

A framework for enabling instructors to create effective customized learning designs with visualization

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by

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Dedication Sheet

Dedicated

to

my Parents, Husband and Sons

Thesis Approval Sheet

This thesis entitled "A framework for enabling instructors to create effective customized learning designs with visualization" by Gargi Banerjee is approved for the degree of Doctor of Philosophy.

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Abstract

Educational visualizations (animations/simulations) have the potential to achieve important learning objectives, especially in science and engineering domains. But these objectives remain unrealized when instructors simply lecture with the tool, which is one of the popular strategies used worldwide. This inability of instructors to create student-centred learning designs (LDs) that exploit visualization affordances, has been identified as an important barrier to effective integration of information and communication technologies (ICT) like visualization. It becomes more challenging for instructors teaching in instructor-mediated classrooms that are common in India and the developing world. In these classrooms students' interaction with the visualization is necessarily mediated via the instructor. Thus the specific problem targeted in this thesis is instructors' inability to design effective learning activities with visualization. The target user population is tertiary level instructors who are novice designers and teach in instructor-mediated classrooms.

We have developed the Customized Visualization Integration System (CuVIS) framework for science and engineering instructors. The CuVIS framework targets four design impediments identified from our studies with instructors - i) operationalizing constructive alignment and ii) meaningful learning, iii) framing group activity questions (conceptual level) and iv) designing implementation of active learning strategies (implementation level). CuVIS framework presents the conceptual level guidelines through the Activity Constructor prompts. They guide instructors to take design decisions at appropriate points in the LD creation process. Each prompt contains guidelines with illustrative examples from the instructor's domain. The implementation level guidelines are provided through the LD Blueprint outlining the classroom implementation design. Both the prompts and the blueprint vary with variation in objective and activity time duration specifications. CuVIS framework prototype was tested iteratively with instructors in four cycles. Effectiveness of CuVIS framework has been shown through its positive impact on instructors' design expertise in terms of: (i) their TPACK levels and (ii) their pedagogical practice. Also, implementing CuVIS LDs have led to successful achievement of the chosen objective through student post-test results. Usefulness and usability of CuVIS tool, built as a digital interface to the framework, has been established through large scale survey with 1200 + instructors.

This thesis is organized as follows: Chapter 2 presents problem space literature followed by existing solutions like teaching principles, best practices portals, teacher training programs and LD frameworks and tools. Gap analysis of existing solutions in our research context leads to our research objective of developing a framework to create constructively aligned, meaningful, customized LDs for teaching using visualization in instructor-mediated classrooms. Chapter 3 presents the research methodology of Design and Development Research (DDR) that was chosen to build such a framework. DDR was deemed suitable since it supports creation of solutions to a real-life problem through iterative prototype testing with the target users who are co-participants in the design process. It proceeds through three phases of Problem Analysis, Design and Development and Summative Evaluation – each of which is described in detail for CuVIS framework in Chapters 4, 5, 6 and 7. Chapter 8 documents development and evaluation of CuVIS tool. Chapter 9 discusses implications and limitations of CuVIS framework and Chapter 10 presents the contributions and future work.

Keywords: Learning design, Constructive alignment, Meaningful learning, Active learning, Instructor-mediated

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Abbreviation Notation and Nomenclature

CuVIS	Customized Visualization Integration System
CSE	Computer Science & Engineering
DDR	Design & Development Research
EE	Electrical Engineering
ET	Educational Technology
ICT	Information & Communication Technologies
LD	Learning Design
NMEICT	National Mission on Education through ICT
TAM	Technology Acceptance Model
T10KT	Train 10000 Teachers
TPACK	Technological Pedagogical Content Knowledge
SUS	System Usability Scale

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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Chapter 1

Introduction

1.1 Background of the research

Use of information and communication technologies (ICT) in education has the potential to significantly impact teaching and learning (Spector, 2013; Krejins et.al, 2013). They facilitate achievement of important teaching-learning objectives like improving students' prediction and reasoning skill (Riess & Mischo, 2010), increase conceptual and procedural understanding (Byrne et.al, 1999; Laasko et.al, 2009) among others. But the achievement of these objectives is subject to effective integration of ICT in teaching by the instructors (Bratina et.al, 2002). Effective integration is defined as 'ICT functioning as an integral or mediated tool to accomplish specific teaching or learning activities to meet certain instructional objectives' (Lim & Hang, 2003). This is achieved when instructors design student centered, active learning activities exploiting affordances of the ICT tool (Mishra &

Koehler, 2006; Angeli & Valanides, 2009; Tsai & Chai, 2014). However, instructors are unable to design such activities with ICT (Angeli & Valanides, 2009; Laurillard, 2012; Bennett et.al, 2015). This lack of instructors' design thinking has been identified as an important barrier to effective ICT integration in teaching (Tsai & Chai, 2012). Design thinking is defined as the 'dynamic creation of knowledge and practice' by the instructors in response to the pedagogical affordances provided by the ICT tools (Tsai & Chai, 2012). Thus the broad problem targeted in this thesis is ineffective ICT integration by instructors due to their inability to design effective teaching-learning activities.

This broad problem is targeted within the context of instructor-mediated classroom setting which is a reality in India and many parts of the developing world. This setting poses additional challenge towards creating effective learning activities since student interaction with ICT is necessarily mediated through the instructor (Banerjee et. al., 2015). Hence, the instructor's pedagogical expertise becomes a crucial factor in effective teaching using visualizations in such classrooms. In these classrooms, we have found through our large-scale survey (N = 2410) that among the modern ICT tools, it is the use of visualization that is widespread. Visualizations like educational animations and simulations are defined as "computer supported, interactive, visual representations of data to amplify cognition" (Tory & Moller, 2004). Visualization can also include videos of science and engineering experiments. However, lecture videos are out of scope. Numerous empirical studies have established visualizations as very useful teaching-learning tool, especially for science and engineering topics (Banerjee et.al, 2014; Rutten et.al, 2012; Guan, Zhang, & Zheng, 2009; Kehtarnavaz, Loizou, & Rahman, 2008). The instructor population targeted in this thesis is tertiary level instructors. This population was chosen since they were accessible to us through the Teach 10000 Teachers (T10KT, http://www.it.iitb.ac.in/nmeict/About_T10kT.html) project running in our institute as part of Indian government's National Mission of Education through ICT (NMEICT, www.nmeict.ac.in). In fact, the ET4ET training program within this project was designed to address the recognized need for training engineering instructors on effective teaching practices for ICT integration (Murthy et. al, 2015). Therefore, the specific problem targeted in this thesis is instructors' inability to design effective learning activities by exploiting the affordances of visualization. These learning activities are specific to teaching-learning using visualizations. The target user population is tertiary level instructors teaching in instructor mediated classroom setting.

Multiple solutions have been developed for the problem of instructors' inability to design effective activities. These solutions include instructor training programs and workshops (Koh, 2013; Lakkala & Ilomaki, 2015), online portals for sharing best practices (Shaffer et.al, 2011), teaching frameworks and guidelines (Biggs & Collis, 1982; Merrill, 1983; Biggs, 1996; Naps et.al., 2002; Krathwol, 2002; Mayer & Whittrock, 2006; Mishra & Schmidt, 2006; Churches, 2009; Morrison et.al., 2010; Howland et.al, 2012; Sorva et.al., 2013) and learning design (LD) frameworks (Emin et.al, 2010; Laurillard, 2013; Conole, 2014) and tools (Lukasiak et.al, 2005; Laurillard, 2012) . The training programs and workshops aim to assist them in translating the theory into practice but are insufficient to develop instructors' design expertise (Conole & Alevizou, 2010). The existing array of frameworks and teaching guidelines provide the requisite know-how to instructors on what constitutes effective learning activities. However, they do not provide guidance to instructors, who are novice designers, on how to apply those theories in their own context (Laurillard, 2012; Shaffer et.al, 2011). LDs were developed to bridge this gap between theory and practice (Laurillard, 2012). They capture the pedagogical pattern of the activity and are defined as the description of "the learning activities and the support activities that are performed by different persons (learners, instructors) in order to achieve the required learning objectives" (Conole & Fill, 2005). The existing LD frameworks and tools guide instructors in authoring student-centered activities with ICT tool. But they do not incorporate the challenges of instructor-mediated classroom setting. Neither do they focus on how to exploit affordances of a specific ICT tool. Consequently, the problem of ineffective ICT integration continues (Laurillard, 2012; Bennett et al., 2015). These gaps in existing solutions underlines the need to develop a solution for instructors in the context of instructor mediated classrooms. It should enable them to design theory informed, student-centered, effective LDs with visualization customized to their requirements.

1.2 Overview of Proposed Solution

The proposed solution is the Customized Visualization Integration System (CuVIS) framework. It is an LD framework that guides instructors to create effective, theory-informed, research-evidence based LDs with visualization that are customized to instructor requirements

of: (a) learning objectives with visualization, (b) domain and (c) activity time duration as also to instructor-mediated classroom setting. Effective CuVIS LDs signify LDs that are constructively aligned (Biggs, 1996) and incorporate five dimensions of meaningful learning with ICT (Howland et.al, 2012). These two theories were chosen as theoretical underpinnings of CuVIS since we found from our studies that instructors were not able to operationalize these theories into their design practice. The principle of constructive alignment (Biggs, 1996) specifies that for effective teaching the designed teaching-learning activity and the assessment should be aligned to the selected learning outcome. Meaningful learning with ICT (Howland et.al, 2012) outlines the dimensions that should be incorporated within LDs to ensure meaningful learning. The five dimensions are: a) Active learning - actively engage with ICT content, b) Constructive – use ICT to construct their own knowledge through self-reflection and articulation, c) Authentic - devise solutions to real-life problems using ICT, d) Intentional - set their learning goals, evaluate their understanding and self-diagnose their errors through ICT and e) Cooperative - do group activity with their peers using ICT. In CuVIS, designing for constructive alignment is ensured through a set of Activity Constructor prompts (Fig. 1.1). These prompts guide the instructor in taking appropriate design decisions like ‘Decide on the multiple condition sets to show’, ‘Decide where to pause the visualization to start activity’ during the LD creation process. The Activity Constructor prompts is mapped to the cognitive process that is known to lead to successful attainment of a particular objective and varies with change in objective. On the other hand, the meaningful learning dimensions are operationalized through Activity Constructor prompts like ‘Decide how to connect to real life’ (Authentic), ‘Decide the group activity question’ (Constructive, Cooperative) and also through the implementation design template called the ‘LD Blueprint’. The template is mapped to the objective and the research-evidence based implementation protocol of the active learning strategy selected.

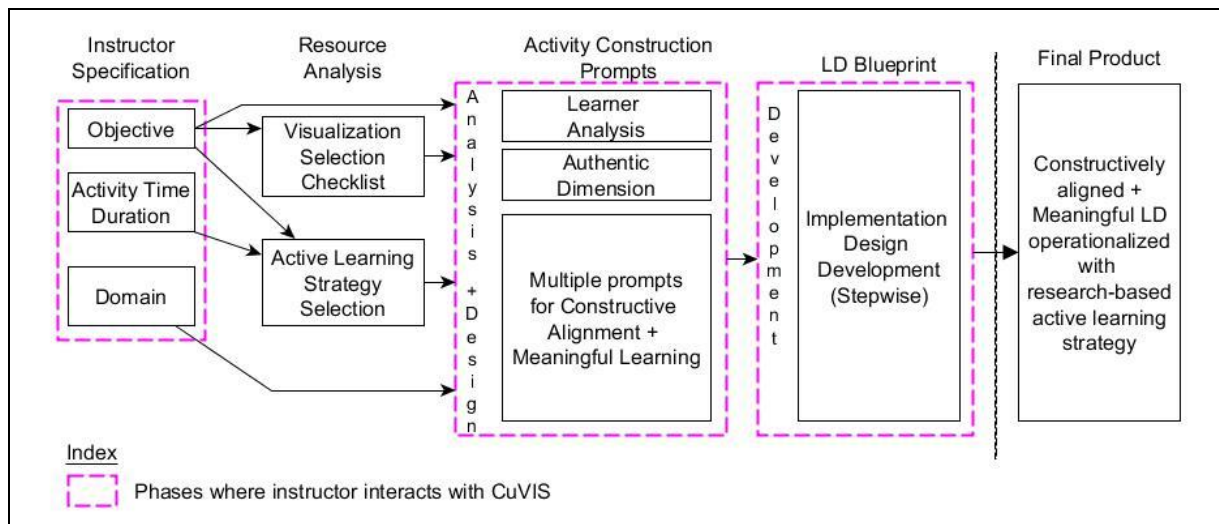


Figure 1.1: Block Diagram of CuVIS Framework functioning

The CuVIS framework presents a series of Activity Constructor prompts that guides the instructor through different phases of the LD creation process - Analysis, Design and Development. Each prompt contains guidelines and an illustrative example from the instructor's domain for better comprehension. Currently, the domains covered in CuVIS are Electrical Engineering (EE) and Computer Science & Engineering (CSE). The CuVIS framework works by taking the following input from the instructor: their objective, domain and activity time duration. In response, CuVIS provides a visualization selection checklist as part of the resource analysis stage (Fig. 1.1.). This checklist contains a set of visualization affordances mapped to the instructor's objective. The purpose of this checklist is to ensure instructors choose a visualization that supports the student-centered, active learning pedagogy of CuVIS. In the resource analysis stage, CuVIS also assists instructors to select an active learning strategy that is aligned to the objective and the activity time duration specified. Once visualization and strategy has been selected, the instructor responds to the relevant set of Activity Constructor prompts. These prompts guide instructors to analyze the learners and the content and then take the design decisions to operationalize the theories of constructive alignment and meaningful learning. The responses to Activity Constructor prompts are then placed by the instructor in appropriate places within the 'LD Blueprint' leading to the final LD that will lead to effective visualization integration in instructor-mediated classrooms.

The demand from instructors for a digital interface to interact with the CuVIS framework led to creation of the CuVIS tool. It is a semi-automatic tool that replicates the functioning of the framework with the additional feature of automating the filling up of the ‘LD Blueprint’ template. Thus, instructors initially give their input specifications to the tool and respond to the Activity Constructor prompts. The tool captures instructor responses to the prompts, chooses the blueprint template mapped to objective and activity duration selected and fills up the blueprint to generate the final LD. Therefore, output from both the CuVIS framework and tool is a theory-informed, research-evidence based LD with visualization, customized to the instructor’s requirements and the context of instructor-mediated classrooms. Table 1.1 presents the layout of the final LD where learning activity is detailed out in terms of what role the instructor, students and the visualization will play at each step and for what time duration (in mins.).

Table 1.1: Layout of final LD output from CuVIS

Step No.	Time (mins.)	What instructor will do	What student will do	What visualization feature used, if any

1.3 Research Methodology adopted to build CuVIS

The broad objective of the CuVIS framework is to enable instructors to create effective LDs with visualization customized to their requirements and instructor-mediated setting. This objective of facilitating creation of effective LDs with visualization by instructors is an ill structured, real-life problem. It requires a practically feasible solution that is usable by the target user population. This requires the target users i.e. instructors teaching using visualization in instructor-mediated classrooms to be co-designers of CuVIS during the framework development process. All the above requirements fit in with the features of Design and Development Research (DDR) methodology (Van den Akker et.al, 2006). Hence, DDR was chosen as the appropriate methodology to build the CuVIS framework. It proceeds through three phases of (a) Problem Analysis, (b) Design and Development and (c) Summative Evaluation (Mc Kenney, 2001).

The first and third phases lead to specific research questions related to identification of the design impediments and effectiveness of CuVIS respectively. The second phase involves the design and development of the framework. Both qualitative and quantitative studies are done in each phase to achieve the objective of that phase. The design impediments are identified in the first phase through inductive content analysis of unguided LDs created by 30 science and engineering instructors who are novice designers (Fig. 1.2). The impediments define what should be the building blocks of CuVIS framework. The specifications for the building blocks are identified through analysis of semi-structured interviews with 28 science and engineering instructors. The specifications lead to the second phase of design and development of the framework. Narrative analysis of literature is carried out to frame the CuVIS guidelines. They are sourced from disparate streams of literature dealing with the cognitive process, the pedagogical support required and the tool affordance needed to achieve a particular objective. In this phase, the prototype of the framework undergoes four iterative rounds of testing with instructors from EE and CSE in form of interviews and small-scale usability survey.

In the summative evaluation phase, effectiveness of CuVIS is tested through its impact on (a) instructors' design expertise (N = 6), (b) achievement of objectives when CuVIS LDs are implemented with students (N = 375) and (c) a large-scale usefulness and usability survey (N = 1200+) of CuVIS tool. The impact on design expertise was assessed with instructors from the domains of EE and CSE. They created LDs with varying degrees of support across three different time points for a learning scenario of their choice (unguided Warmup round, CuVIS guided Scaffold round, Transfer round). The evolution of instructors' design expertise was obtained through evaluation of their LDs using a modified version of an established rubric (Koh, 2013) that measures instructors' ability to design constructively aligned and meaningful LDs with ICT. The effect of LDs, created with CuVIS guidelines, on student achievement of learning objectives was studied through two post-test only control-group field experiments with 375 students from EE and CSE. Each experimental group was taught using CuVIS LD whereas the control group was taught with non-CuVIS traditional LD. Both groups were taught by the same instructor using the same visualization. Usefulness and usability of the CuVIS tool was tested through survey questionnaires based on the established instruments of TAM (Technology acceptance model) and SUS (System Usability Scale)

respectively. They were administered to 1200 + science and engineering instructors after they have used the CuVIS tool to create LDs.

