b', if FT of signal in figure 'a' is given by 2sin (ωT)/ω.



A) $\frac{2\sin(\omega T)e^{j\omega T}}{\omega}$ B) $\frac{2\sin(\omega T)e^{-j\omega T}}{\omega}$

C) $\frac{\sin(\omega T)e^{-j\omega T}}{\omega}$ D) $\frac{\sin(\omega T)e^{j\omega T}}{\omega}$

5. Plot the magnitude and phase spectra of time shifted impulse signal x(t) = 10 δ (t-2).
6. Wind currents cause a telephone wire to oscillate vertically. Midway between two supporting telephone poles, the vertical displacement of the wire from its rest position is $x(t) = 8\cos\left(2\pi.3t + \frac{\pi}{3}\right) cms$. Find the spectrum (amplitude and phase) of the vertical displacement signal.

7. The Fourier Transform of a signal x(t) = e^{-at} u(t) is given by $\frac{1}{a+j\omega}$, where Re{a} >0. The Fourier Transform of x(t) = e^{2t} u(-t) will be

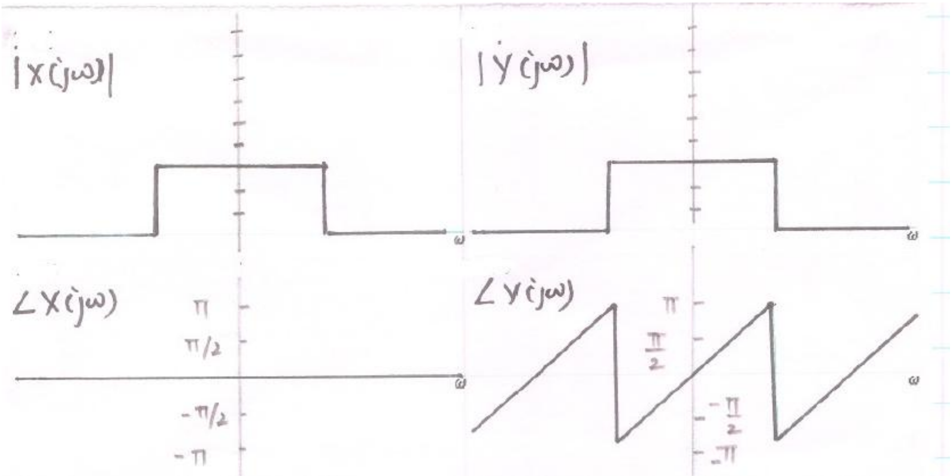
A) $\frac{1}{2-j\omega}$ B) $\frac{2}{1-j\omega}$

C) $\frac{1}{j2-\omega}$ D) $\frac{2}{j2-\omega}$

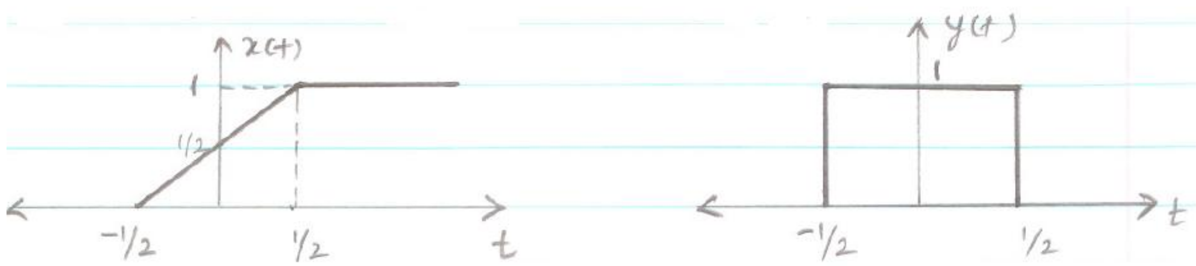
8. Fourier Transform of signals x(t) and y(t) are X(jω) and Y(jω) respectively as shown in the figure below. Identify which mathematical operation on x(t) must have caused change in X(jω) so as to get Y(jω).

A) Time scaling B) Time reversal

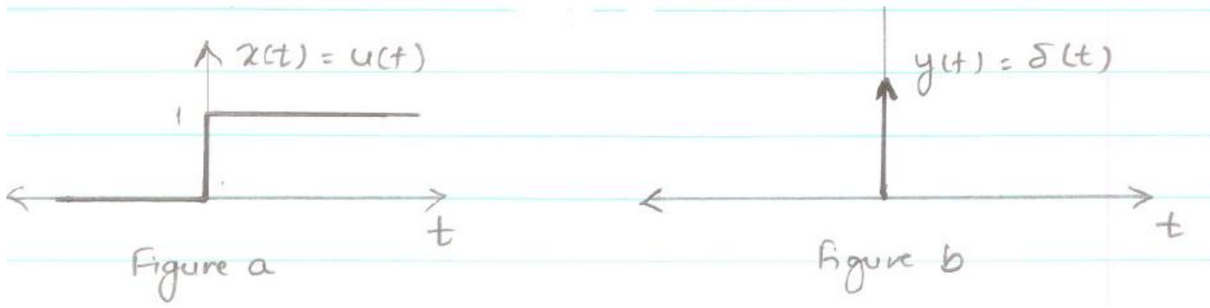
C) Time shifting D) Differentiation



9. Signal x(t) and y(t) are shown in figure 'a' and 'b' respectively. If X(jω) and Y(jω) are Fourier transform of x(t) and y(t) respectively, identify which property can be used to find out Y(jω) from X(jω).



10. Figure 'a' below shows signal x(t)= u(t) i.e unit step function. Figure 'b' shows signal y(t) = δ(t) i.e. impulse function. If Fourier transform of F{ x(t)} = $\frac{1}{j\omega} + \pi\delta(\omega)$, find out Fourier transform of y(t).



F{y(t)} =

11. Fourier Transform of x(t) is $\frac{1}{1+j\omega}$., where x(t) = e^{-t} u(t) . Find out Fourier transform of y(t), if y(t)= x(t) - x(-t).

Appendix E Assessment Questions from the instrument on Convolution (E4)

Class/Batch: ___________ Group : Applet SIM / Applet IE-Viz

Day/Date________ / - 09 - 14

Name: ___________________________

Roll No.: _______ Age:_____

Time: ________

Please write your second year (S.E Sem III + SEM IV) CGPA here: ______________

Section I

Dear student,

Just now you have interacted with an applet that explains to you what is the graphical interpretation of convolution and how to calculate convolution integral by graphical approach when the given two signals are to be convolved.

Here is the question that asks you about the mental effort, that you invested while learning this topic just now.