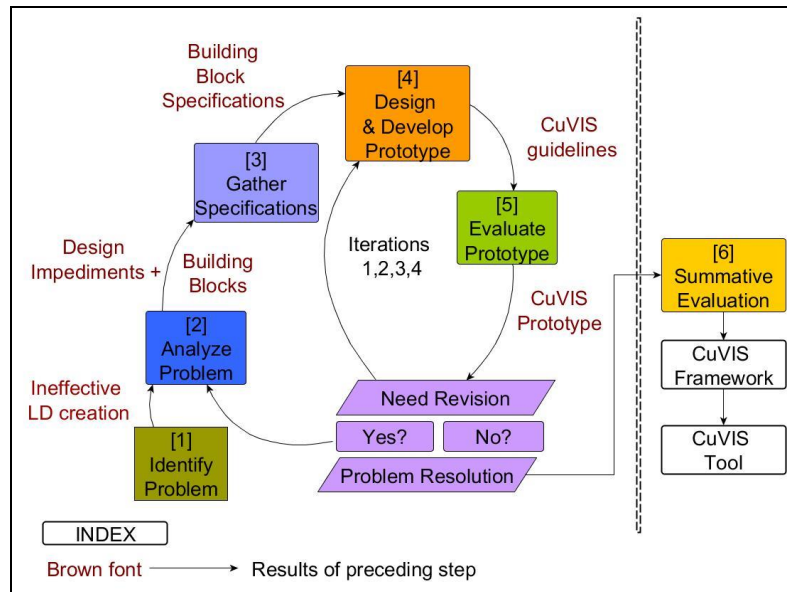


Figure 1.2: Solution Approach for CuVIS framework

1.4 How CuVIS addresses the gap in existing solutions

The CuVIS framework has been co-designed with the target user population of science and engineering instructors using DDR methodology. This increases the practical viability of the solution developed since target users are able to seamlessly translate existing educational theory guidelines into their teaching practice. Each guideline is accompanied by an illustrative example from the instructor’s domain. The instructors felt the domain examples helped them in operationalizing the guidelines to their context. The CuVIS framework addresses the learning objectives that science and engineering instructors have while teaching using visualization. It also accommodates the contextual challenges of instructor-mediated classrooms. Also, empirical studies have been carried out to provide evidence for effectiveness of the CuVIS framework and the CuVIS tool in enabling instructors to design constructively aligned, meaningful LDs with visualization customized to their requirements.

1.5 Thesis Contribution

The major contributions of this thesis are:

- **CuVIS framework:** It enables instructors to create effective customized LD using visualization in instructor-mediated classrooms. Here effective LDs refer to constructively aligned, meaningful LDs that exploit pedagogical utility of visualizations.
- **Design scaffolds:** Scaffolds like Activity Constructor prompts, LD Blueprint, Self-evaluation checklist have been developed which can be used by instructors to facilitate development of their design expertise. These scaffolds were identified as helpful by instructors in developing their expertise as revealed through thematic analysis of instructor interviews.
- **Design impediments:** Identified four design impediments that instructors encounter while designing effective LDs using visualization in our research context, thus contributing to LD research.
- **Framework evaluation:** Evaluated usability and usefulness of CuVIS with 1200 + science and engineering instructors from nine domains. Tested validity of field application in two topics with 375 students and three instructors.

The minor contributions of this thesis are:

- **CuVIS tool:** It acts as the digital interface to the framework. The framework and the tool are useful teacher training resource to develop instructor's design expertise.
- **Design recommendations for scaffolds** targeting development of instructors' design expertise.

1.6 Organization of Thesis

The organization of the thesis is depicted in Fig. 1.3. Analysis of literature on instructors' inability to design effective LDs with ICT tools and the existing solutions that address this problem is presented in Chapter 2. The literature analysis is arranged into problem space literature and solution space related work. This analysis leads to identification

of the thesis research goal i.e. developing a framework to enable instructors to create effective LDs with visualizations. In Chapter 3 we present the overarching research methodology adopted to build this framework.

Chapters 4 and 5 form the central chapters describing the analysis, design and development of the CuVIS framework and tool. In Chapter 4 we give detailed account of the Problem Analysis phase. In this phase, we identify specific design impediments to target through the framework guidelines. These impediments help us determine the building blocks of the framework. The specifications for the building blocks are obtained through analysis of instructor interviews. In Chapter 5, we describe the Design and Development phase of the CuVIS framework including the iterative prototype testing cycles.

Chapters 6 and 7 deal with the summative evaluation phase. The effectiveness of CuVIS is tested along two axes – (i) its impact on instructor design expertise (Chapter 6) and (ii) achievement of intended learning objective by students on implementation of CuVIS LDs (Chapter 7). Based on the feedback received from instructors, the CuVIS tool has been built as a digital interface to the CuVIS framework. The tool automates the operationalization of the implementation design guidelines once the instructor's design decisions are received through the conceptual level guidelines. Chapter 8 documents the design, development and large-scale usefulness and usability evaluation of the tool. The entire thesis work is summed up in Chapter 9 along with limitations of CuVIS in its current state. Chapter 10 presents the major and minor contributions of the thesis work along with the future research directions that can evolve from this thesis.

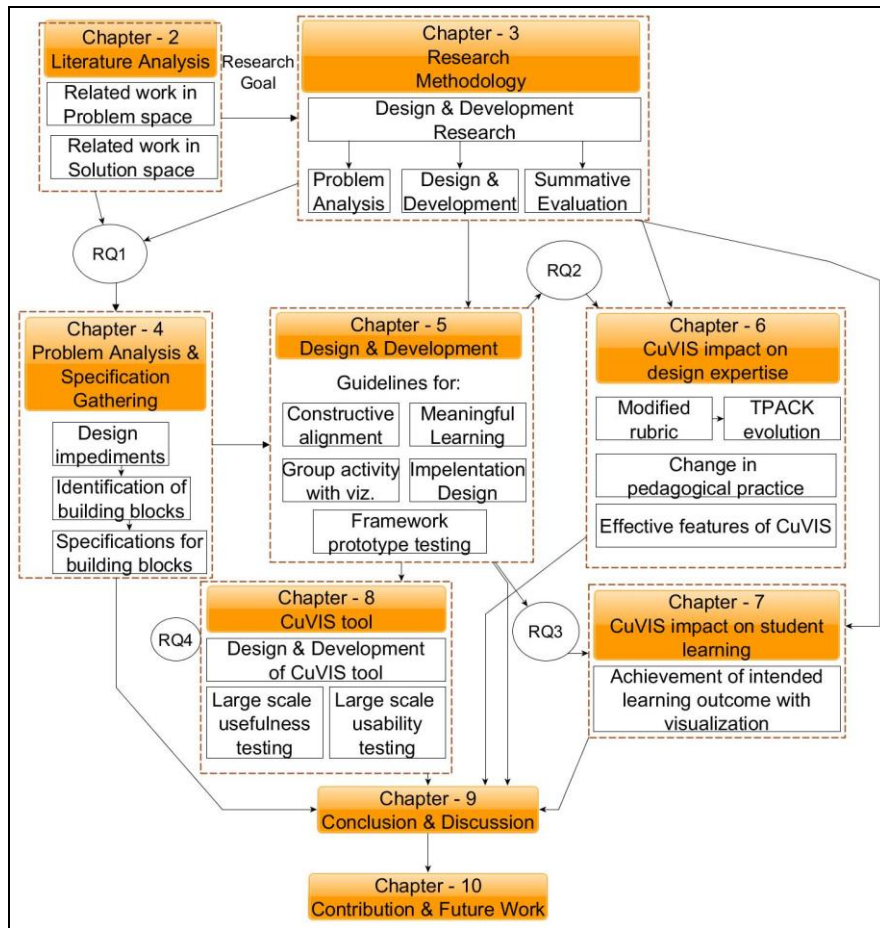


Figure 1.3: Organization of thesis

Chapter 2

Analysis of existing solutions for effective visualization integration

In Chapter -1, the problem space for this thesis was identified as instructors not being able to create effective, student-centered learning activities with ICT tools like visualization. An overview was given of the solutions existing for the identified problem and the gaps that have not yet been addressed. In the current chapter, a detailed analysis of the problem plaguing effective integration of ICT teaching (Section 2.1) is presented. Multiple solutions like teaching-learning taxonomies and principles, instructor training programs, portals for sharing of best practices and learning design (LD) frameworks and tools have been developed to mitigate this problem (Fig. 2.1). These solutions are described and analyzed in two subsections – (i) theory-focused (Sec. 2.2) and (ii) activity-design focused (Sec. 2.3). The basis of the sorting into these two groups is the type of support offered for the process of designing learning activities like focusing chiefly on imparting theoretical knowledge or focusing chiefly on designing practice applying a relevant subset of theories. However, there

are certain lacunae in these solutions that has led to the persistence of ineffective integration of ICT tools in teaching. The chapter ends with Section 2.4 that argues for the need of an LD framework for our context - tertiary level instructors teaching using visualization in instructor-mediated science and engineering classrooms.

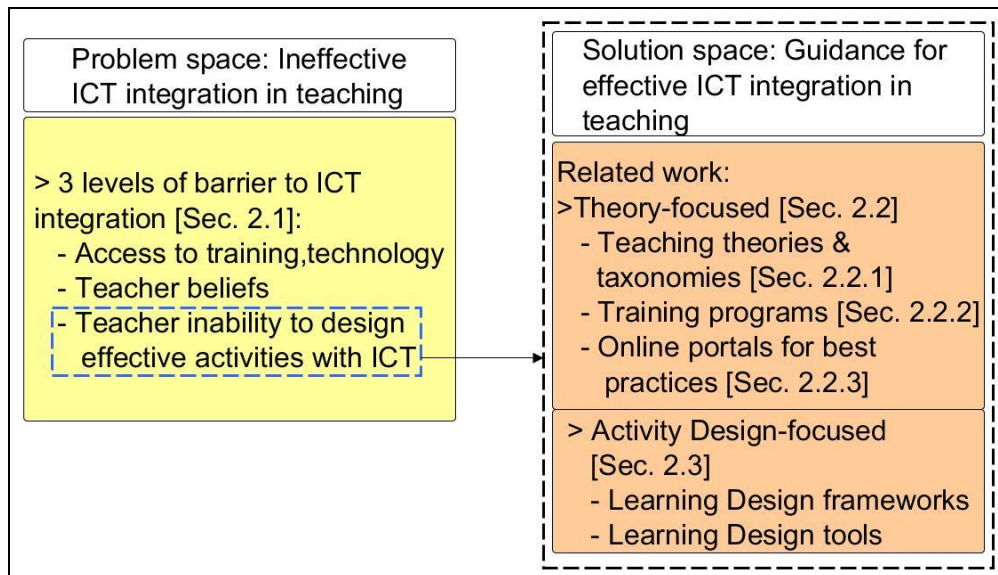


Figure 2.1: Organization of related work

2.1 ICT integration in teaching and learning

A large number of information and communication technology (ICT) tools like visualizations, virtual labs, wikis and mobile apps have been developed for education. These ICT tools have been designed and developed through research in instructional design and multimedia principles to make them effective for learning. The vast array of such well-designed ICT tools for education has led to their widespread use in classrooms across the world (Spector, 2013; Krejins et.al, 2013). However, the learning effectiveness of these tools in the classroom is a function of the way the instructor uses them in their teaching (Bratina et.al, 2002). But the dominant strategy used with ICT worldwide and across educational levels – primary, secondary, tertiary is lecturing with the tool (Angeli & Valanides, 2009). Such a strategy undermines the learning effectiveness of ICT with students being receivers of

information transmission. This points to the inability of instructors to design student-centered activities with ICT.

Researchers have explored the possible reasons for this and have identified three types of barriers to effective ICT integration - extrinsic (1st level barrier), intrinsic factors (2nd level barrier) (Ertmer, 1999) and design thinking (3rd level) (Tsai & Chai, 2012). The extrinsic factors are related to instructors' access to technology, training and support. The intrinsic factors relate to instructors' pedagogical beliefs, technological beliefs and willingness to change. With increased efforts of governments and institutions to provide technology and training, the issue of first level barrier has now almost been mitigated (Ertmer, 2012). However, researchers have argued that overcoming the extrinsic and intrinsic barriers is not enough (Tsai & Chai, 2012). Instructors' lack of design thinking in designing effective learning activities with ICT has been recognized as the third level integration barrier (Tsai & Chai, 2012). Design thinking is described as instructors' ability to dynamically create knowledge and skill in response to the pedagogical affordances of ICT (Tsai & Chai, 2012). In this thesis we target this inability of instructors in designing student centered activities with ICT in the context of tertiary level instructors teaching in instructor mediated classrooms.

2.2 Theory-focused solutions for ICT integration in teaching and learning

In this section, we present an overview of the theory-centric solutions like teaching principles and taxonomies, instructor training programs and online portals for sharing of best practices. They aim to impart the knowledge about student-centered pedagogical practices and its application in designing effective student-centered activities with ICT.

2.2.1 Teaching principles and taxonomies

Various teaching principles and taxonomies exist, some generic and some specific to teaching with ICT that lead to effective learning. One of the fundamental principles for student-centered teaching and learning is constructive alignment (Biggs, 1996). This principle specifies that to successfully attain the learning objective of a teaching unit, both the teaching-

learning activity and the assessment designed should map to the learning objective within a constructivist pedagogy. Empirical studies have shown the positive impact of this principle on student learning in multiple science domains (Morris, 2008; Hoddinott 2000). The operationalization of this alignment is dependent on the cognitive process that learners are known to follow to successfully achieve the specific objective. These cognitive processes are specified by another set of teaching theories like Mayers & Whittrock's (2006) Select-Organize-Integrate (SOI) model of problem solving objective or, Jonassen's (1997) model of problem solving. These models outline the cognitive process that learners adopt to successfully attain a specific objective. The SOI model, for example, presents a six-step linear cognitive model. For each step, the model suggests what type of instructional scaffolds to provide to achieve the problem solving objective.

The learning objectives that instructors have are classified into different levels by multiple learning taxonomies like Revised Bloom's (Krathwol, 2002) and SOLO taxonomy (Biggs & Collis, 1982) to design appropriate assessment tasks or choose an appropriate instructional strategy. The Revised Bloom's taxonomy consists of six different cognitive levels of objectives. It provides a list of action verbs for each level to guide instructors on designing assessment tasks that align with the objective. Similarly, the SOLO taxonomy classifies learning objectives into five levels based on their complexity – prestructural, unistructural, multistructural and extended abstract. There are few empirical studies that attempt to map instructional strategies to different SOLO taxonomy levels (Kanuka, 2005). For example, Kanuka (2005) recommends use of instructional strategies like brainstorming and web quest for the multi-structural and extended abstract levels for a text-based online setting. Then there are theories like Component Display Theory (CDT) (Merrill, 1983) and Extended Content Performance matrix (Morrison et.al, 2010) which guide instructors on what instructional strategy to use for the different types of objectives. For example, the Component Display Theory outlines an instructional strategy set for a complete lesson unit. The strategy set can be chosen based on three major factors – i) content type (Facts, Concepts, Procedures, Principles) and performance objectives expected from students (Remember, Use, Find) ii) set of four primary presentation forms and associated secondary presentation forms and iii) rules relating presentation forms to content performance matrix. Thus for content type - Concept at performance level - Use, the strategy set recommended is give definition followed by give examples and then ask students to classify new entities. Morrison et. al. (2010) also bases

their work on a content-performance matrix where performance is restricted to Recall and Application and instructional strategies to four categories of generative strategy – Elaboration, Organizational, Integrative and Recall. For example, for content type – Concept at Application level, the recommended strategy is integrative wherein learner generates or determines new examples and non-examples. These are established teaching-learning theories but do not have teaching with ICT as their focus.

In recent times, a number of ICT-related taxonomies have been proposed that either guide on choice of ICT tool mapped to objective or the different levels of student engagement that can be generated with ICT like the Digital Taxonomy (Churches, 2009), Naps' engagement with visualization (Naps et.al., 2002), 2DET Taxonomy (Sorva et.al., 2013). The Digital Taxonomy assists instructors in choosing ICT tools mapped to six different cognitive levels of Bloom's taxonomy. Naps et.al (2002) taxonomy of six student engagement levels with ICT presents the link between learning and nature of ICT (algorithm visualizations) use. The engagement levels are classified into No Viewing, Viewing, Responding, Changing, Constructing and Presenting - hypothesizing that learning will increase as the engagement level with visualization proceeds from 'No Viewing' to 'Presenting'. Myller et.al. (2009) adds four additional levels to create the 'Extended Engagement Taxonomy' (EET) and hypothesizes that with increasing levels of engagement both collaboration among students and their learning will increase. Sorva et. al. (2013) proposes the two dimensional engagement taxonomy (2DET) consisting of the dimensions of direct engagement with visualization and content ownership (cognitive engagement). It hypothesizes that learning from visualizations increases not only with direct engagement level but also with content ownership. Researchers have conducted multiple experiments to validate the hypotheses of these taxonomies (Stasko et.al, 1993; Hansen et.al, 2000; Laasko et.al, 2009).

In order to successfully design such student engagement levels, teaching principles like meaningful learning with ICT (Howland et.al, 2012) has been proposed. The hallmark of meaningful learning theory is learners should be able to connect new knowledge with prior knowledge and organize their knowledge into a coherent mental structure. This is enhanced by 'intellectual partnership' formed between the technology and the learners (Jonassen, 1995). This partnership can be brought about if the activity design consists of the five dimensions of - Active Learning, Constructive, Authentic, Intentional and Cooperative. To explain these dimensions further: i) Active Learning – students should be actively engaged with the content

of the ICT tool rather than being passive listeners. ii) Constructivist – students should construct new knowledge themselves by connecting it to prior knowledge using the ICT tools. iii) Authentic – Students use the ICT tool to work on learning activities that connect to real-life applications. iv) Intentional – students should reflect on their learning goals and the learning pathways followed to achieve that goal. v) Cooperative – Students should work with their peers to learn. This theory has been used widely by researchers to design teaching-learning environments and is considered a valuable teaching principle for e-learning and online teaching (Koh, 2013). In addition, rubrics exist for assessment of meaningful learning with ICT that serve as valuable resource for instructors who are novice designers of effective activities with ICT (Koh, 2013; Hornack, 2011).