Now, please rate your answer on the scale of 1 to 9 by encircling the appropriate number. Number 1 indicates **'very very low mental effort'** and number 9 indicates **'very very high mental effort**.'

How much mental effort you invested in the learning of Graphical interpretation of Convolution?

1--------2--------3--------4------5-------6-------7-------8-------9

very very low mental effort | **very very high mental effort**

Section II

Please give your opinion about today's experience by ticking the appropriate box (no.1 to no.5).

1. How interesting was it to learn about graphical convolution today?

Boring						**Interesting**
	1	**2**	**3**	**4**	**5**	

2. How entertaining was it to learn about graphical convolution today?

Tiresome						**Entertaining**
	1	**2**	**3**	**4**	**5**	

3. How eager would you be to learn about some different topic from Signals and Systems in the same conditions you learned today?

Not eager						**Very eager**
	1	**2**	**3**	**4**	**5**	

4. How motivating was it to learn about graphical convolution today?

Not Motivating						**Very motivating**
	1	**2**	**3**	**4**	**5**	

5. How much did the JAVA applet help you to understand about graphical convolution?

Please support your answer by mentioning specific features of the applet that helped you or did not help you. Remember, merely saying *'understood' / 'did not understand'* is insufficient to justify your answer.

Not at all						**Very much**
	1	**2**	**3**	**4**	**5**	

____

____

____

6. How helpful was this JAVA applet for learning about Graphical Convolution?

Unhelpful						**helpful**
	1	**2**	**3**	**4**	**5**	

Do you have any other comment related to your learning experience today? You can write it here.

Section III

Now, here are some questions based on Convolution. Some of them are multiple choice questions, whereas some of the questions need to be answered by drawing appropriate signal waveforms and by showing various steps and numerical calculation involved in the answer.

Write your answer in the box provided. Also show the working in the workspace provided.

1. If the following expression is convolution integral, for finding out convolution which sequence of mathematical operation will you follow?

$$y(t) = x(t) * h(t) = \int_{-\infty}^{\infty} x(\tau)h(t-\tau)d\tau$$

e. folding, shifting, multiplication, integration
f. folding, shifting, integration, multiplication
g. shifting, multiplication, integration
h. multiplication, integration, shifting

Please answer the question below by giving your opinion about question no.1 above.

How 'easy' or 'difficult' was it to work with this question?

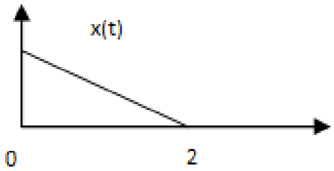
Please rate your answer on the scale of 1 to 9 by encircling the appropriate number. Number 1 indicates 'Extremely easy' and number 9 indicates 'Extremely Difficult'.

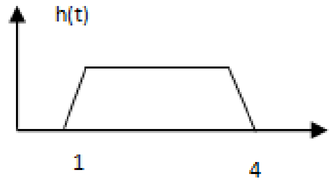
1----------2----------3----------4---------5----------6----------7----------8----------9

extremely easy **extremely difficult**

Workspace

2. If input signal x(t) and impulse response h(t) of a system are as shown, the output of a system y(t) is zero everywhere except for





e. 0<t<4
f. 0<t<5
g. 1<t<5
h. 1<t<6

3. If a system with impulse response input $h(t) = e^{-2t}\ u(t)$ accepts input $x(t)= e^{-4t}\ u(t)$. However, while calculating output, student interchanged the h(t) and x(t).(i.e. h(t) was considered as x(t) and x(t) was considered as h(t)). Predict the change in the answer, the student must have got due to the interchanged signal values.

Workspace

4. Same input signal is applied to two LTI systems. The systems have unit-impulse responses h(t) and 3h(t-2) respectively. Then the response of the second system is the response of the first system,
   e. amplitude scaled by 3 and delayed by 2
   f. amplitude scaled by 3 and advanced by 2
   g. amplitude scaled by 3
   h. none of the above

Workspace

Please answer the question below by giving your opinion about question no 2 to 4 above.

How 'easy' or 'difficult' was it to work with these questions?

Please rate your answer on the scale of 1 to 9 by encircling the appropriate number. Number 1 indicates 'Extremely easy' and number 9 indicates 'Extremely Difficult'.

1----------2----------3----------4---------5----------6----------7----------8----------9

extremely easy | **extremely difficult**

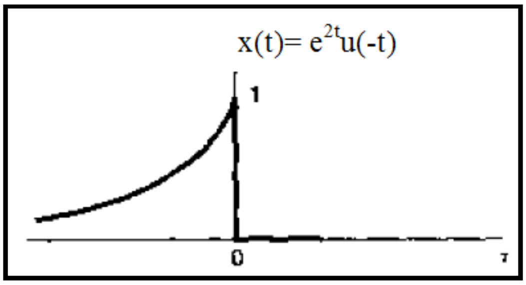
5. If the unit-impulse response h(t) of an LTI system and the input signal x(t), both are rectangular pulses of the same width, then the output will be ______________________, and if the rectangular pulses are of different widths, then the output will be ____________________________. (Please select the appropriate answers from the choices given below and write in the space provided)

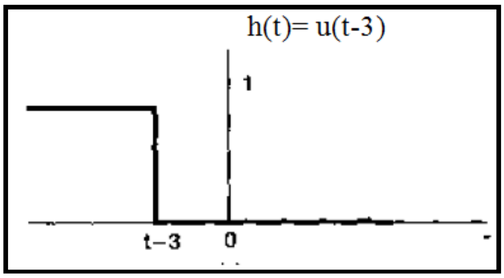
   rectangular pulse, triangular pulse, ramp function , trapezoidal pulse, step function

Workspace

Note: While solving the problems given below, first explain what operation/s you will carry out to get y(t). Please write/ plot waveforms for each of the steps clearly.

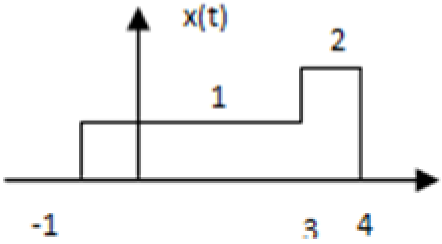
6. Let $x(t)= e^{2t}u(-t)$ and $h(t)= u(t-3)$, find out y(t).

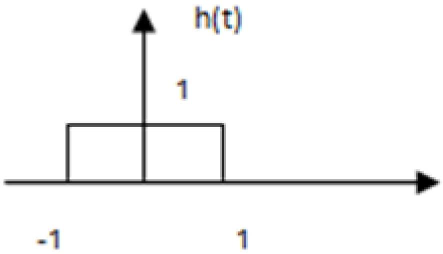




Workspace

7. If x(t) and h(t) of a systems are as shown, plot y(t) by using graphical convolution method





Workspace

Please answer the question below by giving your opinion about question no 6and 7 above. .

How 'easy' or 'difficult' was it to work with these questions?
Please rate your answer on the scale of 1 to 9 by encircling the appropriate number. Number 1 indicates 'Extremely easy' and number 9 indicates 'Extremely Difficult'.
1----------2----------3----------4---------5----------6----------7----------8----------9
extremely easy ... **extremely difficult**

Thank you!
We appreciate your time and patience.

Your valuable feedback will be of immense help.

Appendix F Assessment Questions from the instrument on 'Representation of Sinusoids in Time and Frequency Domain(E5)

Class/Batch: ___________ Group : Applet SIM / Applet IE-Viz

Day/Date ______________________ / ___/___/2015

Name: ___________________________

Roll No.: _______ Age:_____

Time: ________

Please write your second year (S.E Sem III + SEM IV) CGPA here: _____

Section I

Dear student,

Just now you have interacted with an applet that explains to you how sinusoidal signals are represented in time and frequency domain.

Here is the question that asks you about the mental effort, that you invested while learning this topic just now.

Now, please rate your answer on the scale of 1 to 9 by encircling the appropriate number. Number 1 indicates **'very very low mental effort'** and number 9 indicates **'very very high mental effort**.'

How much mental effort you invested in the learning of Graphical interpretation of Convolution?

1--------2--------3--------4-------5--------6--------7--------8--------9

very very low mental effort | **very very high mental effort**

Section II

Please give your opinion about today's experience by ticking the appropriate box (no.1 to no.5).

2. How interesting was it to learn about signal representation today?

Boring	1	2	3	4	5	Interesting

2. How entertaining was it to learn about signal representation today?

Tiresome	1	2	3	4	5	Entertaining

3. How eager would you be to learn about some different topic from Signals and Systems in the same conditions you learned today?

Not eager	1	2	3	4	5	Very eager

4. How motivating was it to learn signal representation today?

Not Motivating	1	2	3	4	5	Very motivating

5. How much did the JAVA applet help you to understand about signal representation?

Please support your answer by mentioning specific features of the applet that helped you or did not help you. Remember, merely saying *'understood' / 'did not understand'* is insufficient to justify your answer.

Not at all	1	2	3	4	5	Very much

____

____

____

____

6. How helpful was this JAVA applet for learning about signal representation?

Unhelpful	1	2	3	4	5	helpful

Do you have any other comment related to your learning experience today? You can write it here.

Assessment Questions

1. For a signal waveforms shown in figure 1 below, plot their single sided spectras (i.e. magnitude spectra and phase spectra).

Hint: Mathematically sin x= cos (x-90˚). Remember, phase of a cosine signals is considered as a reference for showing phase of any other signal. Thus, a sine function can be considered as cosine function with a pase shift of (-π/2).

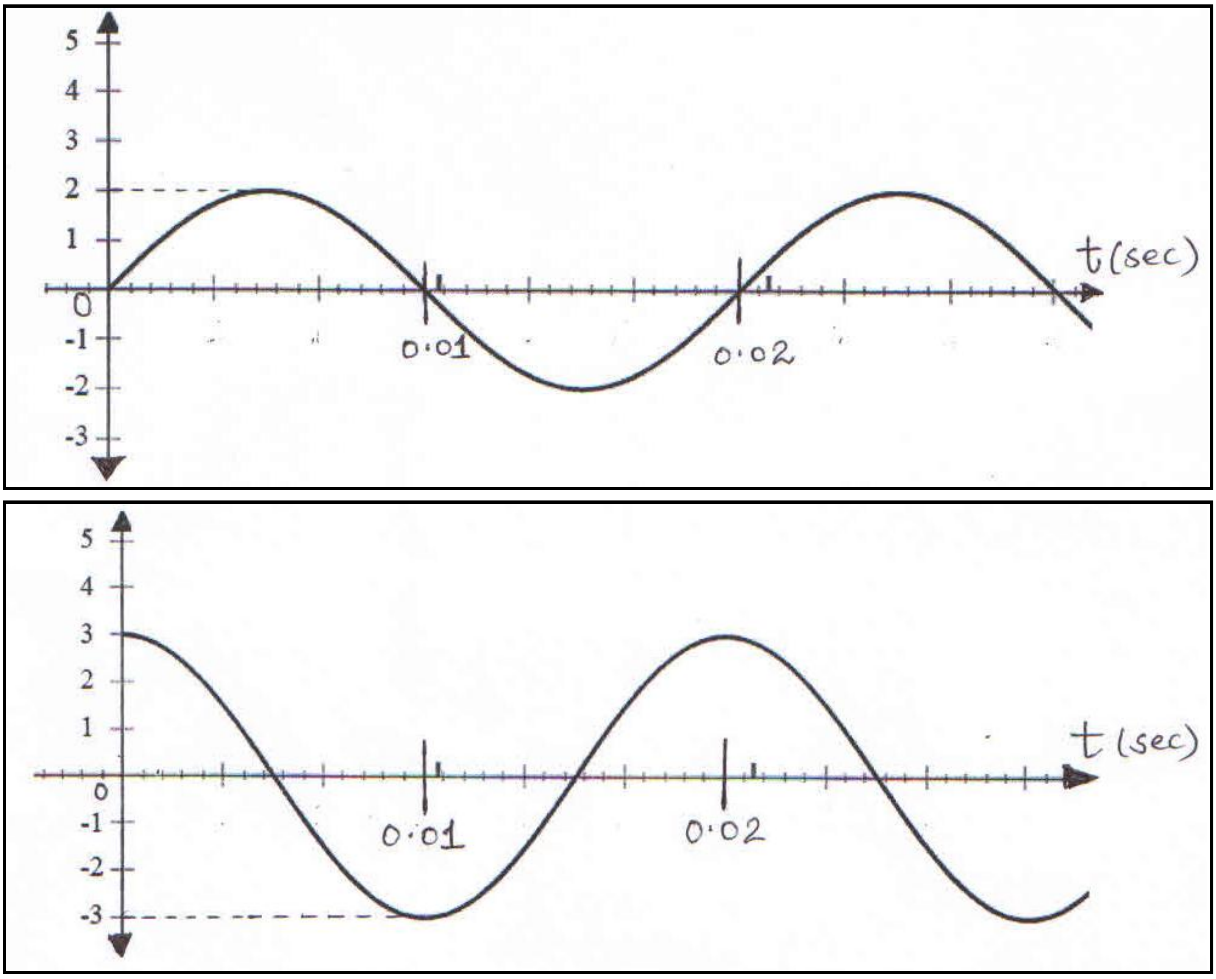


Fig 1 (a and b)

Solution:

2. Figure 2 below shows spectra for some signals. The mathematical description of some signals is also given after the figure. Identify which mathematical expression belongs to which of the signal spectra shown in the figure.