However, to be able to operationalize these dimensions in their design practice, the type of knowledge that instructors need is described by the technological pedagogical content knowledge (TPACK) framework (Mishra & Koehler, 2006). It describes the knowledge base required for designing activities with ICT as a synthesis of their content as well as technological and pedagogical knowledge. The ICT-TPCK framework (Angeli & Valanides, 2009) stresses that in addition to the three TPACK constructs, instructors' also need to incorporate knowledge about their own context and their learners to make teaching with ICT effective. Multiple studies have been conducted to validate both TPACK (Banerjee & Murthy, 2012) and ICT-TPACK frameworks (Angeli & Valanides, 2009). There also exists many assessment instruments to measure TPACK (Schmidt et al., 2009; Archambault & Barnett, 2010; Koh, 2013).

2.2.1.1 Theoretical underpinnings of the proposed framework

The theories of constructive alignment and meaningful learning with ICT are chosen as the theoretical underpinnings of the proposed framework. Constructive alignment is chosen not only because it is one of the fundamental principles of student-centered teaching-learning but also because it aligns with the objective of the thesis. The objective of effective ICT integration entails instructors designing student-centered learning activities that meets the learning objective through exploitation of pedagogical affordances of ICT (Lim & Hang, 2003; Angeli & Valanides, 2009). Constructive alignment does not focus on ICT which is

brought in by meaningful learning with ICT, another fundamental teaching principle. Besides, from our studies with instructors we have found that instructors face problems designing for each of the dimensions covered by these two theories. TPACK is another important framework for teaching with ICT. It describes the knowledge base instructors need to have to be able to design effective activities with ICT whereas theories like meaningful learning and constructive alignment specify the dimensions along which the TPACK needs to be built.

2.2.2 Instructor Training Programs

Several instructor training workshops and programs have been designed to develop instructor's TPACK (Angeli & Valanides, 2009; Koh, 2013). These range from three-day workshops to a semester long course within a teacher training program. Most of the training programs are targeted at pre-service instructors at K-12 level who are novice designers (Angeli & Valanides, 2009; Koh, 2013). These K-12 level training programs report improvement in instructor's TPACK at the end of the program. For example, Angeli & Valanides (2009) reports positive impact on instructor's ICT-TPCK after pre-service primary instructors underwent a semester-long course designed on the ICT-TPCK framework. Koh (2013) reports positive impact of their training program on instructors' TPACK for designing effective activities with ICT. In their training program, pre-service Chinese language instructors underwent a twelve-week course focused on learning and applying the theory of meaningful learning. The training program strongly developed the active learning dimension in their designs with the other dimensions developing up to the medium level. Teacher training for ICT has also been introduced for in-service tertiary level instructors who are novice designers (Trentin, 2006; Brent & Felder, 2009; Murthy et.al, 2015). National Effective Teaching Institute (NETI) program conducts annual workshops at North Carolina University for engineering instructors (Brent & Felder, 2009). These workshops are three-days long and focus on pedagogical practices and evaluation. 87% of the instructors who attended these workshops perceived them to have positive impact on quality of their teaching. Again, the Xanadu project at University of Turin conducts a series of seminars and four weekly meetings with university instructors at basic and advanced levels. At the basic level the aim is to motivate the use of ICT in teaching and at advanced level it targets effective

teaching practices with ICT (Trentin, 2006). In India, the Indian Institute of Technology Bombay (IITB) conducts a seven-week course split into three days synchronous mode, five weeks asynchronous mode followed by three days synchronous mode based on the A2I model. It teaches student-centered pedagogical practices for teaching with ICT and has reported positive impact in terms of instructor feedback (Murthy et.al, 2015).

2.2.3 Online portals for sharing of best practices

Sharing of best practices with ICT tools provide an avenue for less experienced instructors to study an application of the established teaching principles for teaching with ICT from their colleagues who are expert designers. Best practice examples inspire confidence in instructors for designing effective activities with ICT for their classrooms (Shaffer et. al., 2011). Various online portals like COSMOS, AlgoViz (Shaffer et. al., 2011), WISE are now operational that promotes easy dissemination of best practices with ICT to the teaching community at large. The best practices are however specific instantiations in a particular context. Instructors who are novice designers need to adapt them to their own context (Shaffer et.al, 2011).

2.2.4 Analyzing strengths and limitations of existing solutions

The existing solutions for the problem of deficiency in instructors' design expertise are – teacher training workshops or programs, learning taxonomies and teaching principles, online portals for sharing of best practices. In this sub-section we analyze the strengths and limitations of these existing solutions and discuss their applicability to our context of instructor-mediated tertiary level classrooms.

(a) Teaching theories & best practices difficult for instructors to translate into practice

Diverse sets of teaching theories exist for teaching with ICT tools (Section 2.1). These theories make invaluable contributions to the field of educational technology. They are however, meant more for the educational technology (ET) researchers than the instructors

who are novice designers. For the instructors, being on the periphery of ET research, these principles and taxonomies prove overwhelming (McNaught, 2003) and difficult to translate to their own context (Laurillard, 2012). This is especially true for tertiary level instructors who have neither the time nor the support needed to make the translation (Laurillard, 2012). This difficulty extends to sharing of best practices also (Shaffer et.al, 2011).

(b) Instructor training programs not sufficient for developing design expertise

The training programs and workshops aim to develop instructors' pedagogical practices with ICT. They do produce positive impact on instructor practices (Murthy et.al, 2015; Brent & Felder, 2009). However, what exists for the tertiary level instructors are short in-service workshops and in absence of requisite policy support, ICT integration at this level is largely left to individual instructors (Dettori & Forcheri, 2003) unlike in K-12. Besides, one-time workshops or hands-on training programs are insufficient to develop instructor's design abilities (Conole & Alevizou, 2010; Lakkala & Ilomaki, 2015). This is because instructors need to iteratively work on their activity designs with ICT which demands sustained mentoring (Lakkala & Ilomaki, 2015).

(c) Most of the solutions assume high level of technology access in classrooms

The existing solutions, whether they are taxonomies, teaching principles and best practices or, training programs, assume an instructional context where learners can directly manipulate the ICT tool. Most existing studies refer to technology-rich classrooms where learners have 1:1 access to the ICT tool (Koh, 2013; Barak, 2007; Naps et. al, 2002). However, in many developing countries where ICT integration is being promoted, this is not the case. In India and many parts of the developing world, the technology use in classrooms are instructor-mediated i.e. learners do not have direct access to the tool. Their interaction with the tool has to be necessarily mediated through the instructor (Banerjee et.al, 2015). In such classrooms, instructors' ability to design student centered activities with ICT becomes crucial.

Hence, an effective solution for tertiary level instructors will be one that will guide them to seamlessly translate existing theories on teaching with ICT into their teaching practice. A solution that will provide them with scope to iteratively develop their design practice and accommodate the challenges of instructor-mediated classrooms. Learning Design

(LD) frameworks and tools evolved to assist instructors to bridge this gap between educational theory and their teaching practice (Laurillard, 2012).

2.3 Activity design focused solutions for ICT integration

The LD frameworks provide guidelines to help instructors take theory-informed design decisions for different stages of the LD creation process. Majority of the LD tools are digital extensions of the existing LD frameworks like the Learning Designer tool is based on the Conversational framework. These tools help in creation of LDs by providing scaffolds both at the conceptual level as well as implementation design level. Examples of the implementation design level scaffolds are LD layout template or pie charts showing distribution of active learning activities designed for a course. The end product from both LD frameworks and tools are LDs which are defined as a description of “the learning activities and the support activities that are performed by different persons (learners, instructors) in order to achieve the required learning objectives. It is based on the metaphor of learning as a play instantiated through a series of acts with associated roles and resources” (Conole & Fill, 2005).

2.3.1 Learning Design Frameworks

There are but a few LD frameworks developed to guide instructors’ design of the learning experience with ICT tools. The foremost of them are Conversational Framework, 7C Framework, ISiS Framework and Smart LD Framework which are presented below. The Conversational framework (Laurillard, 2012) provides guidelines on designing learning experience of students for different types of ICT such that it leads to deep-level learning. The guidelines are at two levels – (i) cognitive level and (ii) behavioral level. At the cognitive level, the framework specifies the superset of dialogs (conversation) that should take place between the instructor and the student and in what sequence when teaching (Fig. 2.2: Steps 1-4). For example, teacher (T) will describe a concept (Step 1), then student (S) will explain it back to the instructor (Step 2). The teacher will spot the inaccuracies in student description and explain further (Step 3) and student will re- describe the concept back to the instructor

correcting the inaccuracies (Step 4). To operationalize these into the design process, the framework specifies the behavioral levels (Fig. 2.2: Steps 6-9). For example, instructor should define the learning objectives (Step 6), the student then does an activity to meet the learning objective (Step 7) and so on. Given the type of ICT (narrative, interactive, communicative, adaptive and productive) chosen, the framework specifies the ideal set of cognitive and behavioral set of conversations to design for.

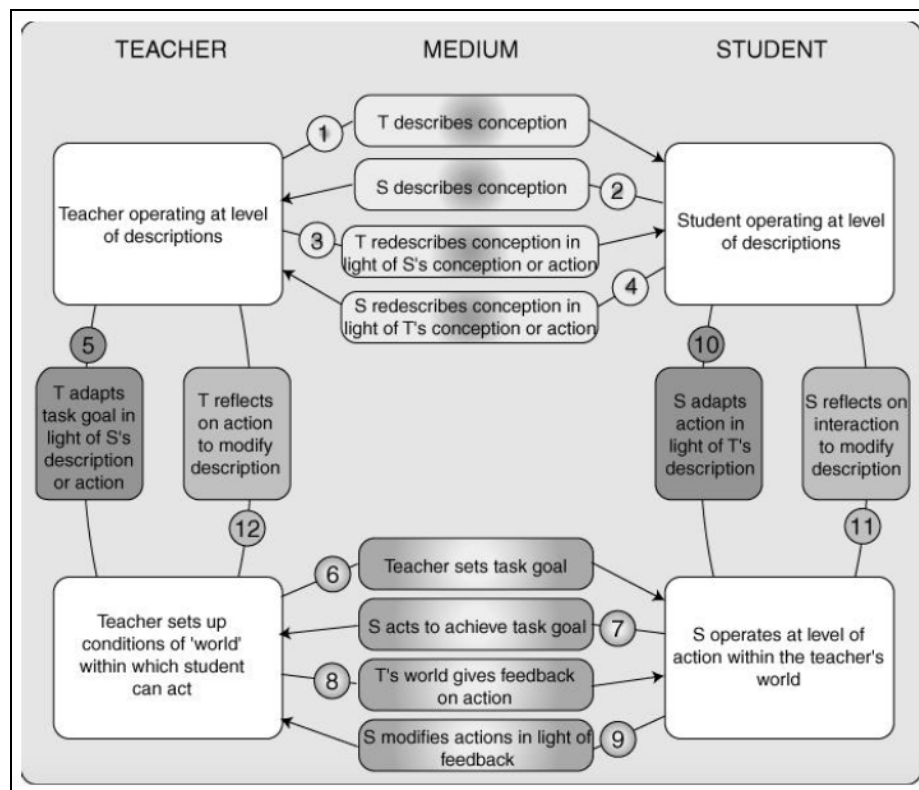


Figure 2.2: Functioning of Conversational Framework (Laurillard, 2012)

The 7C framework (Conole, 2014) guides instructors through a four-phase learning design creation process – Vision, Activity designing, Synthesis and Implementation and provides pointers for design decisions at each phase. In phase – 1 comes the first C i.e. Conceptualize. Instructors are asked to decide – a) Why, Who and What you want to design? , b) The key principles and pedagogic approach they want to adopt (constructivist, collaborative, didactic, inquiry based, problem based, situative, dialogic, authentic, case based, vicarious) and c) the nature of the learners. Instructors can access a database of principles (e.g. Aesthetic, sustainable, community based, theory based, practice based etc.)

and pedagogic approaches to choose from. In Phase – 2, instructors are similarly guided to Capture (decide the interactive learning material to use), Communicate (mechanisms to foster communication), Collaborate (mechanisms to foster collaboration) and Consider (activities to promote reflection and enable assessment) to design the activities. In Phase-3, instructors take design decisions on Combine (combining the activities to give a holistic overview of the design and associated learning pathways) and finally, in phase – 4, Consolidate (in terms of running the design in a real learning context, evaluating, refining and sharing the design) (Fig. 2.3). The aim of these design decision scaffolds is to enable instructors to create a pedagogically informed LD for effective technology integration. The framework guides the instructor through different steps of the LD creation process. At each step it scaffolds the instructor to take theory-informed design decisions and challenges them to think beyond the traditional instructor-directed pedagogy. However, the operationalization of the design decisions is left to the individual instructors. For example, 7C framework provides the guideline ‘Map learning outcomes to assessment’ but does not specify how instructors are to achieve this.

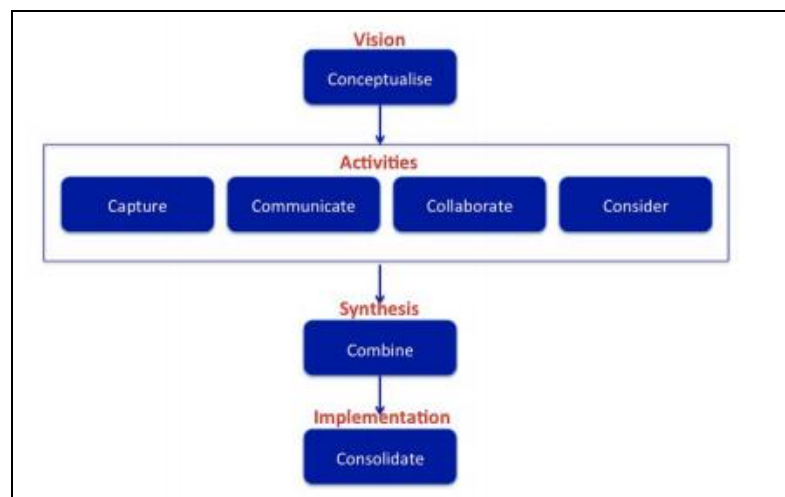


Figure 2.3: The 7Cs Learning Design Framework (Conole, 2014)

Another LD framework, the ISiS framework (Emin et.al, 2010) divides the LD creation process into three levels: i) Intention level (I) where instructors decide their learning goal in terms of which competencies or misconceptions to be targeted for e.g. learners should have ability to ‘work in a collaborative way’ or ‘manage knowledge and capacities acquired’ or ‘resolve a problem based situation’, ii) Strategic level (S) where instructors decide the

teaching method to implement to achieve the objective specified at the Intention level like PBL strategy or Scientific Investigation strategy and iii) Interactional Situation level (iS) where instructors define the set of interactions that would take place between the instructor, student and the digital resources to operationalize the chosen strategy. It follows a patterns based approach to design learning scenarios that can be shared and reused among the teaching community. This approach is driven by intentions and strategies. The instructor chooses their intention like resolving a misconception and then specifies its properties (Fig.2.4a). Next, instructor selects a strategy from the array provided by the framework like ‘Scientific Investigation’. The framework informs the instructor of the four stages of this strategy - making hypothesis, solution elaboration, hypothesis testing and conclusion (Fig. 2.4b). Again, if intention selected is students should work collaboratively, then the strategy suggested is ‘Elaborating a proposal by making a consensus’. This strategy is further divided into two sub-stages – ‘Make individual proposals’ and ‘Make a consensus proposal’. In the third stage of LD creation, instructors detail out the interactions situation. They define resource to be used, for whom tool to be used, by whom and in what location.

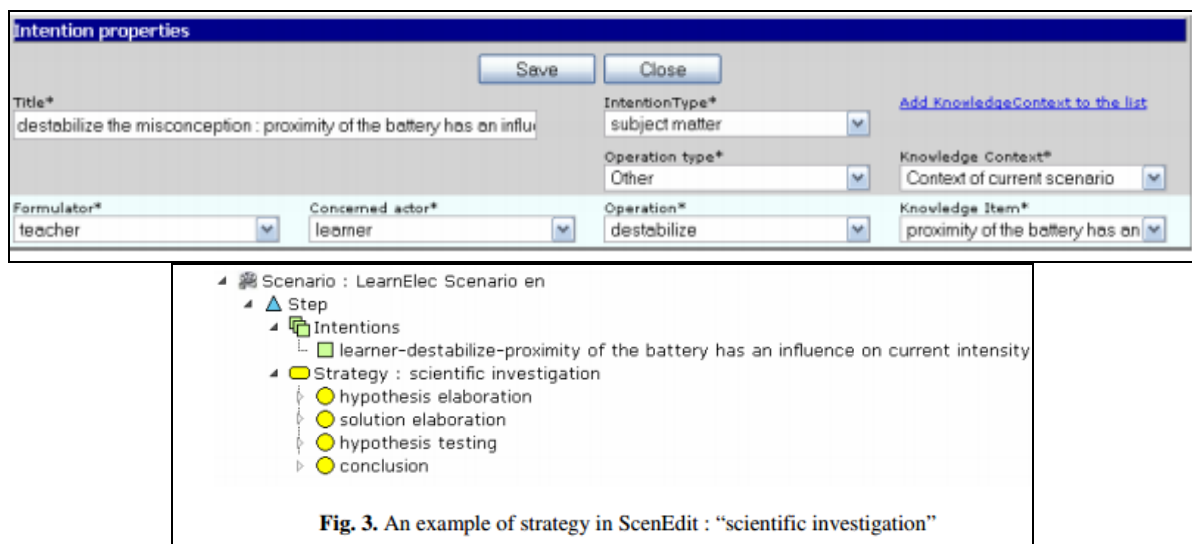


Figure 2.4: Examples of (a) intention and (b) strategy in ScenEdit (Emin et.al, 2010)

The Smart Learning Design Framework (SLDF) (Lukasiak et.al, 2005) provide support for creation of LDs that are pedagogically sound and also interoperable across different standard compliant platforms. It guides instructors on (a) selecting and adapting LDs to the instructor’s context, (b) selecting and aggregating learning objects compatible with the chosen

LDs and (c) packaging the LD in standard technical format that conforms to international e-learning standards on metadata and IMS-LD. The framework notifies instructors if there is a mismatch between pedagogical metadata of the LD and the learning object selected. The LDs in this framework are specific to established active learning strategies like Predict-Observe-Explain (POE) LD. The LD is described in terms of resources, tasks and supports needed. Detailed pedagogical guidance like how to frame the POE questions and answer options are not provided (Fig.2.5)

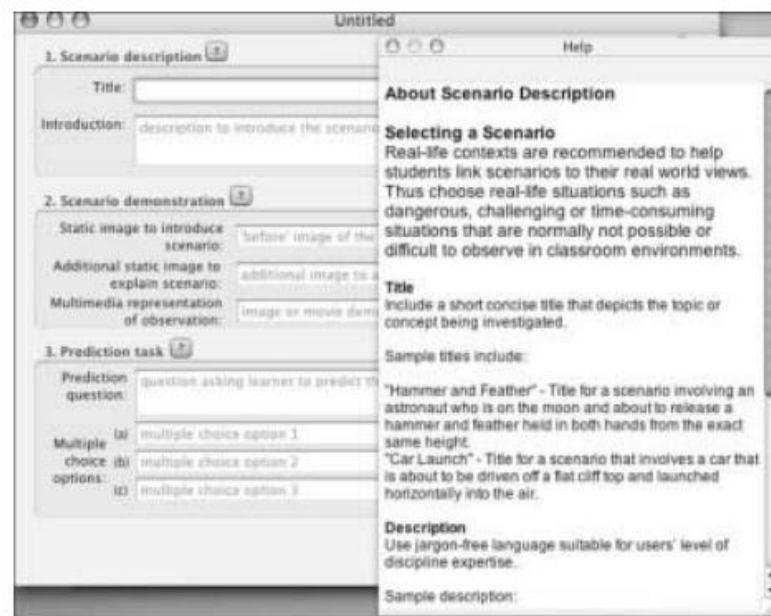


Figure 2.5: Sample pedagogical support in SLDF for a chosen LD (Lukasiak et.al, 2005)

2.3.2 Learning Design Tools

Each of the above frameworks have been operationalized into LD tools to help instructors author effective LDs. For example, Learning Designer is based on the Conversational framework (Laurillard, 2012), LD toolkit incorporates 7C framework (Conole, 2014), SMART tool (Lukasiak et.al, 2005) based on the SLDF and ScenEdit on ISiS framework (Emin et.al, 2010). The type and degree of pedagogical scaffolding provided varies from tool to tool. The type of scaffolding provided by LD tools is either at the conceptual model level (Learning Designer) or at the flow model level (OpenGLM) or both (CADMOS).

The degree of scaffolding ranges from being open-ended (Learning Designer) to prescriptive (ScenEdit). For example, the Learning Designer offers intelligent guidance through wikis on the different types of active learning strategies that instructors can use. Instructors can then take an informed decision on which strategy to adopt to design their activity. It also provides visual analytics in form of a pie chart on the percentage of different categories of learning types used in the LD. Learning Designer accommodates six categories of learning types like read-watch-listen, collaborate, discussion, investigate, practice or produce. In comparison a tool like ScenEdit takes the instructor’s learning goal and presents a pedagogical pattern to achieve that goal. A detailed comparative analysis of a subset of six such LD tools is presented in Chapter 8.

2.3.3 Comparative analysis of LD frameworks

LD frameworks address the gap of aiding instructors to translate appropriate teaching theories into practice. In fact, the few LD frameworks that exist provides a resource base to instructors to design theory-informed LDs. Table 2.1 presents a comparative analysis of the LD frameworks existing along dimensions like setting targeted, degree of guidance that will help us in developing a solution relevant for our context i.e. tertiary level instructors in instructor-mediated setting.

Table 2.1: Comparative Analysis of LD Frameworks

<i>LD Framework</i>	<i>Setting Targeted</i>	<i>Degree of guidance</i>	<i>Affordance exploitation</i>	<i>Functioning of framework</i>	<i>Evaluation Result</i>
Conversational	Online, Students directly controls tool	Broad. E.g. Specifies learning activity should be aligned to objective. But does not specify how to operationalize alignment	Specifies cognitive and behavioral interactions between student & teacher mapped to group of ICT tools	Focused on mapping between types of media and the dialog set and behavior of instructor & learners	Used by researchers But instructor evaluation result not reported
7C	Same as above	Broad E.g. Informs instructor of importance of aligning assessment questions to objective. No guidance on how to achieve it.	Agnostic to tool affordances	Takes the instructors through the 7 components of the LD process	No evaluation result reported

<i>LD Framework</i>	<i>Setting Targeted</i>	<i>Degree of guidance</i>	<i>Affordance exploitation</i>	<i>Functioning of framework</i>	<i>Evaluation Result</i>
SLDF	Same as above	Comparatively less broad. E.g. Provides pedagogical patterns mapped to selected learning object like visualization, ppt. No guidance on framing activity question or operationalize alignment.	Uses metadata of learning objects to suggest learning objects suitable for a particular LD	Integrating learning objects with learning designs based on metadata	No evaluation result reported
ISiS	Blended, assumes learners have direct access to ICT	Comparatively more specific. E.g. for objective = Scientific investigation, gives overall cognitive structure for the LD. But no guidance on what student should do or what type of guiding questions to ask to achieve objective.	Agnostic to tool affordance	Takes intention (objective) & suggests a broad strategy. Then provides a pedagogical pattern (interactional situation) for LD	Instructor interviews capturing secondary school instructors' perception of usefulness

The comparative analysis of the LD frameworks reveal the following gaps (Table 2.1) that are pertinent to the thesis context of tertiary level instructors teaching using visualization in instructor-mediated classrooms.

(a) Context of instructor-mediated classrooms not addressed

The instructional setting targeted by majority of the LD frameworks like Learning Designer, 7C, SLDF and the LD tools is the online setting. Only the ISiS framework targets the blended setting. The underlying assumption of all the LD frameworks and tools is a technology rich classroom context. They assume there is 1:1 interaction of learners with the technology tool. They do not address the challenges of executing student-centered teaching in instructor mediated classrooms. However, these are the type of classrooms common in India and many parts of the developing world. In these classrooms, it is the instructor who controls the manipulation of the tool. Learners do not have direct access to the tool in the classroom. Hence, with none of the LD frameworks or tools addressing this context, instructors in such settings lack the guidance that would enable them to design effective learning activities and frame activity questions with visualizations.

(b) *Level of guidance provided*

LD frameworks and tools face the challenge of striking a fine balance between being open-ended and being rigid templates in order to enable instructors to design effective LDs with ICT tools (Bennett et.al, 2015). As a consequence, majority of the existing framework guidelines are at a broad level. For example, frameworks like the Conversational and 7C inform the instructors of the importance of constructive alignment. But they do not provide guidelines on how to achieve the alignment, let alone how to achieve it with affordances of their chosen ICT tool. SLDF suggests a strategy to operationalize the alignment between objective and the assessment question. However, it does not provide guidance on how to frame a constructively aligned question based on the ICT tool. Also it does not address alignment between the learning activity and objective. Thus these frameworks assume that instructors will have the requisite knowledge to expand these guidelines to their context and be able to create a theory-informed LDs. In comparison, ISiS gives guidelines on a generic set of cognitive steps to incorporate to achieve constructively aligned LD. However, specific guidelines on how to operationalize these cognitive steps is missing. For example, when objective is ‘Scientific Investigation’, ISiS assumes instructors would know what type of guiding questions are recommended by theory for the observation phase or how to exploit the affordances to achieve their objective. In context of the known design impediments like instructors unable to customize to their requirements (Schaffer et.al, 2011; Laurillard, 2012) or unable to utilize pedagogical tool affordances (Web & Cox, 2004), the existing guidelines may not be able to resolve instructor difficulties for tertiary level instructors. We have found from our studies with that they need guidelines at a more detailed level for appropriate operationalization of theory than what exists.

(c) *Few empirical studies with instructors*

Frameworks like the Conversational framework are important contributions in LD research. It synthesizes multiple learning theories to highlight the set of desired interactions and behaviors of both instructors and learners mapped to the different categories of ICT tools. It has been extensively used by researchers to design their learning environments. However, what is missing are usability and effectiveness results with instructors. Only ISiS framework provide some measure of effectiveness with instructors. It reports on usefulness and usability of the ScenEdit tool based on the framework with a small set of secondary school instructors

from France (Emin et.al, 2010). The existing frameworks have not reported large-scale usefulness and usability results of their guidelines. The effectiveness studies so far reported have been related to instructor perceptions of the benefits of framework use. Assessment of the impact of the framework on instructor's LDs has not been explored.

(d) Few guidelines on pedagogical utility of affordances

Except for Conversational Framework, all the other frameworks and tools are agnostic towards the role of affordance for specific tools. Conversational framework too does not focus on exploitation of affordances of ICT in order to design effective LD. This is perhaps because it aims to cover a wide range of tools rather than focus on one. It maps the type of instructor-student interactions possible for a given type of ICT. But instructors who are novice designers need guidance on how to exploit affordances of a specific tool in order to come up with an effective LD (Angeli & Valanides, 2009; Tsai & Chai, 2014). This is a notable gap since instructors are known to face difficulty in recognizing the pedagogical utility of tool affordances (Angeli & Valanides, 2009; Tsai & Chai, 2014).

2.4 Emergence of Research Objective

One of the barriers to effective ICT integration is instructors' inability to design student centered effective activities with ICT (Mishra & Koehler, 2006; Angeli & Valanides, 2009; Tsai & Chai, 2012). This has been termed as instructors' lack of design thinking (Tsai & Chai, 2014). In this thesis we target that aspect of design thinking that deals with the knowledge and skill required to 'enact a design process' (Huizinga, 2014). The knowledge required includes knowledge of content, learner, context and pedagogical affordances of ICT (Angeli & Valanides, 2009). In this thesis we refer to it as instructors' design expertise.

Further, when we consider the context in this thesis, i.e. instructor-mediated classrooms, existing solutions such as LD frameworks are not sufficient because they largely target online and blended settings (Bjaelde et.al, 2015), technology-rich classrooms and do not focus on pedagogical affordances of a specific ICT tool like visualization. Visualization is a widely used ICT tool especially in science and engineering domains (Rutten et.al, 2012; Guan et.al, 2009; Kehtarnavaz et.al, 2008). We have also found through a large-scale survey

of instructors that visualizations are one of the popular ICT tools used in our context. The setting of instructor-mediated classrooms poses additional challenge in designing effective activities with such visualization since students do not have 1:1 access to the visualization and have to interact with it via the instructor. Thus the research objective of this thesis is:

Develop a framework that will enable instructors to create effective, customized LDs for teaching using visualizations in instructor-mediated classroom setting

This LD framework should fulfil the following requirements:

- a) Be easily comprehensible to tertiary level instructors to customize application of existing theories to their context.
- b) Incorporate the challenges of instructor-mediated setting
- c) Guide in exploiting visualization affordances to create an effective LD.

The LD framework would be scoped to tertiary level science and engineering instructors teaching using visualizations. The types of visualizations to be addressed by the framework would be videos, animations and simulations. Therefore, the framework guidelines should include guidance on exploitation of the affordances for each of the different types of visualizations. The types of visualizations targeted are science and engineering experiment videos, animations and simulations. The LDs generated using this framework would focus exclusively on teaching-learning activities that involves visualization. The framework guidelines also need to be framed to override the constraints of an instructor-mediated classroom setting.

Chapter 3

Research Methodology

3.1 Introduction

Analysis of related work in Chapter 2 reveals that in spite of existing solutions like teaching principles and frameworks, instructor training programs, LD frameworks and tools, the problem of ineffective integration of ICT continues (Tsai & Chai, 2012; Bennett et.al, 2015). One of the contributory reasons is instructors' lack of design expertise. Thus the research objective of the thesis is to: Develop a framework that will enable instructors to create effective and customized LDs while teaching using visualization in instructor-mediated settings.

To address this objective, the overall solution approach will entail the following steps:
Step 1 - Identify design impediments faced by instructors particularly in the context of tertiary level instructors teaching using visualization in instructor-mediated classrooms. Currently this

is an open-question in LD research (Bennett et.al, 2015). Hence we need to design a qualitative study to identify the design impediments for our context. This will help specify the building blocks of the proposed framework. Thus the research question at this step corresponds to: What are the points in the LD creation process where instructors need support to design LDs for teaching using visualization? (RQ1).

Step 2 – Design the framework guidelines targeting these design impediments. The guidelines will evolve from analysis and synthesis of the diverse set of existing theories on teaching and learning.

Step 3 – Test prototype of the proposed framework with the intended user population i.e. instructors who teach using visualization in instructor-mediated classrooms. This will need both qualitative and quantitative studies to obtain formative feedback from the instructors for refining the framework.

Step 4 – Test the effectiveness of the developed LD framework with multiple stakeholders – instructors and students. This can involve both qualitative and quantitative studies. The set of research questions corresponding to this step will be:

- What is the effectiveness of CuVIS in improving instructors' TPACK to create effective & customized LDs with visualization? (RQ2.1)
- What is the impact of CuVIS on instructors' pedagogical practice exhibited through LD? (RQ2.2)
- What features of CuVIS scaffolds do instructors find effective in developing their design expertise for effective and meaningful LDs with visualization? (RQ2.3)
- What is the effectiveness of the CuVIS LDs on student learning with visualization? (RQ3)
- What is the instructor perception of the usefulness and usability of the CuVIS tool? (RQ4)

Thus, the research methodology required involves a mix of qualitative and quantitative studies, the findings of which will together address the research objective. The final outcome will be a framework that is customized to the context of instructor-mediated classrooms. It should be a practically viable solution. Hence, instructors should be co-participants at each phase of framework development.

3.2 Choosing a potential research methodology

There are two research methodologies that incorporates a mix of qualitative and quantitative studies – Mixed-method and Design & Development Research (DDR) methodologies. The mixed-method methodology is “a procedure for collecting, analyzing, and ‘mixing’ both quantitative and qualitative methods in a single study or a series of studies to understand a research problem” (Creswell, 2013). It is used when both qualitative and quantitative studies are needed to better comprehend the research problem and either one of them alone is not sufficient. However, mixed-method does not meet the other requirements of our desired methodology like generating a solution to a real-life problem which is practically viable in our research context and has been created through iterative feedback cycles involving the target users. All these requirements are satisfied by the DDR methodology.

DDR is defined as “a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories” (Wang & Hannafin, 2005). It has the following characteristics (Van den Akker et.al, 2006):

- a. Interventionist : Aspires to create an intervention for a real-life problem
- b. Iterative: Involves cycles of analysis, design and development, evaluation and revision.
- c. Practitioner involvement: The target user population is involved in all stages of the research
- d. Process oriented: Focus is on improving and understanding the intervention. A blend of both qualitative and quantitative research studies is needed.
- e. Utility oriented: Solution designed is contextualized. The research results are “connected with both the design process through which results are generated and the setting where the research is conducted” (Wang & Hannafin, 2005, p. 11)
- f. Theory-oriented: The solution design is based (at least partially) on existing theories and conceptual frameworks while ‘systematic evaluation of prototypes of the intervention contributes to theory building’. The theory-building can lead to one of the following three types of theories – Domain theories, Design framework, Design methodologies.

3.3 How my research problem fits into DDR

In this subsection we map the DDR features to the solution approach outlined above to illustrate the suitability of DDR methodology for our research context:

- a. Interventionist: We aspire to create an intervention for a real-life problem - lack of instructors' design expertise while teaching with ICT (Tsai & Chai, 2012).
- b. Iterative: Design and development of framework will involve iterative cycles of prototype testing with the target users i.e. instructors.
- c. Practitioner involvement: The user population of tertiary level instructors teaching in instructor-mediated classrooms will be a co-participant in each phase of framework development.
- d. Process oriented: Both qualitative and quantitative studies are required to build the framework.
- e. Utility oriented: The framework to be built will be contextualized to teaching using visualization in instructor-mediated classroom setting.
- f. Theory-oriented: The framework guidelines will evolve from synthesis of disparate streams of literature like cognitive science studies on the cognitive process learners follow to successfully achieve an objective, studies on pedagogical support and visualization affordances to aid this cognitive process. Of the three types of theory outcomes possible from DDR, our research outcome will be a design framework that will provide instructors with guidelines to design student-centred effective LDs for teaching with visualization.

3.4 Phases of DDR

The research methodology of DDR proceeds through three phases of Problem Analysis, Design and Development and Summative Evaluation (McKenney, 2001) (Fig. 3.1). This figure gives an overview of the DDR methodology though the detailing in the figure represents a specific instantiation of DDR carried out by McKenney (2001) for her CASCADE study. Hence, the details like the y-axis representing the number of participants and the number of pink loops representing the number of studies are specific to her

CASCADE study. In this section we explain those features of Fig. 3.1 that are inherent to every DDR methodology. The top row in the figure represents the three different phases whereas the bottom row indicates the objectives of the corresponding phase.

The research carried out in the three phases are:

- Problem Analysis Phase – The aim of this phase is to identify and analyze the problem in association with the instructors. The need analysis step involves literature analysis of the problem and the existing solutions (Fig. 3.1). This is followed by context analysis step wherein the problem is analyzed in the research context through site visits i.e. interacting with instructors in their teaching environment (Fig. 3.1).
- Design and Development Phase - In this phase, the contextualized solution is designed and developed through iterative cycles of formative evaluation of the prototype being developed. Each iteration is in itself a micro cycle of research aimed at improving the framework solution. Thus this phase takes up the maximum time among all the three phases. This is depicted in Fig. 3.1 where the x-axis represents the cycle width in relation to time demand of the phases.
- Summative Evaluation phase: The objective of the phase is to assess how well the solution developed addresses the identified problem. It is referred as a semi-summative phase as it may result in recommendations to improve the intervention further. Final evaluation leads to ‘systematic reflection and documentation’ by the researcher to formulate the theory outcome from the research like domain theories, design frameworks or design methodologies.

In Fig. 3.1 the white boxes shown represent the number of studies, with sample size for each that has been carried out in each phase of DDR in this thesis.