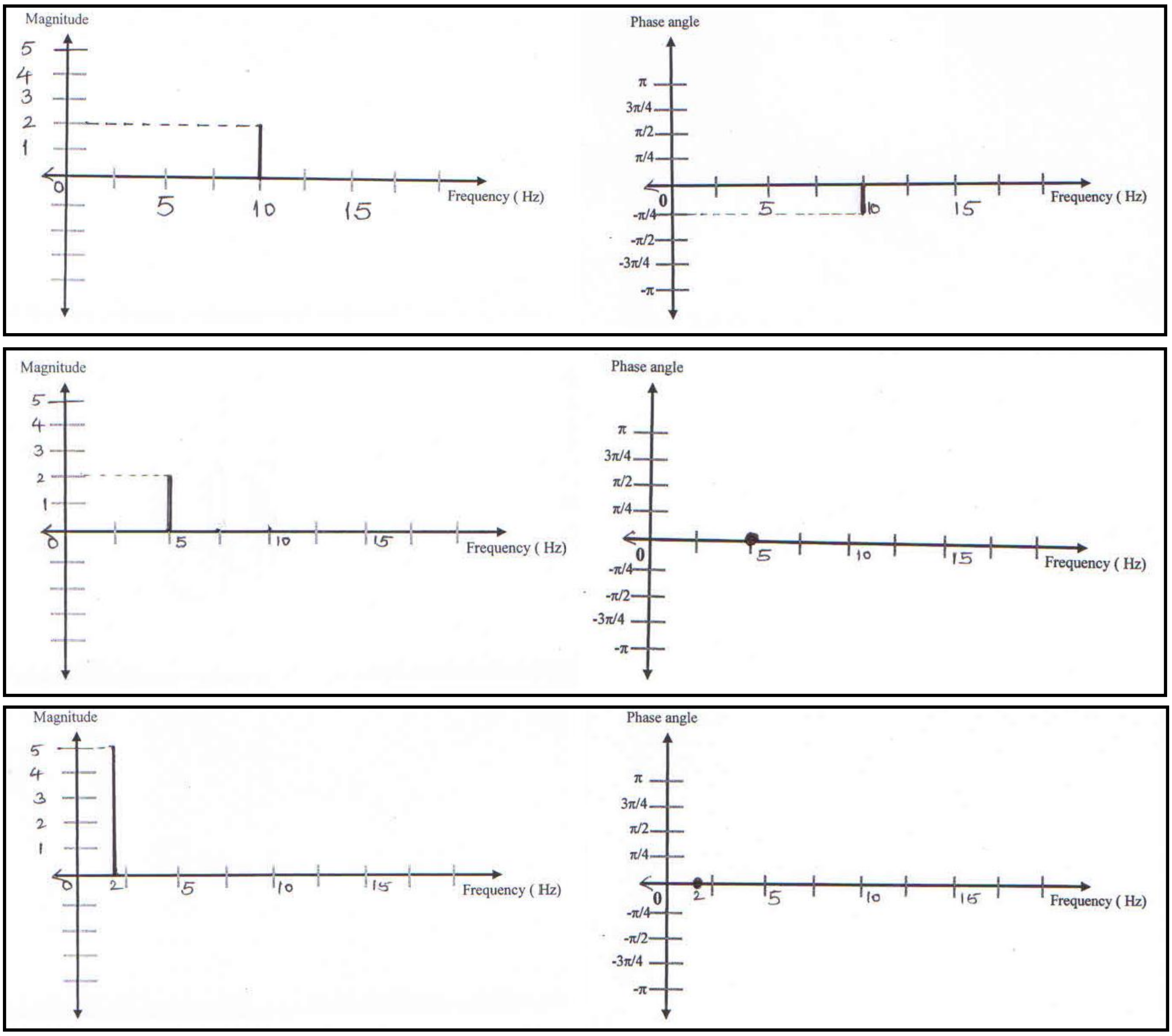


Figure 2 (a, b and c)

Mathematical description of signals

A) $x(t) = 10\cos(2\pi\,(10)t + \frac{\pi}{4})$

B) $x(t) = 5\cos(2\pi\,(2)t)$

C) $x(t) = 2\cos(2\pi\,(5)t)$

D) $x(t) = 2\cos(2\pi\,(10)t - \frac{\pi}{4})$

Write which mathematical description that relates to the above mentioned signals spectra shown in the above figure. Write your answer in the boxes provided below.

Signal spectra 1-->	Signal spectra 2-->	Signal spectra 3-->

3. A signal x(t) is expressed as a linear addition of sinusoids $x_1(t)$, $x_2(t), x_3(t)$. i.e. $x(t) = x_1(t) + x_2(t) + x_3(t)$. The waveform for signal $x_1(t)$, $x_2(t), x_3(t)$ are shown below in figure 3. (a, b and c respectively) Plot individual signal spectra for $x_1(t)$, $x_2(t), x_3(t)$ and also the single sided spectra for signal $x(t)$.