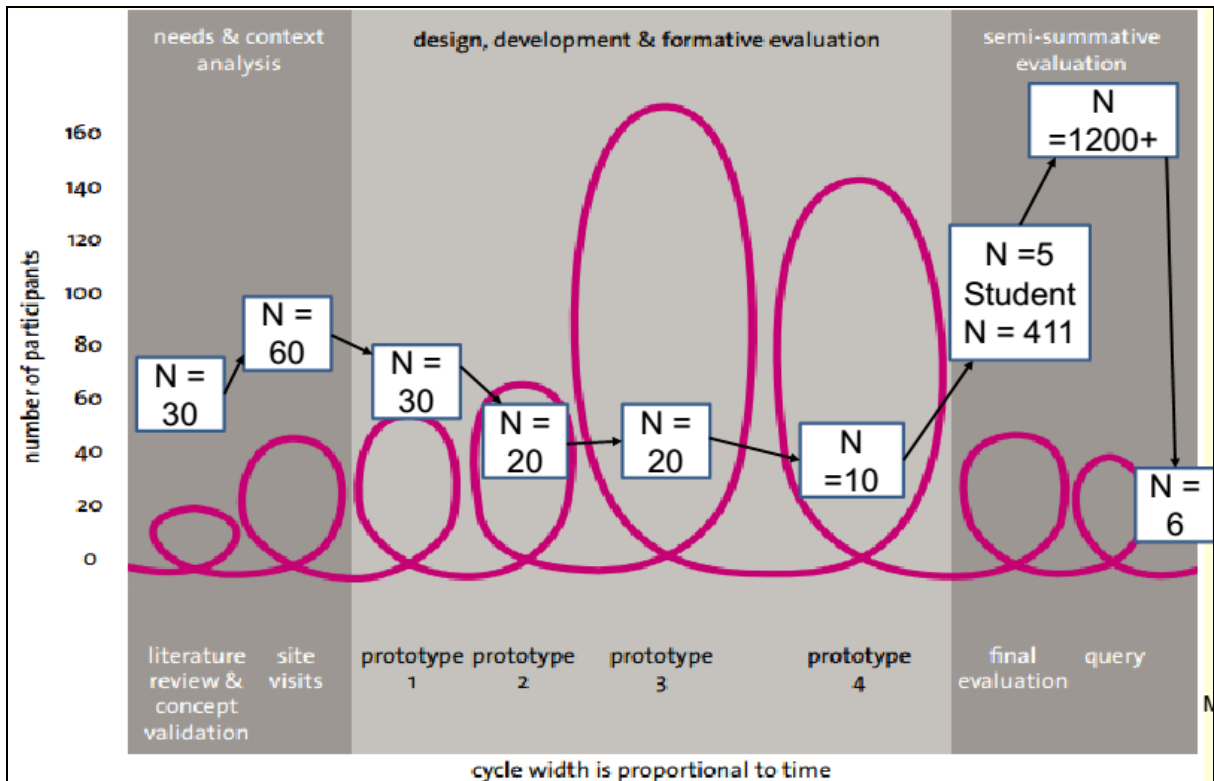


Figure 3.1: Design & Development Research Phases (McKenney, 2001)

The DDR implementation in this thesis is illustrated in Fig. 3.2. The figure shows our solution approach, represented by rectangular boxes and ovals, across the middle panel. The top grey panel represents the different DDR phases while the bottom grey panel shows the purpose of studies carried out in each phase of DDR, based on McKenney's (2001) representation of DDR. Thus, Fig. 3.2 illustrates the mapping between DDR phases and our solution approach. The following subsections describe qualitative and quantitative studies done in each of the phases leading to creation of the CuVIS framework.

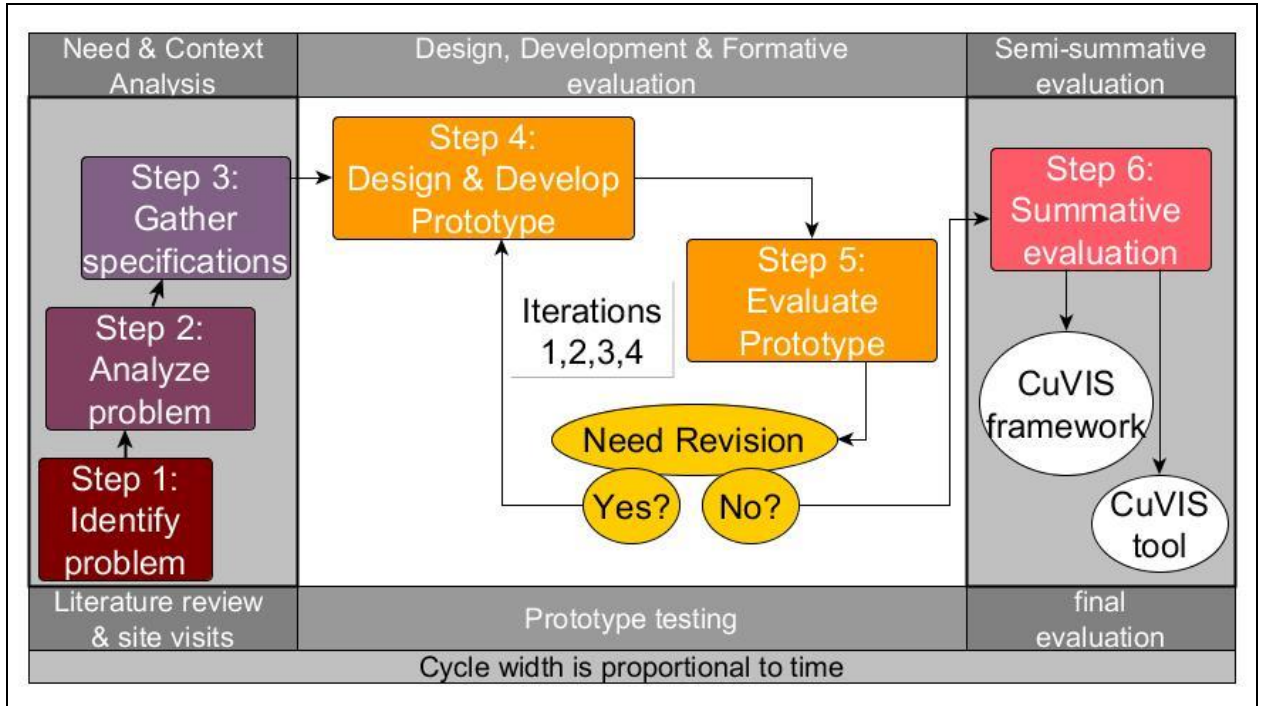


Figure 3.2: Design & Development Research (DDR) as implemented in this thesis [adapted from McKenney (2001)]

3.5 Sampling Process in different DDR phases

In this subsection we present the sampling process followed for the qualitative and quantitative studies in different phases of DDR (Fig. 3.3). The user population targeted by the framework was science and engineering instructors teaching using visualizations in instructor-mediated classrooms. The population accessible to us were science and engineering instructors undergoing the blended T10KT pedagogy workshops in India (Refer Section 1.1). Thus the sampling frame was the list of instructors from the 147 institutes all over India who were undergoing our blended pedagogy workshops. The sample size was 2010 science and engineering instructors. The probabilistic sampling strategy of stage sampling was used for all the qualitative and quantitative experiments with instructors in different phases of DDR, since the population was scattered over a wide geographical area (Cohen & Manion, 2010). As is typical of this sampling strategy, we went from a wide sample to a focused one in stages.

In stage 1, we looked at the demographic data of these 2010 instructors and extracted out a sampling unit of 1830 instructors who satisfied our set of parameters to ensure representativeness of the target population. The parameters were:

- (i) instructors should have attended a prior pedagogy training workshop that has exposed them to theory of active learning
- (ii) instructors should have taught with visualization in instructor-mediated classroom setting
- (iii) But are novice designers i.e. have not designed active learning activities using visualization for their class.

We contacted the head of the institution of these 1830 instructors for permission to access them for our research study. Once permission was obtained, we established email contact with the instructors stating our research purpose i.e. exploring their learning design creation process with a disclaimer that all the data generated by them will be used only for research purpose and they will remain anonymous. In stage 2, we divided the sampling unit of 1830 instructors into smaller units based on their domains i.e. different branches of science and engineering. We did simple random sampling within the domain units to get the sample for all the qualitative studies. The sample sizes for these qualitative studies depended on attainment of data saturation (Mason, 2010). For the quantitative survey experiment, we sampled all the instructors within each domain unit, if they satisfied the validity check of having uploaded a completed learning design assignment using the framework developed.

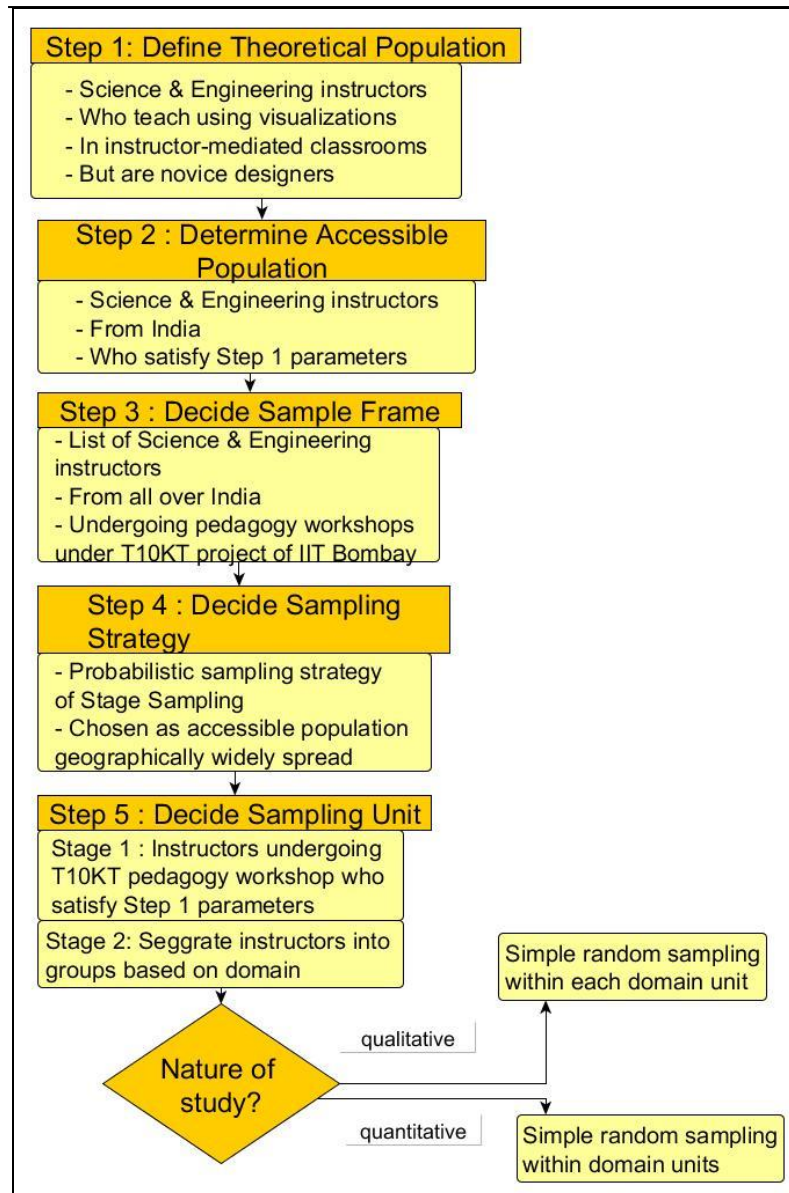


Figure 3.3: Sampling Process followed in different DDR Phases

3.6 Problem Analysis Phase

The problem of instructors creating ineffective LDs with visualization was identified from analysis of literature on teaching with ICT tools like visualization (Fig. 3.2, step 1). Next task was to identify the specific points in the LD creation process where our target instructors need help so that we could build a framework useful to them. The research question addressed in this phase is: What are the points in the LD creation process where instructors need support

to design LDs for teaching using visualization? (RQ1). Analysis of existing research studies presented in Chapter 2 reveals that the problems identified are: (i) Difficulty in customizing teaching principles and frameworks to their own context (Laurillard, 2012; Schaffer et.al, 2011) and (ii) Inability of instructors to perceive the pedagogical utility of tool affordances (Webb & Cox., 2004). To probe deeper into the design impediments faced by instructors, a qualitative study (Study-1) was conducted with 30 engineering instructors undergoing a 2-week blended pedagogy workshop. The research question that Study-1 answered is: What are the design impediments that instructors need help with? (RQ1). In the study instructors create LDs for teaching using visualization on a face-to-face learning scenario of their choice but no guidance is provided. Instructors are expected to apply the knowledge learnt in the workshop to design the LDs. These LDs are analyzed using inductive content analysis methodology to identify a list of problem points. The problem points or, design impediments identified are at the conceptual as well as implementation level. This study helps in identifying the specific design impediments that need to be addressed by the framework and is described in detail in Chapter 4. The identified impediments determines the building blocks of the framework.

The next step is to gather specifications for these building blocks from the instructors who teach using visualization in instructor-mediated classrooms (Fig. 3.2, Step 2). Thus, objective of Study 2 is to gather specifications for the building blocks of the framework. Semi-structured interviews are conducted with 28 science and engineering instructors who have taught with visualization before. The instructors are asked to show the visualizations they have used and how they have taught with them in different instructional settings. Analysis of the interview transcripts is done to arrive at the specifications like the different categories of objectives that instructors have while teaching using visualization. Study-2 has been described in detail in Chapter 4. Hence, at the end of the Problem Analysis phase, we have identified the design impediments that the framework should address, obtained the specifications for the building blocks of the framework from the target users themselves.

3.7 Design and Development Phase

In this phase, the framework guidelines are framed based on the specifications obtained from the Problem Analysis phase. The guidelines are created so that instructors can

design constructively aligned and meaningful LDs with visualization. They are mapped to learning objectives and accommodate the contextual specifications. To design the guidelines, a narrative literature analysis is done to summarize the interconnections between a disparate set of research articles (Baumiester & Leary, 1997) on teaching a particular objective. The interconnections identified form the foundation for framing the guidelines for teaching using visualization. The set of research articles include i) cognitive science studies that outline the cognitive process followed by learners to successfully attain a particular objective, ii) studies on pedagogical support and iii) visualization affordances that can facilitate this cognitive process. The synthesis of these three strands of research leads to creation of the Customized Visualization Integration System (CuVIS) framework.

We also look at different types of active learning strategies that have been successfully used with visualization to achieve a particular objective. The main purpose of this is to choose a research-evidence based strategy to design the classroom implementation. The CuVIS guidelines are iteratively tested with the target user population. The formative feedback received is used to refine the framework guidelines (Fig. 3.2, Step 4). Detailed explanation of this phase is given in Chapter 5. Acting on the formative feedback received from instructors during prototype testing of the framework, the CuVIS tool is built as digital interface of the framework. The design process for the tool is guided by existing design guidelines for LD tools (Chapter 8).

3.8 Summative Evaluation Phase

In this phase the effectiveness of CuVIS framework as well as that of the tool thereof is tested with science and engineering instructors (Fig. 3.2, Step-5). The impact of CuVIS framework on instructors' design expertise is evaluated through a semester-long qualitative study with six instructors from the domains of EE and CSE. The research question answered is: What is effectiveness of the CuVIS framework in developing instructors' design expertise for LDs? (RQ2). CuVIS impact on design expertise is assessed along three axes – i) their TPACK for designing effective LDs for teaching using visualization, change in pedagogic practice in terms of ii) time allocation for student-centered activities with visualization and iii) sequence of activities.

The instructors execute LD projects at three different time points with varying degrees of support with CuVIS intervention given only at the second time point. All three LDs created by each instructor are evaluated using a rubric based on Koh (2013) to capture evolution of instructors' TPACK for designing effective activities that are constructively aligned and supports meaningful learning. This study provides answers to sub-RQ 2.1: What is the effectiveness of CuVIS in improving instructors' TPACK to create effective and customized LDs with visualization? The LDs are also analyzed to record changes in pedagogical practice due to CuVIS, using the time allocation analysis (Kong et.al, 2011) and temporal sequence of activities analysis (Laurillard & Ljubojevic, 2012). The findings from this analysis answers sub-RQ2.2: What is the impact of CuVIS on instructors' pedagogical practice exhibited through LD?

The instructors in the study are also interviewed twice - after the first and third time points. Thematic analysis of the interviews is done to answer the RQ2.3: What features of CuVIS scaffolds do instructors find effective in developing their design expertise for effective and meaningful LDs with visualization? It helps identify design scaffold features that make them helpful to develop instructors' design expertise. The findings from this study contributes to LD research in the area of development of design scaffolds for instructors' design expertise. The details of the studies addressing RQ2 are presented in Chapter 6.

The selection criteria for instructors in this study were instructors who have attended our blended pedagogy workshop and had been able to produce LDs (not involving visualization) of reasonable pedagogical quality at the end of the workshop. This criterion ensured that instructors selected will be aware of the benefits of active learning. The instructors chosen were from the domains of EE and CSE since CuVIS framework guidelines contain examples from these two domains. The study was designed to be a qualitative one wherein we aimed at extracting rich data on effect of CuVIS on instructors' design expertise. We approached seventy instructors to participate in this semester long study. Sixteen instructors volunteered but the attrition rate was high. Only six of them went till completion. Each instructor had to create three LDs at three different time-points. Content analysis was done of each of these 18 (3x6) LDs analyzed along three dimensions to assess evolution of their design expertise with use of the CuVIS framework. These dimensions were (i) tracking their TPACK scores using a rubric, (ii) charting out the evolution in time allocation for student-centered activities through time allocation analysis technique and (iii) evolution in the

sequence of activities across a semester. In addition, each of the instructors were interviewed twice during the study. Thematic analysis of their interviews helped us in identifying the design features of CuVIS that the instructors found helpful in developing their design expertise. Studies that involve multiple methods (like LD analysis for TPACK assessment, time allocation, sequence of activities and interviews) or studies that require application of one method (like LD analysis along three dimensions or interviews) multiple times on the same participant require fewer participants (Mason, 2010). The guiding principle of sample size in such qualitative studies is saturation i.e. when data do not provide any new information (Mason, 2010). Since we found improvement in design expertise along all the three dimensions for all the instructors who completed the study, we settled with the sample size of six that we obtained.