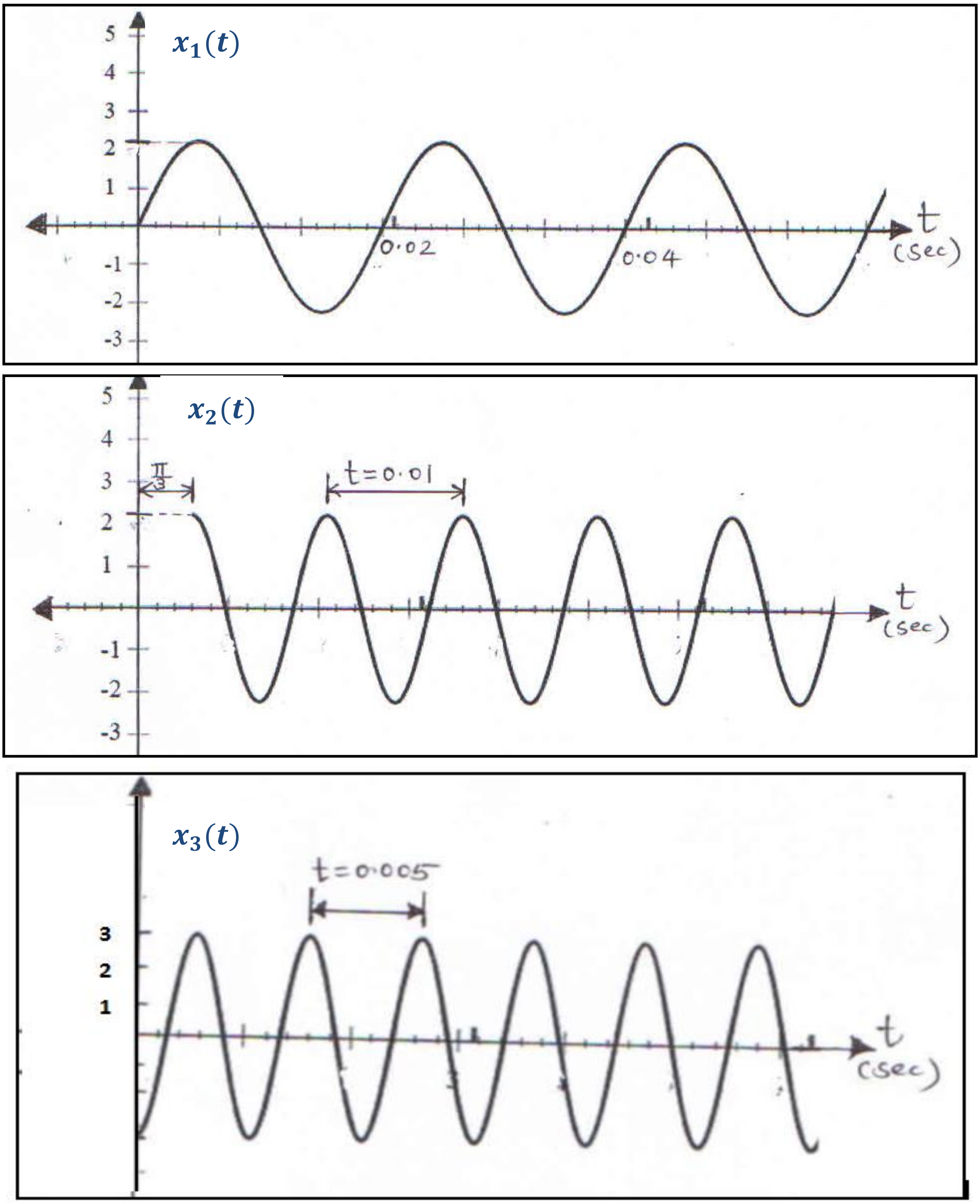


Figure 3 (a, b, and c)

Solution:

4. Plot signal waveform whose spectra (magnitude and phase spectra) are shown in the following figure. Also write down mathematical expression for the signal.

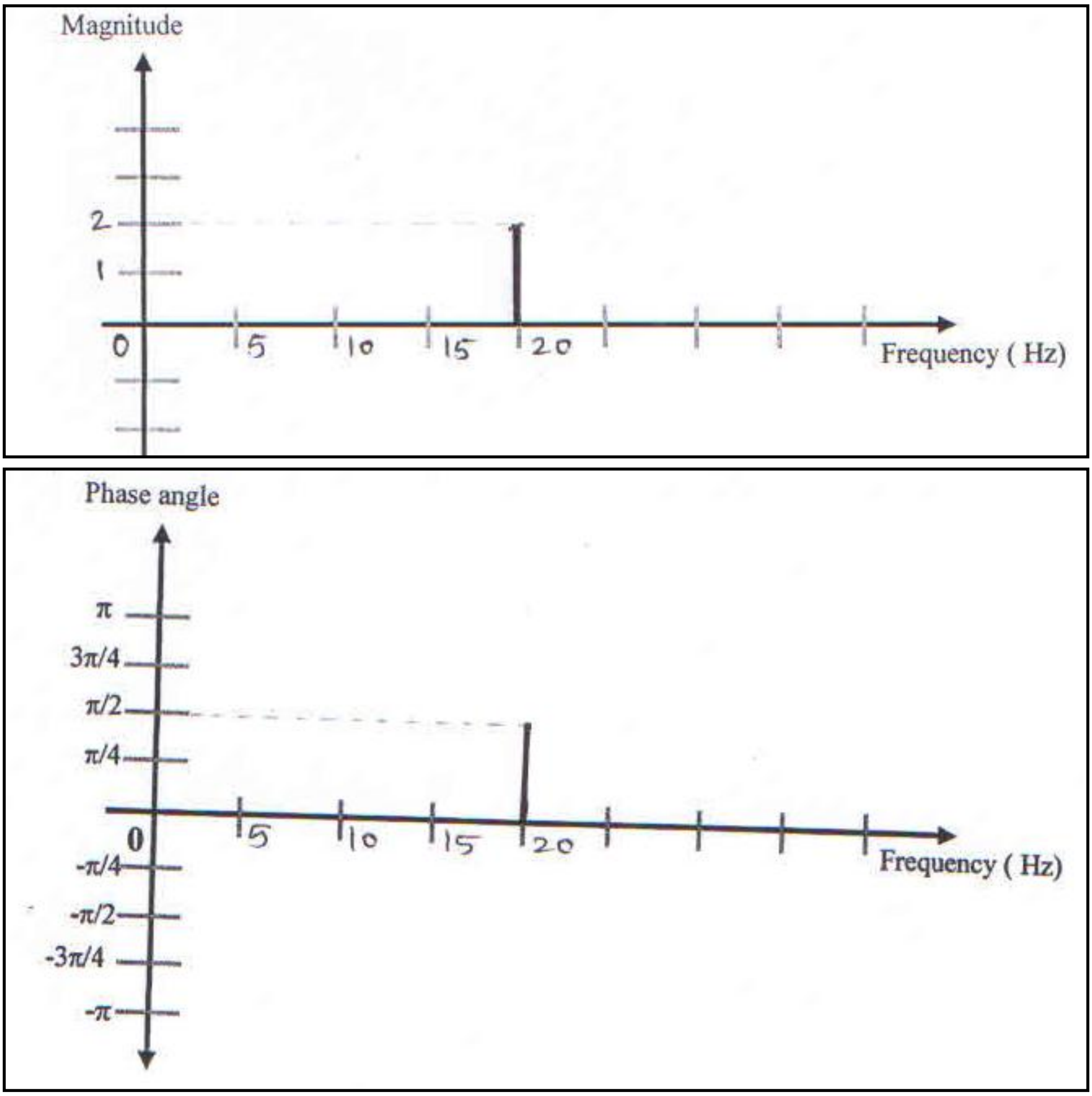


Figure 4 (a and b)

Solution:

5. Given below is the spectra (magnitude and phase spectra) for signal x(t). Write down mathematical expression for the signal x(t).