The impact of the framework on student learning is assessed through three post-test only control-group field experiments. The corresponding research question targeted is: What is the effectiveness of the CuVIS LDs on student learning with visualization? (RQ3). The sample size of students involved are 375. The LDs used with the experimental group are generated using the framework and covered the topics of Signal Transformation (EE) and Pointers (CSE). The LDs used with the control group are the LDs used traditional by the instructor. These experiments are described in detail in Chapter 7.

The usefulness and usability of the CuVIS tool is tested with science and engineering instructors from multiple domains like Electrical, Computer Science, Mechanical, Civil, Chemistry, Physics and other domains through quantitative surveys. The corresponding research question (RQ4) is: What is the instructor perception on usefulness and usability of CuVIS tool? Instructors respond to the surveys after using the CuVIS tool to design an LD. The usefulness questionnaire, based on the TAM survey (Davis, 1989), is responded to by 1219 instructors. The usability testing based on the SUS survey (Brooke, 1996) was responded to by 1290 instructors. The data analysis and results of these large-scale surveys are presented in Chapter 8.

3.9 Summary

A summary of the research questions answered in each phase of DDR in this thesis work along with the research design and sample size for the studies and experiments conducted in each phase is given in Table 3.1. The research studies and experiments conducted involve probabilistic stage sampling technique.

Table 3.1: Overview of research work done in different phases of DDR

<i>Goal of study/ experiment</i>	<i>DDR Phase</i>	<i>Research Question</i>	<i>Research Design</i>	<i>Sample size</i>
Study 1 – Identify design impediments instructors face in our context	Problem Analysis	What are the points in the LD creation process where instructors need support to design LDs for teaching using visualization? (RQ1)	Qualitative study involving inductive content analysis of unguided instructor LDs for teaching with visualization	30 science & engineering instructors who have taught with visualization
Study 2 - Gather specifications for building blocks of framework			Qualitative study involving inductive thematic analysis of semi-structured interviews	28 science & engineering instructors who have taught with visualization
Study 3 – Evaluate CuVIS impact on instructors' design expertise	Summative Evaluation Phase	a) What is the effectiveness of CuVIS in improving instructors' TPACK to create effective & customized LDs with visualization? (RQ2.1) b) What is the impact of CuVIS on instructors' pedagogical practice exhibited through LD? (RQ2.2)	Instructors create LDs at three different time points with CuVIS intervention only at 2nd time point. a) Evaluate all three LDs based on a TPACK rubric for designing constructively aligned, meaningful LDs b) Evaluate pedagogical practice through time allocation (Kong et.al, 2011) & sequence of activity analysis (Laurillard & Ljubojevic, 2011) of LDs	Six engineering instructors (EE & CSE) who have taught with visualizations but are novice designers
Study 4 – Identify features of CuVIS scaffolds that helped improve instructor design expertise		What features of CuVIS scaffolds do instructors find effective in developing their design expertise for effective and meaningful LDs with visualization? (RQ2.3)	Qualitative study involving thematic analysis of semi-structured instructor interviews	
Experiment 1 – Evaluate effectiveness of CuVIS LDs on implementation with students		What is the effectiveness of the CuVIS LDs on student learning with visualization? (RQ3)	Post-test only control group field experiments. Visualization used, topic taught & instructor for both groups. Only the LD implemented differs.	375 engineering students (EE & CSE)
Experiment 2 – Test usefulness & usability of CuVIS tool		What is the instructor perception of the usefulness and usability of the CuVIS tool? (RQ4)	Instructors respond to surveys after using CuVIS tool a) TAM usefulness survey b) SUS usability survey	1422 (usefulness) & 1290 (usability) multi-domain instructors

3.10 Ethical Considerations

The following ethical considerations are followed since the experiments involved human participants (Cohen, Manion & Morrison, 2000):

(a) Informed consent

Instructors are informed about the research design of control-group experiments. It is stressed that students in both groups will get the same learning material and instructor. Only the instructional strategy will differ. All other misgivings are addressed in a meeting between the instructor, researcher and in two cases, the academic unit head in the institute. An informed consent form is signed by the instructors before the qualitative studies and experiments.

Informed consent is taken from the students in the control-group experiments in writing. They are free to opt out of the experiment at any point of their choice. The consent form contains purpose of the experiment with contact details of the researcher and the researcher's affiliation. They are free to contact the researcher for further clarification.

(b) Anonymity and confidentiality

Instructors are assured that they will not be identified and all the results of the experiments will be used purely for academic purposes. Nor will their institutes be identified. Similar assurance is given to the students. They are also assured that their post-test marks will in no way affect their college grades.

Chapter 4

Problem Analysis and Specification Gathering Phase for CuVIS framework

4.1 Introduction

Customized Visualization Integrations System (CuVIS) framework was built through five iterative cycles following the DDR research methodology. The current chapter presents the problem analysis and specification gathering phase for CuVIS framework. To address the broad research goal of developing a framework to enable instructors to create effective, customized LDs with visualizations, the first step was to identify problem points in the LD creation process. Thus RQ1 was: “What are the points in the LD creation process where instructors need support to design LDs for teaching with visualizations? It was answered through Study 1 with the objective of identifying design impediments faced by instructors. It was a qualitative study with 30 instructors drawn from the target user population of science

and engineering instructors who teach with visualizations in instructor-mediated classrooms. Also, these instructors are novice designers. The LDs created as part of the two iterations with varying degrees of support were analyzed to locate design impediments. The results of the LD analyses also helped determine the building blocks of the CuVIS framework. Figure 4.1 below gives an overview of the research question addressed and the solution approach for this phase of framework development.

The next step was to gather specifications for the building blocks of the CuVIS framework. It was collected through analysis of semi-structured interviews with a separate set of 28 instructors drawn from the same user population. In the sections below, the research methodology adopted to answer the research question and the findings obtained thereof are given in detail.

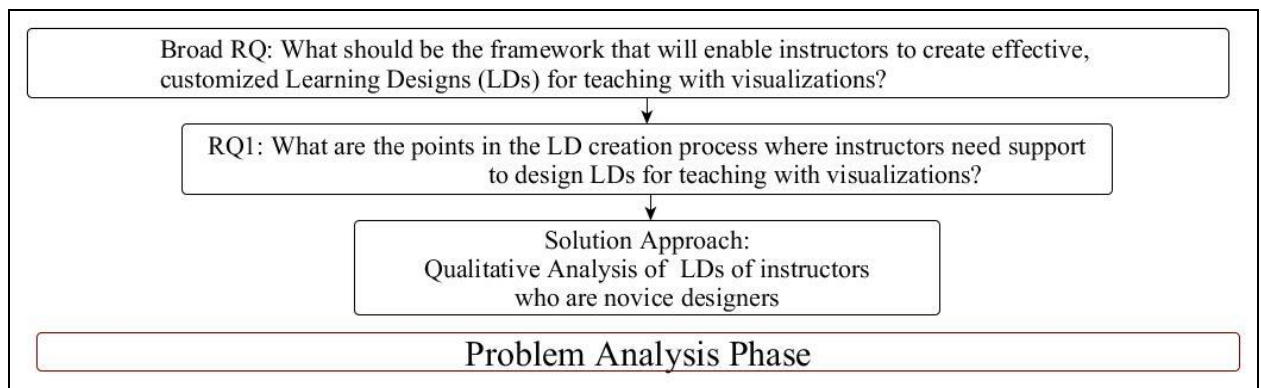


Figure 4.1: Research Question in ‘Problem Analysis’ Phase

4.2 Identifying design impediments in the LD creation process

Prior studies have identified factors that influence instructors’ design decisions when planning activities with ICT tools (Sec. 2.3). These factors are instructors’ pedagogical belief (Tsai & Chai, 2012; Bennett et.al, 2015), their perception of student characteristics (Bennett et.al, 2015) and their context like resource availability (Tsai & Chai, 2012), demand of completing the syllabi within stipulated time (Lim & Chai, 2003), class size, non-academic workload (Bennett et.al, 2015) among others. Also literature reports two design impediments faced by instructors in the design process – (i) instructors find it difficult to customize existing

teaching principles to their own context (Laurillard, 2012) and (ii) instructors are unable to perceive pedagogical utility of the tool affordances to design student-centered activities (Web & Cox, 2004). However, identification of design impediments remains an open question in LD research (Bennett et.al, 2015).

With this backdrop, the aim of Study1 was to identify the design impediments faced by instructors teaching in our research context. It addressed the research question ‘What are the points in the LD creation process where instructors need support to design effective and customized LDs for teaching with visualization?’ (RQ1). This was answered through a qualitative study involving inductive content analysis of unguided instructor LDs for teaching with visualization.

4.2.1 Study 1: Sample Criteria and Characteristics

The sampling strategy employed to draw sample from our accessible population was stage sampling (Refer Section 3.5). In stage 1, those instructors were shortlisted who satisfied the parameters for representativeness – (i) science and engineering instructors who have taught using visualizations in their instructor-mediated classrooms, (ii) who have attended pedagogy training workshop focusing on active learning, (iii) but are novice designers. In stage 2, these instructors were grouped into sample units based on their domains. In stage 3, we employed simple random sampling strategy to draw sample from the EE and CSE sample units. The sample size for this qualitative study was determined by data saturation. This was achieved with 30 engineering instructors (Male = 11; Female = 19) from EE (N = 16) and CSE (N = 14). Their teaching experience ranged from 5 -15 years and they hailed from cities (N = 18) and towns (N = 12) across India. These instructors had attended a 2-week blended pedagogy workshop prior to the study. Through this workshop, they learnt about learning objectives, importance of constructive alignment, choosing appropriate visualizations for their objectives, designing collaborative student activity, type of teacher-student dialogs that are recommended and other teaching principles. Such a sample was chosen so that the focus of the study could be on their application of knowledge to create LDs with visualization. The instructors were however novice designers.

4.2.2 Study 1: Methodology

The three-step methodology of inductive content analysis (Elo et.al, 2008) consisting of Preparation phase, Organization phase and Reporting phase (Figure 4.2) was chosen to identify the design impediments. This methodology was chosen to answer RQ1 since content analysis probes deeper than the surface to identify latent variables (Koehler et.al, 2007).

In the Preparation or data collection phase, instructors were given an open-ended design project to execute. They were advised to use student-centered, constructivist strategies to design activities with visualization. It was assumed instructors would be able to take theory-informed design decisions and apply the knowledge and practice acquired in the workshop to create an effective LD. This was akin to the frameworks that inform the instructor of the existing theory like 7C but leaves the operationalization open to the instructors. They choose a learning scenario for a face-to-face setting and create an LD for teaching with visualization. They were given two weeks to choose a topic, find an appropriate visualization from the internet and create the LD for face-to-face classroom setting. They were given a list of repositories of well-designed visualizations as reference like PhET, OSCAR, Wisconsin Online, Learning about Electronics. They were not provided with any guidelines.

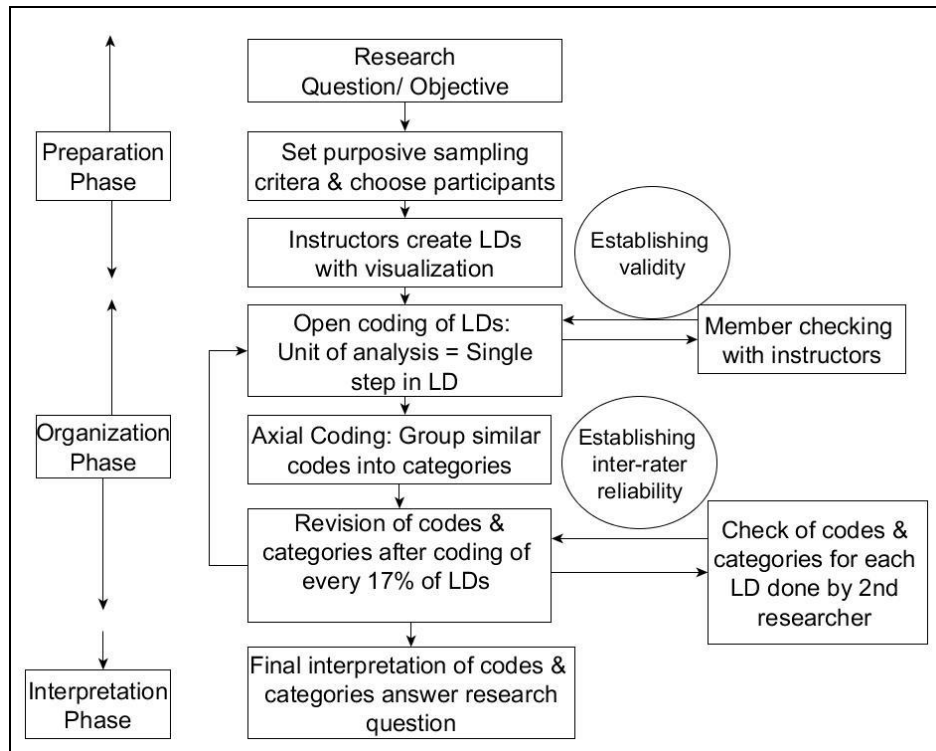


Figure 4.2: Inductive Qualitative Content Analysis Methodology of Study1

The only support provided in this study was an LD table that outlined the layout in which the LDs were to be created (Fig.4.3). This was necessary to capture the nuances of instructors’ design since instructors are not accustomed to planning in detail (Lim & Hang, 2003). Therefore, the layout prompted instructors to organize their LD in a sequence of steps with time duration and the role of instructor, student and visualization affordance specified for each step.

Step No.	Time Chunk(mins)	What Instructor Does	What Student Does	Visualization feature used, if any	Add Row
	Select mins			Select	Delete Row

Figure 4.3: CuVIS LD table layout

4.2.3 Study 1: Data Analysis

In the Organization or Data Analysis phase, the design impediments were abstracted from the LDs into categories through the process of open coding and axial coding (Cohen et.al, 2010). Each row of the LD table was taken as the unit of analysis. The coding process was iterative and proceeded in stages. The data set was revisited multiple times to refine the codes. Member checking was done with each instructor via e-mail to confirm the researcher’s interpretation of the units of analyses. The coding of LDs was stopped when no new codes emerged. An example of the coding methodology followed is illustrated in Table 4.1. The coding was done by two researchers in parallel and the inter-rater reliability was given by unweighted Cohen’s kappa = 0.81. Table 4.2 presents the set of axial codes that emerged identifying the specific problem points in the LD creation process where instructors needed help.

Table 4.1: Illustrative example of coding methodology followed for LD analysis

<i>From Instructors’ LD (quote)</i>				<i>Open Code</i>	<i>Axial Code</i>
Instructor does: ‘Show activity question: Draw the graph of T _c , H _c , and J _c . And name the regions on it. – Ask students to Think for 3 mins. Ask students to discuss with peer – 2 min. Discuss solution – 5 mins.’				Activity question not properly framed as per strategy protocol	Design implementation of active learning strategies
Time (min.)	Instructor does	Student does	Affordance used	‘What students should do’ not adequately specified	
4	TPS activity – What is IDSS? Give the value of IDSS from the animation.	2 mins. for individual thinking 1 min. for pairing 1 min. for sharing	Slider		

Table 4.2: List of codes & categories emerging from instructor LD analysis

<i>Sr. No.</i>	<i>Open Code</i>	<i>Axial Code (Categories)</i>
1	Learning objective framed correctly	Operationalize constructive alignment
2	Teaching-learning activity not mapped to objective	
3	Activity question not mapped to objective	
4	Time allotted for instructor-directed activity with visualization (Active Learning)	Operationalize meaningful learning with ICT

<i>Sr. No.</i>	<i>Open Code</i>	<i>Axial Code (Categories)</i>
5	Time allotted for student-directed activity with visualization (Active Learning)	
6	Real Life Application of topic (Authentic)	
7	Promoting self-diagnosis by students (Intentional)	
8	Active synthesis of knowledge gained from visualization by students (Constructive)	
9	Group activity (Cooperative)	
10	Not using visualization content to design group activity	Frame group activity questions based on visualization
11	Not exploiting visualization affordances to design group activity	
12	Activity question not properly framed as per strategy protocol	Design implementation of established active learning strategies
13	Inadequate specification for what students should do	

4.2.4 Study 1: Results

This subsection presents the design impediments emerging from analysis of instructor’s unguided LDs. 93% of the instructors are unable to create effective, student-centered LDs with visualization. The design impediments identified were:

(i) *Operationalizing constructive alignment:*

Biggs (1996) states that for effective learning to take place: (a) the teaching-learning activity designed with constructivist pedagogy should align to the stated objective and (b) the assessment question should also align with the objective. The criteria to assess if the activity aligns with the objective is that the activity follows the established cognitive process that learners are known to go through to successfully achieve that particular objective. For example, if objective is related to improving learner’s prediction skill, then the activity should have steps that prompt learners to first identify the causal relationship between variables and then develop a mechanistic model of the system through reasoning (Jonassen & Ionas, 2008).

During analysis of the unguided LDs, it was found that problem arose in alignment of both the activity designed and the activity question. 93% of the LDs have a teaching-learning activity that did not map to the cognitive requirement of the objective. An example of this problem is given in Table 4.3 Row 1. For example, instructors would have a Prediction

objective but the teaching-learning activity would not conform to the cognitive process established in literature for this objective. Again, 62% of the instructors could not frame activity questions aligned to their objective with visualization. Example of this error found in our analysis was instructors defining learning objective at the Understand level but framing the activity question at Apply level and vice versa. For example the objective stated was – ‘Students should be able to describe the working of step up chopper’ but the corresponding activity question constructed was ‘What will happen if the switch is turned off?’ Again, in some cases the objective was at conceptual understanding level but the activity question designed had an inquiry-driven pedagogy at the analyze level (Table 4.3 Row 1).

Table 4.3: Design impediment points where instructors need help

<i>Design impediment identified: Instructors unable to</i>	<i>At the level of :</i>	<i>Example</i>
(i) Operationalize constructive alignment	a) Activity question not mapped to objective b) Teaching – learning activity not mapped to objective	a) Objective = Explain the working principle of D.C. motor. The activity question was – ‘Discuss your interpretation of the working of DC motor (with your group) after watching the animation’. b) Objective = Predict what happens if, but learning activity designed does not contain activities that asks students to do both identify the causal relationship + create a mechanistic model of the system with reasoning, as is prescribed in cognitive theory for this objective.
(ii) Operationalize Meaningful Learning dimensions	LDs not being student-centered, constructive, cooperative, does not include real-life application nor promotes student reflection involving visualization	a) LD uses visualization only for instructor lecture. Students not doing any activity with the tool b) No activity designed where students do the meaning making themselves through use of visualization c) Individual student activity designed with the visualization but no group activity designed.
(iii) Frame group activity questions based on visualization	a) Not exploiting visualization content to design group activity b) Not exploiting visualization affordances to design group activity	a) Topic – OSI model, Instructor lectures with visualization then gives activity question to solve. Visualization not used in the activity: Draw flow diagram for email transfer from one PC to another PC b) Topic – Stack operation, Instructor uses affordances like input boxes to push/pop elements in the stack & points to the position of the pointer variable. But the activity students do is observe & listen.

<i>Design impediment identified: Instructors unable to</i>	<i>At the level of:</i>	<i>Example</i>
(iv) Design implementation of active learning strategies	a) Framing activity question as per strategy protocol b) 'What students should do' not adequately specified	a) Example in Table 4.1, Row 1. Only parent question designed. There is no 'Think' or, 'Pair' phase questions of increasing difficulty designed. b) Example in Table 4.1 Row2. No specification to students of what group size should be, what specifically they are to do in Pair phase like discuss their reasoning with their peer.

(ii) Operationalizing meaningful learning

Howland et.al (2012) states that for meaningful learning to take place with ICT, LDs should satisfy the five dimensions of: a) Active learning - active engagement with ICT content, b) Constructive - construct their own knowledge through self-reflection and articulation using ICT, c) Authentic - devise solutions to real-life problems through ICT use, d) Intentional - set their learning goals, evaluate their understanding and self-diagnose their errors using ICT and e) Cooperative - do group activity with their peers using ICT. What emerged from LD analysis were:

- (a) Active Learning – Instructors had, on an average, allocated 46.85% of the lesson time to instructor-directed activity with visualization like lecturing with visualization. 15.35% of lesson time on average was budgeted for doing student-centered activity with visualization. Rest of the lesson time involved activities without visualization.
- (b) Constructive – 96% of the instructors cannot design an activity with visualization that required students to do active meaning making with visualization content.
- (c) Authentic – 58% of instructors did not plan for connecting the topic being taught to their application in real-life.
- (d) Intentional – 96% of instructors had not planned for activities that would prompt students to self-diagnose their errors.
- (e) Cooperative – 73% of instructors did not include any group activity with visualization.

Thus instructors needed support along all dimensions of meaningful learning.

(iii) Framing group activity questions based on visualization

61.5% instructors were unable to frame group activity questions involving visualization content and exploiting the affordances. For example an instructor used an

animation on the OSI model solely as a lecture resource. This was followed by an activity where students are required to draw the flow model of email transfer from one PC to another (Table 4.3, Row3). But the activity does not involve visualization. Again, another instructor used the animation affordances (input boxes) to show push/pop stack operations and the different positions of the pointer variable. However, he failed to design a student-centered activity exploiting the affordance of input boxes.

(iv) Design implementation of active learning strategies

96% of instructors were not able to design the implementation as per the standard protocol of established active learning strategies like Think-Pair-Share. For example, common error noted was instructors were able to frame the overall parent question. But were not able to split them into ‘Think’ and ‘Pair’ phase questions or, the ‘Pair’ phase question does not involve group activity where students build on the ‘Think’ phase answer together. In most LDs, students were asked to discuss their ‘Think’ phase answers with their group member (Table 4.1, Row 4). Majority of the LDs also contained insufficient details on ‘what the students should do’, especially in the ‘Pair’ phase. Fig. 4.4 illustrates this point.

Step No.	Time (mins.)	What teacher will do	What student will do	Which visualization feature used, if any
1	5	Teacher will tell the student what is the LO of the topic	student will listen	--
2	10	Teacher will show the visualization	Student will see the visualization.	animation
3	10	Conducting quiz	Will attempt the test	ppt
4	5	Will make TPS activity	Will pair and then share the answer	--

Figure 4.4: Sample unguided LD created by an instructor

4.2.5 Study 1: Discussion of results

Close examination of the findings from Study 1 revealed that the findings extended the known design impediment categories and located specific points in LD creation process

where instructors required help. For example, it had been reported that instructors were not able to perceive the pedagogical utility of tool affordances (Web & Cox, 2004). This experiment revealed that instructors were using affordances like slider bars and input boxes to show the system/phenomenon under multiple conditions. But they were not able to exploit these affordances to frame student-centered group activity questions. Again, implementation fidelity was a known problem where instructors profess using active learning in classroom, but in-class observation studies reveal they veer towards instructor-directed teaching since they deviate from the implementation protocol of the strategy (Froyd, 2013). Our study showed two of the potential causes for implementation fidelity crops up at the design phase itself – (a) Instructors not framing activity questions as per protocol and (b) Insufficient thought given to what the student should do in each step. The results of this study showed instructors need detailed guidelines on how to operationalize the existing theories in their context and also how to design the implementation for the research-evidence based active learning strategies.

4.3 Identifying building blocks of the framework

The results of Study 1 indicated the teaching-learning theories of constructive alignment (Biggs, 1999) and meaningful learning with ICT (Howland et. al, 2012) should form the theoretical basis of the CuVIS framework. Thus the building blocks of CuVIS framework should be:

- (a) Learning objectives
- (b) Customization parameters to customize to instructor's context
- (c) Learning Designs (LDs)

Specifications for objective and customization parameters were obtained from the instructors themselves (Study 2) while specifications for the LDs were gleaned from the results of Study1.

4.4 Study 2: Gathering specifications for building blocks of the framework

The specifications for learning objectives and customization parameters were answered from analysis of semi-structured interviews with engineering instructors (Study 2). A qualitative study of semi-structured, face-to-face interviews with science and engineering instructors were conducted. The objective of the study was to identify the learning objectives that instructors have while teaching with visualization in the classroom. We also needed to identify the customization parameters needed by instructors that CuVIS should target.

A. Sample Characteristics:

The sampling strategy employed to draw sample from our accessible population was stage sampling (Refer Section 3.5). In stage 1, those instructors were shortlisted who satisfied the parameters for representativeness – (i) science and engineering instructors who have taught using visualizations in their instructor-mediated classrooms, (ii) who have attended pedagogy training workshop focusing on active learning, (iii) but are novice designers. In stage 2, these instructors were grouped into sample units based on their domains. For Study 2, we employed simple random sampling strategy to draw sample from all the domain sample units with the condition that they should be within the geographical unit accessible to the researcher for face-to-face interview. The sample size for this qualitative study was determined by data saturation. The sample consisted of 28 science and engineering instructors (male = 12, female = 16) from multiple domains like Mechanical, EE, Chemical, Civil, Biotechnology, Chemistry, Physics, Mathematics and CSE from colleges across western India. They had teaching experience in the range of 5-20 years and had prior experience of teaching using visualization. Thus aim of Study 2 was to identify the set of learning objectives and customization parameters that our target user population have while teaching using visualization.

B. Methodology

Each instructor was interviewed on an average for 45 minutes. During the interview, instructors were asked to show examples of visualizations they have used in their teaching and what their objective was while teaching using that visualization. They were also asked

how they taught using visualizations in different instructional settings like classrooms and laboratory and what factors of their context influenced their learning design (LD) with the visualization. Thus the interview data covered multiple engineering domains and a range of visualizations like videos, animations and simulations. Instructor response to each question was taken as the unit of analysis. During analysis to identify the range of learning objectives that instructors have with visualization, only those objectives were included in the data set that required the use of visualization as per Weiss graph (Weiss et.al, 2002).

C. Data Analysis & Results

An inductive thematic analysis of instructor interviews was chosen as the data analysis method since this study aimed to find the different ‘patterns’ of learning objectives and customization parameters emerging from the data set (Braun & Clarke, 2006). It progressed through the stages of open and axial coding of interview responses. The set of open codes obtained for all the interviews was further grouped into broader categories of objectives in the axial coding phase. Table 4.4 shows an illustrative example. This was an iterative process with discussion between the two researchers who coded in parallel till mutual agreement was arrived at. The data set was visited multiple times to refine the codes. A total of nine objective categories emerged after analysis of interview data and are presented with examples in Table 4.5. These categories map to Understand, Apply and Analyze levels of Bloom’s taxonomy. In our study, we have delved one level deeper for each of these Bloom’s levels. Here, each category corresponds to a particular skill being targeted by the objective like Prediction skill or Multiple Representation. The entire list of these skills included in CuVIS is given in Table 5.3.

Table 4.4: Coding of instructional objectives with visualization

<i>Interview response (verbatim)</i>	<i>Open Code</i>	<i>Axial Code</i>
Observe the phenomenon & construct an explanation of the properties of conductors & fields	Frame the definition of a concept after observing the viz.	Derive, through logical reasoning, definition of a concept/ relationship between variables or algorithm of a process from observations made from the visualization
Observe the visualization on sorted linked list & write a simple algorithm for it	Develop the execution logic of a process to achieve the specified output, given the input parameters, after observing generic visual demonstration of the process	
Observe the Brayton cycle visualizations & draw the temperature-entropy diagram	Predict relationship between different variables while watching the visualization, when the concept has not yet been taught	

Table 4.5: Instructional objective categories with visualization

<i>Instructional Objective Types</i>	<i>Illustrative Examples : After interacting with this visualization, students should be able to -</i>
1. Visualize to explain a concept with illustration	Explain the concept of integration using trapezoid OR, Explain the theory behind asymmetric key cryptography with illustration
2. Visualize to explain the working of a process/algorithm or compare multiple processes	Explain how do the safety systems work when aircraft engine catches fire? OR, What is the difference between 2-stroke and 4-stroke engine?
3. Write/Draw alternate representations (like graph to equation) from the given visualization or vice-versa.	Given mathematical function, draw the vector field & vice-versa.
4. Use a given visualization to compute the solution to the given problem by executing single process	Draw the output signal when the input signal $x(t)$ is time shifted by 0.5 units.
5. Use a given visualization to compute the solution to the given problem involving multiple processes	Given the input signal & output signal equations, write the transformation equations of the intermediate steps.
6. Predict output of next step or a set of steps in a multi-step process	Predict the output of the given program for the given set of input variable values
7. Predict output of a phenomenon	Predict the direction of rotation of the field vector in electromagnetic wave polarization
8. Devise an explanation for a given process or phenomena, through logical reasoning, from observations made from the visualization, before the topic has been taught	Derive the plot of I_D vs. V_{GS} for junction field effect transistors (JFET) from the visualization
9. Visualize a micro-physical structure that is otherwise difficult to observe	Visualize the internals of a heat exchanger.

The interview responses were also analyzed to identify the specifications for customization parameters. For example multiple instructors were found to adopt student-centered LDs with visualization when the instructional setting was laboratory. They typically asked group of students to explore the visualization on their own and often gave them a set of guiding questions to respond to during this exploration phase. However, when the setting changed to instructor-mediated classrooms the very same instructors switched to LDs where the instructor lectures using the visualization. The reasons instructors attributed for this anomaly is that students do not have direct access to the visualization in the classroom and also class size, which is typically in the range of 60-100 students. Thus, the instructional setting of instructor-mediated classrooms posed additional challenge in designing student-centered LDs with visualization. Again, the type of visualizations instructors used ranged from videos to animations and simulations. Such factors were identified and summarized into specification list for customization parameters with visualization (Table 4.6).

Table 4.6: Specifications for customization parameters when teaching with visualization

<i>Sr. No.</i>	<i>Customization Parameters Specifications</i>
1	Instructional Context = Instructor-mediated classroom
2	Time requirements= Time duration of teaching- learning activity (~10mins./~20mins.)
3	Visualization type = Video/Animation/Simulation

The components to be included in a learning design (LD) layout is currently not standardized (Laurillard, 2012). In this thesis, the LD layout adopted is based on the one developed by Laurillard (2012) that specified what the instructor and student should do. The analysis of LDs in Study 1 (Sec. 4.2) led to additional design specifications for the LD layout like a) time duration of 5 minutes (maximum) and b) specifying which visualization affordance, if any will be used along with what the instructor and students will do for each step in the LD.

4.5 Summary and Implications

The findings from Study 1 helps identify four design impediments faced by instructors in our research context. Three of the impediments – operationalizing the theories of constructive alignment and meaningful learning and framing group activity questions with visualizations are at the conceptual level. The fourth impediment of designing implementation of active learning strategies is at the implementation level. The design impediments help finalize the three building blocks of the CuVIS framework as learning objectives, customization parameters and LDs. Study 2 defines the specifications for each of these building blocks gleaned from the target users themselves. Thus we get nine categories of learning objectives that science and engineering instructors have for teaching using visualization in instructor-mediated classroom (Table 4.5). We also get three types of customization parameters with their specifications that are important for instructors in our context – instructor-mediated setting, visualization types (video/animation/simulation) and activity time duration (5-10 mins. /15-20mins.). This step concludes the Problem Analysis phase of the DDR methodology.

The results from the Problem Analysis phase feeds into the next phase of Design and Development. The design impediments identified indicate that CuVIS framework guidelines need to be developed both for conceptual and implementation levels. The conceptual level guidelines should address how to design LDs in order to achieve constructive alignment and meaningful learning through exploitation of visualization affordances. CuVIS guidelines should also include guidance on implementation protocol of the chosen active learning strategy. There should be provision in CuVIS to design either short (5-10 mins.) or long (15-20 mins.) activities for a given objective. The guidelines also need to accommodate challenges of instructor-mediated setting i.e. students cannot directly manipulate the visualization. The guidance on exploitation of visualization affordances should accommodate all the three types of visualizations that are popularly used by our instructors. The layout of CuVIS LDs should incorporate stepwise design of activity with visualization with time duration (in minutes) and role of instructor, student and visualization affordance specified for each step. Thus the results from the Problem Analysis phase outlines the requirement specifications for the CuVIS framework.

Chapter 5

Design and Development of CuVIS Framework

5.1 Introduction

In this chapter we describe the design and development phase of CuVIS framework (Fig.3.2). The objective of this second phase of DDR methodology is to – (a) design guidelines addressing the four design impediments (Chapter 4) from existing theory but customized to our research context and (b) develop the framework by integrating the guidelines at appropriate steps in the LD creation process and (c) do iterative testing of the framework prototype with the target users i.e. instructors. It proceeds through eight steps as shown in Fig. 5.1. An overview of how the design impediments have been addressed in CuVIS is presented in Table 5.1.

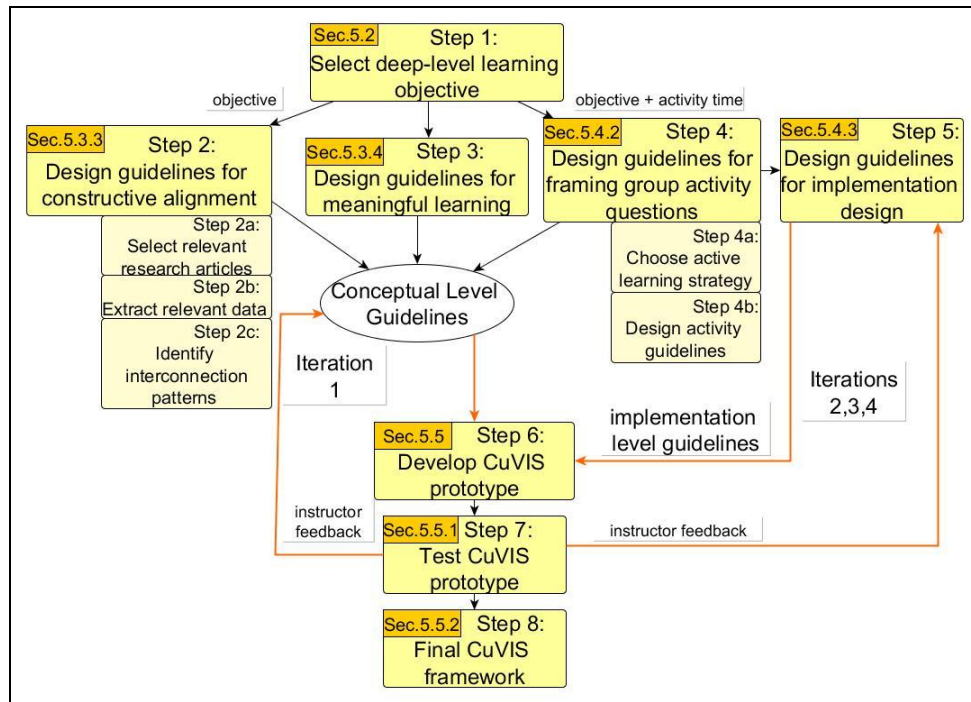


Figure 5.1: Workflow of Design & Development phase of CuVIS

Table 5.1: Design decisions taken to frame CuVIS guidelines

Sr. No.	Design Impediments	Design decisions taken to address the impediments through CuVIS framework	Customized to
1	Operationalize constructive alignment	Step 1- Identify the cognitive process mapped to the objective from literature Step 2 - Identify pedagogical support & visualization affordances that support the cognitive process	i) instructor-mediated setting ii) activity time duration iii) visualization type
2	Operationalize meaningful learning with ICT	Frame guidelines for each dimension based on the multiple guidelines existing for different levels of operationalization of the dimensions	
3	Frame group activity questions based on visualization	Use implementation protocol of the example active learning strategy + the cognitive process for selected objective to frame activity question guidelines	Active learning strategy need to conform to : (i) Activity time requirements (ii) Cognitive process for selected objective
4	Design implementation of established active learning strategies	Create an implementation design template that contains stepwise guidance on the implementation protocol of the chosen strategy + cognitive process mapped to selected objective	

The initial five steps constitutes the design phase of CuVIS framework : (1) Selecting deep-level learning objectives (Section 5.2), (2) Designing constructive alignment guidelines

(Section 5.3.1 -5.3.3), (3) Designing meaningful learning guidelines (Section 5.3.4), (4) Framing guidelines for creating group activity questions (Section 5.4.1 – 5.4.2) and (5) Designing implementation design guidelines (Section 5.4.3).