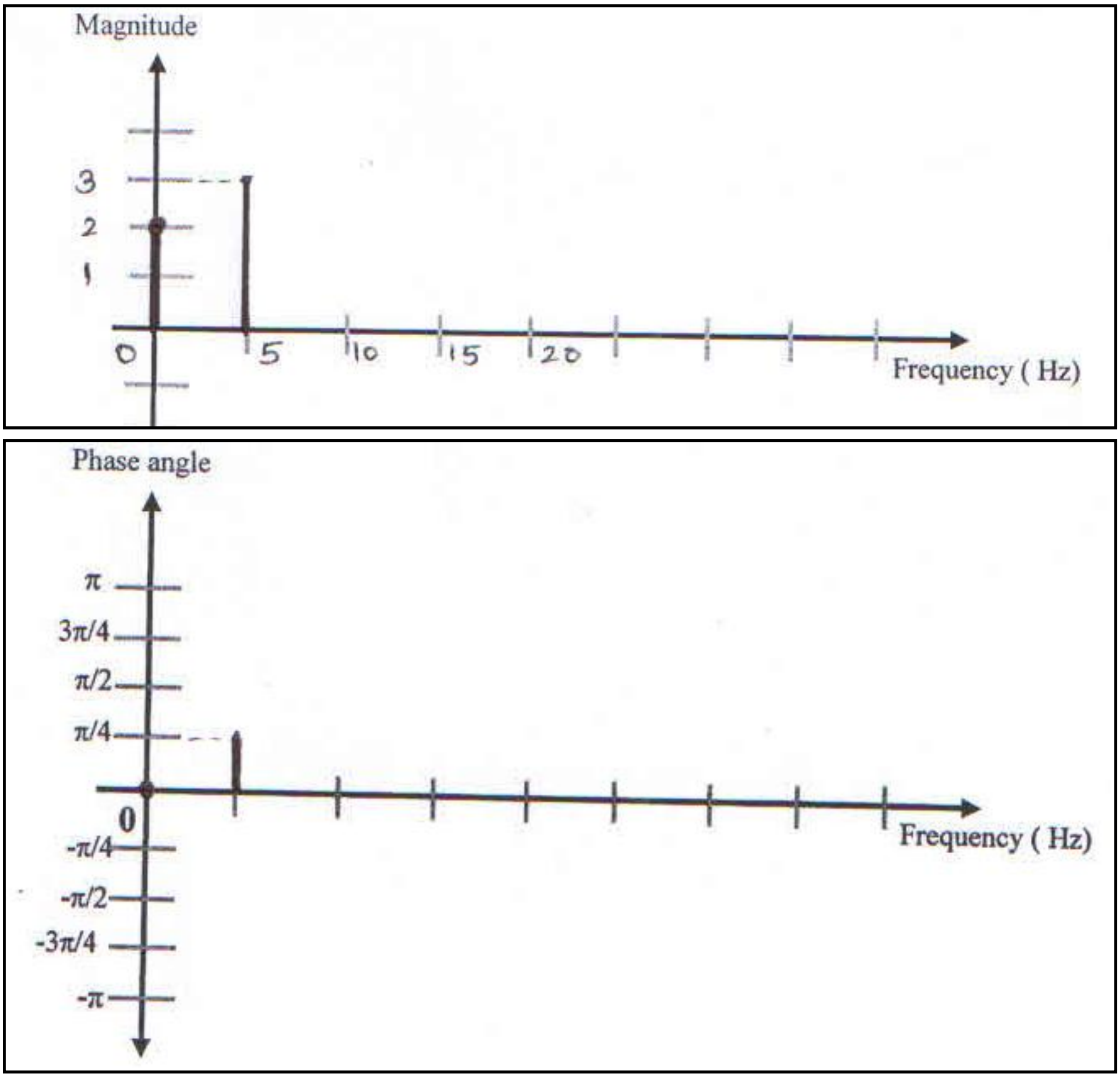


Figure 5 (a and b)

Solution:

6. If signals $x_1(t)$, $x_2(t)$ are sinusoids represented by following mathematical expression, plot the frequency spectra (amplitude and phase spectra) for these sinusoids.

$x_1(t) = 10\cos(20\pi\, t + \frac{\pi}{3})$ $\qquad$ $x_2(t) = 5 + 3\sin(20\pi\, t)$

Hint: Mathematically sin x= cos (x-90°). Remember, phase of a cosine signals is always considered as a reference for showing phase of any other signal. Thus, a sine function can be considered as cosine function with a pase shift of (-π/2).

Solution:

7. Let x(t) be a sinusoid represented with mathematical expression

$$x(t) = 10\cos(20\pi\, t + \frac{\pi}{2})$$

   a. Make use of Euler's formula and express the signal x(t) in the form of complex exponential form.
   b. Plot double sided frequency (magnitude and phase) spectra for signal x(t) using its complex exponential representation.

Solution:

8. Figure shown below shows double sided spectra for signal x(t). Write down mathematical expression for the signals x(t) in the form of sinusoid as well as complex exponential form.

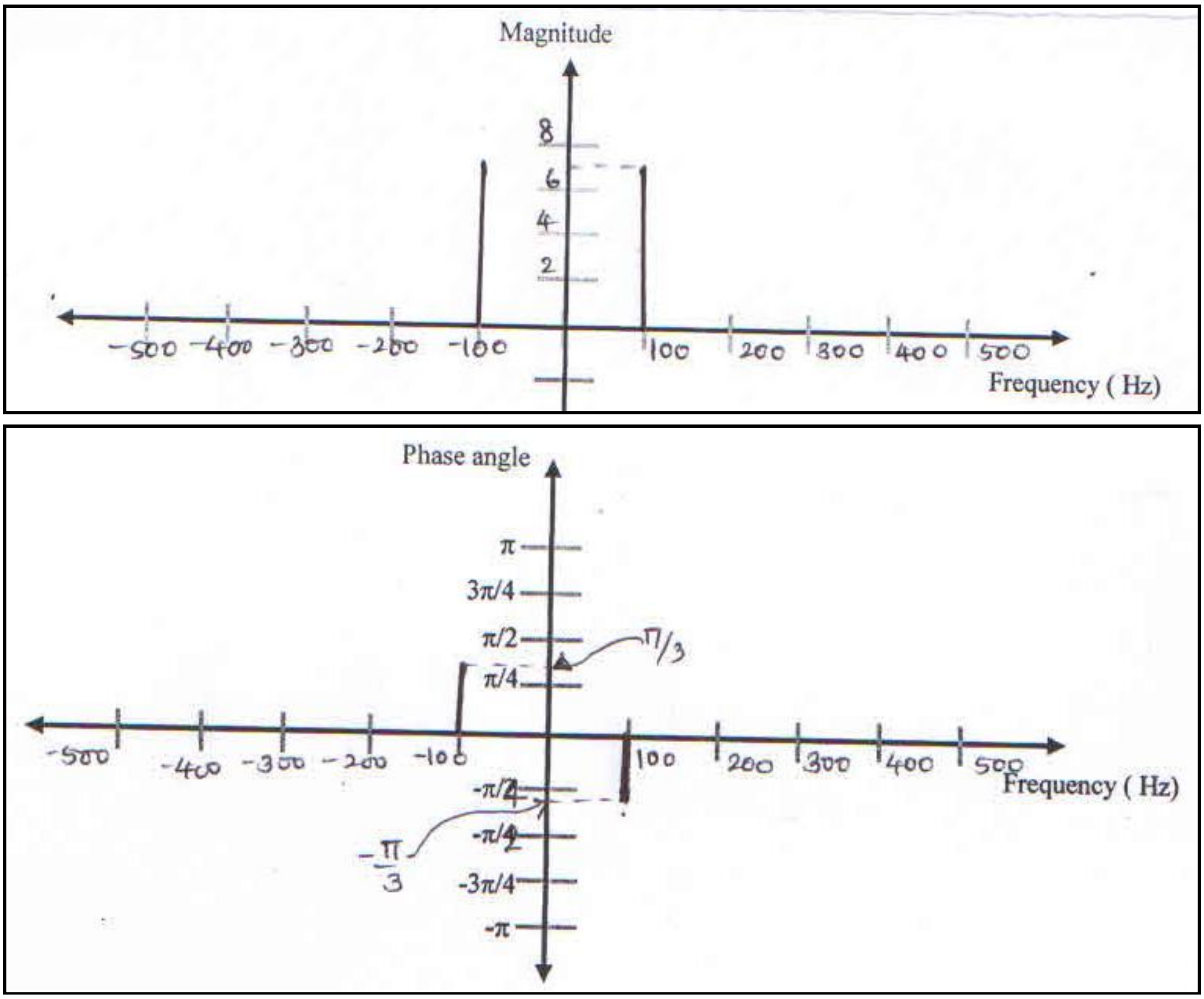


Figure 6 (a and b)

Solution:

9. Observe the signal spectra of signal x(t) as shown in the figure given below. The signal x(t) is passed through an ideal amplifier that offers a linear gain of 3 units. Predict the change in the spectra of signal x(t) after it passes through an amplifier and plot its spectra (of the amplified signal)

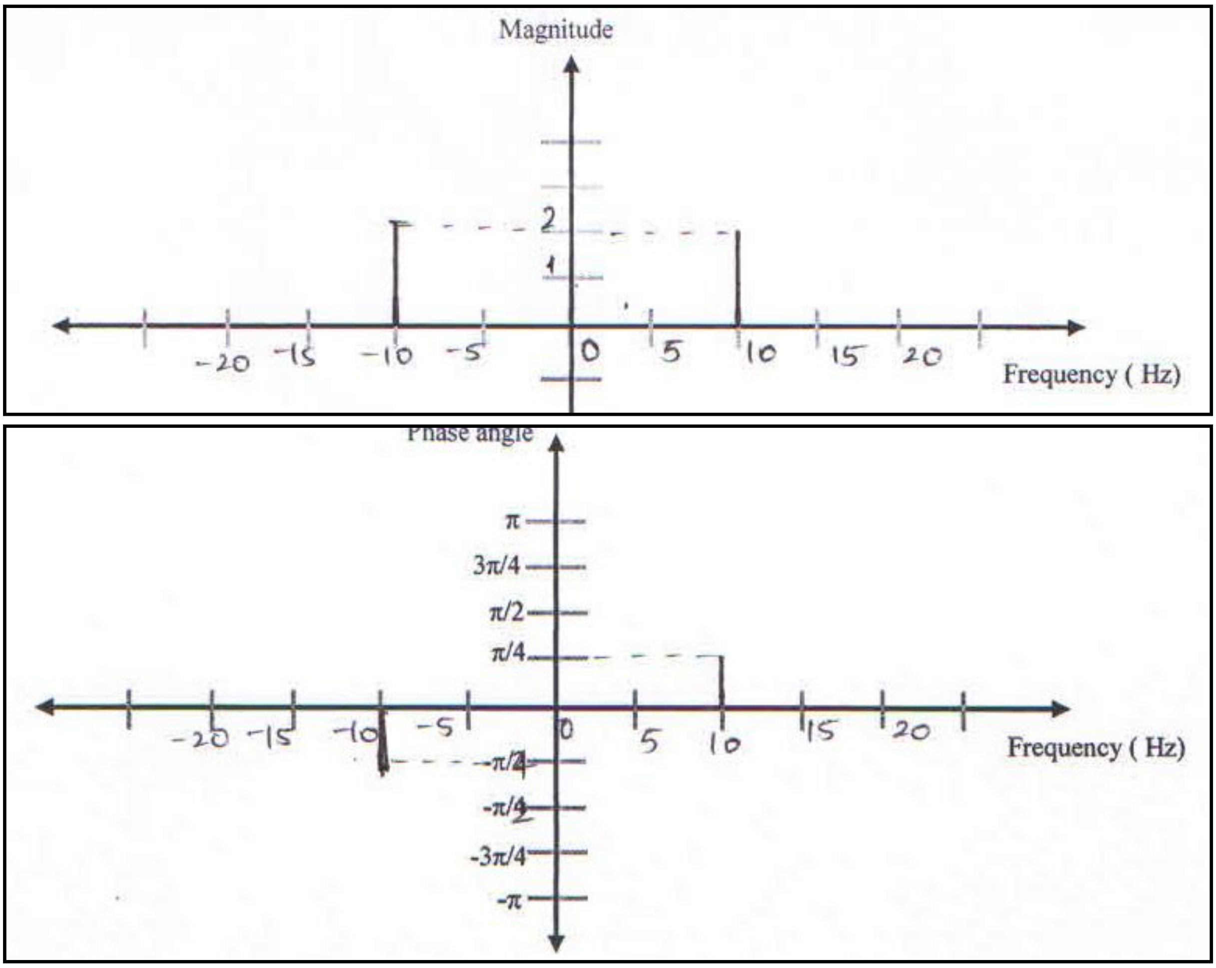


Figure 7(a and b)

Solution:

10. Observe the signal waveform x(t) as shown in the figure given below. The signal x(t) is passed through a phase shifter that introduces phase shift of (-π/2). Predict the change in the spectra of signal x(t) after it passes through the phase shifter and plot its spectra (of the phase shifted signal)

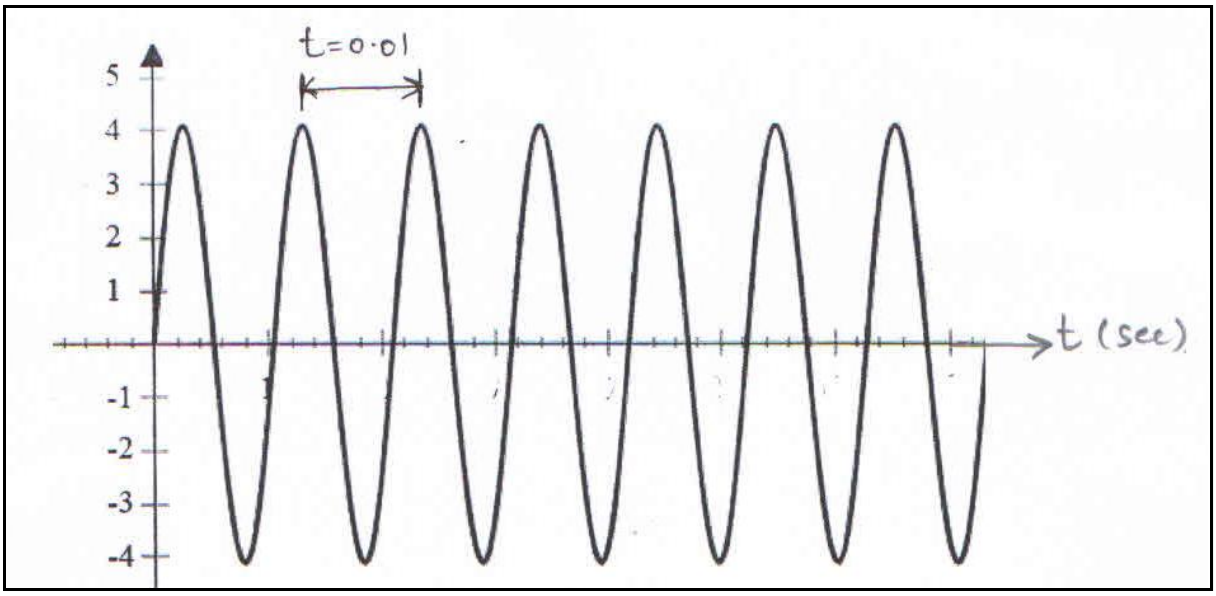


Figure 8

Solution:

11. The signal x(t) = $3 + 4\cos(200\pi\, t + \frac{\pi}{2}) + 8\sin(250\pi\, t + \frac{\pi}{3})$ is passed through an ideal (rectangular) low pass filter that offers uniform unity gain in its pass band and the low pass filter has a cut off frequency as 120Hz. Draw the double sided frequency spectra of the signal that will be present at the output of the filter.

Solution:

Appendix G Rubrics for assessing learner's competency developed in selecting, constructing and relating appropriate representation

Revised and adapted based on https://sites.google.com/site/scientificabilities/rubrics

	Ability	Missing	Inadequate	Needs Improvement	Adequate
A1	Is able to extract the information from the given representation correctly	No visible attempt is made to extract information from the given form of representation.	Information that is extracted contains errors such as selecting incorrect terms/ quantities, labelling incorrect quantities of the selected terms etc. (For example incorrect selection of amplitude/phase/frequency information about signal/ spectra or their values)	Some of the information is extracted correctly, but not all of the information. For example physical quantities are represented with numbers there are no units, or polarities are missing.	All necessary information has been extracted correctly, and written in a comprehensible way. Signal amplitude, phase, frequency are identified correctly from the given time/frequency / mathematical representation and units are correct.
A2	Is able to construct new representations from previous representations	No attempt is made to construct a different representation.	Representations are attempted, but use incorrect information or the representation does not agree with the information used. For example, showing double sided / single sided spectra in place of single sided/ double sided spectra OR sinusoidal / complex exponential in place of complex exponential	Representations are created without mistakes, but there is information missing, i.e. units, labelling in the graphical representation.	Representations are constructed with all given (or understood) information and contain no major flaws
A3	Is able to evaluate the consistency of different representations and modify them	No representation is made to evaluate the consistency.	At least one representation is made but there are major discrepancies between the constructed representation and the given one. There is no attempt to explain consistency. for example change in the phase spectrum of the time shifted signal has not been shown correctly. Or associated changes have not been shown in the magnitude and phase spectrum of the signal.	Representations created agree with each other but may have slight discrepancies with the given representation. Or there is no explanation of the consistency.	All representations, both created and given, are in agreement with each other and the explanations of the consistency are provided.
A4	Is able to use/ select appropriate representations to solve problems	No attempt is made to solve the problem.	The attempt has been made to solve the problem but the choice of selected representation is not correct. For example, while making an attempt to plot double sided spectrum, sinusoidal mathematical representation is selected in place of complex exponential.	The problem methodology is correct, but there is some information that has not been used/ depicted in the solution of the problem.	The problem is solved correctly with all the required forms of presentation will appropriate and sufficient use of information provided in the problem statement.
A5	Mathematical expression representation (descriptive representation) Sinusoidal / complex exponential	No representation is constructed.	Mathematical representation lacks has the wrong concepts being applied (for example change in the phase of the given signal in the given form of representation also translated to change in the frequency), signs are incorrect, or progression is unclear.	No error is found in the reasoning, however they may not have fully completed steps to solve problem or one needs effort to comprehend the progression.	Mathematical representation contains no errors and it is easy to see progression of the first step to the last step in solving the equation. The solver evaluated the mathematical representation.
A6	Graphical representation (Depictive) in the form of signal waveform/ spectra	No representation is constructed.	Diagram does not show its all constituents. (For example either magnitude or phase spectrum is constructed in place of both OR, labelling of either of them is done to related to amplitude/ phase or frequency.	Diagram has correct information depicted, however some part of labelling is inadequate.	The diagram contains no errors and it clearly describes the spectra accurately and in totality.

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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.

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