5.2 Selecting deep-level learning objectives

The purpose of this step was to filter out those objectives which require only surface level knowledge from the purview of the CuVIS framework. Surface level knowledge is defined as knowledge ‘associated with rote learning, memorization and a lack of critical judgement. This knowledge is stored in memory as more or less a copy of external information.’ The decision to omit surface level knowledge is derived from empirical evidence that shows instructor-directed non-constructivist LD is sufficient for them (Garside, 1996; Banerjee et.al., 2014). Deep knowledge in contrast is defined as external knowledge embedded in memory as a basic concept, principle or procedure (De Jong and Fergusson-Hessler, 1996). The methodology followed to classify the nine identified objectives (Sec.4.4.1) into deep level and surface level is based on the ‘Knowledge Matrix’ (De Jong and Fergusson-Hessler, 1996). This matrix categorizes knowledge into two types, conceptual and procedural, and then defines their depth (Table 5.2).

Table 5.2: Knowledge depth as defined by De Jong & Ferguson-Hessler, 1996

<i>Type</i> <i>Depth</i>	<i>Conceptual</i>	<i>Procedural</i>
Surface	Symbols & Formulae	Rules, Recipes, Algebraic manipulations
Deep	Concepts & Relations	Meaningful action

The application of the ‘Knowledge Matrix’ is illustrated with the objective category ‘Problem solving involving a single process’ (Table 4.5). An example objective like ‘Draw the output signal when the input signal $x(t)$ is time shifted by 0.5 units’ involves a single process - time shifting. Hence, the problem can be solved by application of a specific formula. Therefore, it is classified as surface level objective as per the Knowledge Matrix guidelines.

The other surface-level objective obtained is ‘Visualize a micro-physical structure that is otherwise difficult to observe’. This is because visualizing a micro-physical structure required students to simply view the internal configuration of a system that cannot otherwise be easily viewed like the internal organization of a heat exchanger. Thus two of the identified objectives – ‘Use a given visualization to compute the solution to the given problem by executing single process’ and ‘Visualize a micro-physical structure that is otherwise difficult to observe’ were found to be at surface level. They were consequently removed from objective set. CuVIS framework focuses on the set of seven deep level objectives (Table 5.3) with each objective targeting a particular skill. Henceforth, in this thesis the objectives are referred on the basis of the skills they target.

Table 5.3: Learning objectives addressed by CuVIS framework

<i>Sr. No.</i>	<i>Deep Level Objectives Addressed</i>	<i>Skill targeted</i>
1	Visualize to explain a concept with illustration	Conceptual Understanding
2	Visualize to explain the working of a process/ algorithm or compare multiple processes	Procedural Understanding
3	Write/Draw alternate representations (like graph to equation) from the given visualization or vice-versa.	Multiple Representation
4	Use a given visualization to compute the solution to the given problem involving multiple processes	Multi-process problem solving
5	Predict output of a phenomenon	Prediction
6	Predict output of next step or a set of steps in a multi-step process	Prediction
7	Devise an explanation for a given process or phenomena, through logical reasoning, from observations made from the visualization, before the topic has been taught	Inquiry-based learning

5.3 Design guidelines for constructive alignment & meaningful learning

Framing design guidelines for constructively aligned and meaningful learning LDs with visualization is composed of two steps – (i) Determining design requirements from literature analysis (Sections 5.3.1, 5.3.2 & 5.3.4) and (ii) Applying the requirements to frame CuVIS framework guidelines for constructive alignment (Section 5.3.3) and meaningful learning (Section 5.3.4) with visualization customized to the context of instructor-mediated classrooms.

5.3.1 Requirement specifications for constructive alignment design

The teaching principle of constructive alignment states that both the teaching-learning activity and assessment should map to the learning objective within the constructivist paradigm. The challenge for instructors is to determine what the learning design (LD) requirements are so that it maps to the chosen objective. This would require knowledge of: (a) the cognitive process learners follow to successfully achieve that objective, (b) the pedagogical support instructors can provide to facilitate the cognitive process and (c) the visualization affordances that can aid this process. Thus, CuVIS framework guidelines for constructive alignment should evolve from the synthesis of existing literature on cognitive process, pedagogical support and visualization affordances to achieve a particular objective. The guidelines should also be customized to our research context.

5.3.2 Methodology of determining design requirements for constructive alignment

The design requirements for constructive alignment, for each of the seven learning objectives in CuVIS framework, were obtained through narrative literature review. Narrative review is a qualitative study that summarizes disparate sources of literature related to a specific research topic (Dochy, 2006). The output is a holistic interpretation of different aspects of the topic. The rationale for choosing narrative review methodology was that this review aimed to summarize the interconnections between a diverse set of research articles (Baumiester & Leary, 1997; Dochy, 2006) on cognitive process, pedagogical support and visualization affordances for teaching a particular objective. These interconnections formed the foundation for building a comprehensive set of constructive alignment guidelines for teaching using visualization in our research context. Thus, the focus questions for the narrative review were:

- (a) What cognitive process do learners follow to achieve the specified objective successfully?
- (b) What are the pedagogical support to be given to aid learners in the cognitive process?
- (c) What visualization affordances are required such that the tool supports the cognitive process?

The three-step narrative review methodology followed in this thesis (Fig. 5.1) was based on the steps outlined by Panadero & Jonsson (2013) : (2a) Decide inclusion criteria for research articles and select appropriate ones, (2b) Extract relevant data from the selected articles that addresses our research objective and (2c) Compare the extracted data to identify possible pattern of interconnections. The patterns are discussed with another researcher to validate the analysis.

Step 2a: Selecting relevant research articles

Two research databases – SCOPUS and ERIC were chosen as potential sources for relevant research articles. They were chosen because they were widely-consulted, multi-disciplinary database of peer-reviewed articles in educational technology. To ensure that the narrative review was comprehensive, the following journals were searched in addition – Learning and Instruction (Impact factor = 4) and Educational Technology Research and Development (Impact factor = 0.9). These journals were chosen since relevant papers found through cross-referencing were published frequently in these journals. The inclusion criteria for the research articles were set as:

- (i) Should be either peer-reviewed journal or conference papers or book chapters.
- (ii) Should be theoretical or empirical studies on teaching that particular objective with or without visualization.
- (iii) Has to address at least one of the following: cognitive process underlying the objective or, pedagogical support or visualization affordances required to teach that objective.
- (iv) Should address the domains of science or, engineering teaching.

While searching the databases, no restriction was placed on the year of publication. But for journals, only papers published in the last 10 years were surveyed along with their cross-referenced articles. The following type of search keywords were used while searching within paper titles, abstracts and keywords – prediction, teaching, learning, cognitive process, visualization, multimedia, simulation, design support, multiple representations, causal reasoning, inductive reasoning among others. Typically, a search in a database or journal would return 20 papers. Inclusion criteria was then applied returning typically 2-4 papers of relevance. The main reasons for rejecting papers were that they targeted domains like Language learning, Sports or History or, they reported empirical study results without pedagogical recommendations of how to teach/learn the objective or, were focused on

curriculum development or teaching the skill to the differently abled. On an average, 6-10 relevant papers were obtained for analysis for each of the seven CuVIS framework objectives.

Step 2b: Extract relevant data from selected research articles

In this step data from the selected papers were extracted along those dimensions that answer the focus questions of the narrative review – Type of study (Cognitive process/Pedagogical support/Visualization affordances), Research context (setting, grade), Study Description, Study Conclusions (Findings & Interpretations). Table 5.4 below presents an example of extracted data for prediction objective, sourced from eight appropriate research articles covering different combinations of cognitive process, pedagogical support and affordance.

Table 5.4: Data extracted data from selected articles for objective = Prediction skill

A. Article on Cognitive Process + Pedagogical Support + Visualization affordance for Prediction					
Study (Authors, Journal)	Context (Domain, Educational Level)	Study Description	Study Conclusion about		
			Cognitive Process	Pedagogical support	Visualization affordance
1. Jonassen & Ionas (2008) Cited by 81 Educational Technology R&D	Generic	Theoretical: Describes cognitive process behind achievement of prediction. No empirical evidence.	Cognitive process for prediction proceeds through 2 stages : (a) Identifying different aspects of co-variational relationship, (b) Construct mechanistic model of the relationship	(a) Ask guiding questions that focus on various aspects of covariation like directionality, strength, duration, probability etc.	(a) Identifying different aspects of covariation aided by variable manipulation (b) Simulations unable to show the underlying mechanistic model
B. Article on Cognitive Process for Prediction					
Study	Context (Domain, Educational Level)	Study Description	Study Conclusion about Cognitive process		
2. Ahn et.al,1995 Cited by 397 Cognition	Cognitive Psychology, Adults	Qualitative study: Seeks to find out how people predict. 4 experiments were conducted with sample size of 3-4 each and the type of questions they asked of a given case in order to predict were analyzed.	(a) Covariation and Mechanism approach are complementary to each other in the complex prediction process. (b) Covariation deals with questions on who/what caused the event (surface factors) whereas mechanism deals with how did this even occur? (c) Empirical generalizations lead to covariational approach whereas theoretical explanations lead to mechanism approach. (d) Most people seek answers to the ‘how’ mechanism questions to frame a hypothesis for prediction rather than covariational questions		
C. Articles on Cognitive Process + Pedagogical Support for Prediction					
Study	Context (Domain, Educational Level)	Study Description	Study Conclusion about		
			Cognitive Process	Pedagogical Strategy	

3. Maier, 2012 Cited by 12 International Handbook on Teaching and Learning Economics : Chapter 8	Physics, Economics, K-16	Theoretical – Analyzes the strategy for Prediction	Theoretical justification for each step of ILD: (a) Predict before viewing – Students retain and use new ideas if they articulate their prior understanding (Bransford, 2000; Redish, 2003) (b) Experience phase is the lecture time. Students focus on the new concept & more receptive to new ideas Reflection helps students store new ideas in long-term memory since they think about what has changed in their understanding.	ILD contains 3-steps: (a) Students frame hypothesis (prediction) before watching the visualization (b) Test hypothesis with visualization using data (experience) Interpret the result (reflection)
4. Costu et.al, 2012 Cited by 10 Instructional Science	Chemistry (Condensation); K-16	51 students in Introductory Chemistry course underwent 3 tasks using a POE-derived strategy PDEODE. Pretest – posttest study to explore effect of strategy on student misconceptions. Student interviews conducted to understand effect of strategy. No visualizations used.	(a) Group & Class wide discussion prompted students to evaluate their understanding. (b) Observation prepared them to accept better scientific explanations than their own (c) Final round of explanations & discussion helped retain the knowledge gained in long term memory	6-step process: P - Predict what will happen with reasoning, D –Discuss in groups, E – Each group presents to the class in class wide discussion, O – Observed changes in phenomenon during hands-on experiment individually & recorded observation. Instructor asked guiding questions to focus on the concepts, D – Group discussion on reconciliation of observation with prediction, E – Resolve all contradictions in groups
D. Articles on Pedagogical Support + Visualization affordance for Prediction				
Study	Context (Domain, Educational Level)	Study Description	Study Conclusion about	
			Pedagogical strategy	Visualization affordance
5. Hennessy, S., Wishart, J., Whitelock & 6 others (2007).	Domain – Science; K-12 Level	Experimental - Field study with 11 instructors. What we get - Experiential instructor recommendations. What we do not get – No theoretical	Instructor’s experiential recommendations: a) Control to be given to students to construct their own ‘What-if’ scenarios & explore.	Deficiency in visualization – Imperfections in idealized models shown in visualizations. To overcome this, see recommendation number c).

<p>Cited by 136</p> <p>Computers & Education</p>		<p>justification</p> <p>a) Classroom observations of implementation of LDs with ICT including visualization created by instructors, followed by instructor interviews.</p> <p>b) LDs designed for prediction with visualization among others.</p> <p>c) Gives a set of instructor recommendations</p>	<p>b) Different strategies needed for students with different achievement levels. For high level students – Reasoning to construct the mechanistic model whereas low level students – focus on aspects of causal relationship</p> <p>c) Ask students to research on these imperfections.</p> <p>d) Instructors need to stimulate discussion with strategic questioning, cognitive conflict addressal and interpretation.</p>	
<p>6. Chang & Linn, 2013</p> <p>Cited by 22</p> <p>Journal of Research in Science Teaching</p>	<p>Domain – Chemistry (thermodynamics), K-12 level, self-study mode, instructor absent</p>	<p>a) Study explores effect of various visualization scaffolds to assist prediction.</p> <p>b) Comes up with visualization design guidelines</p> <p>c) Pretest-Posttest, in class observations and instructor interviews with 8 instructors done.</p> <p>d) Students divided into 3 groups based on different ways visualization can be used for prediction – Observation (N = 60), Research Guidance (N = 63) and Critic (N = 83)</p> <p>e) Students under all conditions showed improvement in understanding heat transfer</p>	<p>a) LD guided by the knowledge integration pattern to make predictions, use the visualization to add ideas, conduct observations or virtual experiments to distinguish their predictions from the ideas they added, and reflect on their progress</p> <p>b) Question prompts designed to scaffold students ‘to predict what would happen to the temperature of the cup and the counter, to explore the visualization, to distinguish between their predictions and the results, and to reflect on the phenomena of heat transfer.’</p> <p>c) Observation condition – Students view the phenomenon; Video used,</p> <p>d) Research Guidance – Explore their own questions by conducting virtual experiments; interactive animation used,</p> <p>e) Critic – Critic the experimental design of a fictitious peer & then</p>	<p>a) Guiding questions that prompt students to summarize their idea in the 2nd step (add idea)</p> <p>b) Questions that help them link between molecular and observable data</p> <p>c) Ask students to critic another’s solution. This helps in students recognizing confounds</p> <p>d)Instructors to examine student ideas and identify confusions</p>

		conduct experiment	
E. Articles on Pedagogical Support for Prediction			
Study	Context (Domain, Educational Level)	Study Description	Study Conclusion about Pedagogical Strategy
7. Kala et.al, 2013 Cited by 05 Journal of science and mathematics education	Domain – Chemistry; Level – High School, K-12; Setting – Self-study, instructor absent	Case study with 27 students: a) Uses POE strategy without visualization to discover misconceptions about acid-base. b) Describes POE implementation design without visualization	a)The open-ended answers written by students as reasoning for their prediction is helpful resource for instructors to discover student misconceptions. b) Students able to predict well but reasoning was most times erroneous. c)POE Implementation design followed: Step 1 – Students were given a situation. They have to predict outcome of event. Step 2 - Students observe the event by doing experiment. Step 3 – Students given worksheets to record observations, predictions, reason for prediction and reconciliation between prediction and observation.
8. Giuliodor i et.al, 2006 Cited by 39 Advances in Physiology Education	Domain – Physiology, Setting – Lecture, K-12 level, No visualization used	a) Tests effect of Peer Instruction on students' prediction skill (qualitative problem solving) b) Sample – 114 veterinary students across 10 classes	a)LD followed: A 90-min. lecture class divided into 4-6 lecture sessions of 15-20mins. After each session, a 3-4mins. PI activity of 1 question. b)Students solved the question & wrote down their reasoning for 1 min., peer discussion – 1min. followed by class wide discussion – 1-2mins. c)Finding: Significant improvement in prediction

Step 2c: Identify patterns from analysis of extracted data

The objective of analysis of the extracted data was to summarize the interconnection between cognitive process, pedagogical support and visualization affordances for a given objective (illustrated for the objective of prediction in Table 5.4). The analysis was done independently by two researchers and discussed to arrive at a common conclusion. The output of analysis from the extracted data (like in Table 5.4) is explained below with the example of prediction objective. The analysis revealed the following interconnection: The cognitive process for prediction is composed of two stages –

- (1) Learners identify the covariational relationship between system variables in terms of strength, directionality, duration, probability (Jonassen & Ionas, 2008)
- (2) Learners construct mechanistic model of the system (Jonassen & Ionas, 2008; Ahn, 1995). They need to understand the underlying model of the relationship to explain how the change takes place (Ahn, 1995; Jonassen & Ionas, 2008; Hennessey et.al, 2007).

The visualization affordances recommended for the covariational stage are those that allow variable manipulation. This is because learners can explicitly view the covariation and decipher different aspects of the relationship (Jonassen & Ionas, 2008; Hennessey et.al, 2007; Costu et.al, 2012). In fact, to gain a better understanding of covariation, students are recommended to do the variable manipulations themselves (Hennessey et.al, 2007; Costu et.al, 2012). The pedagogical support recommended for the covariational stage is posing guiding questions that focus learners' attention on multiple aspects of the covariational relationship like what caused the event (Ahn, 1995). For the model construction stage, visualizations do not have any affordance to explicitly depict the mechanistic model of the relationship (Jonassen & Ionas, 2008). Here the pedagogical support provided by instructors becomes crucial. Such support can be asking guiding questions like how the change takes place or prompt learners to link the observable data to existing theories (Chang & Lin, 2013; Costu et.al, 2012). Other possible pedagogical support include asking learners to write down their reasoning for prediction, discuss with their peers, reconcile their predictions with observations and reflect on how their understanding has changed (Maier, 2012).

5.3.3 Framing CuVIS framework guidelines for constructive alignment

The synthesis of the interconnection between cognitive process, pedagogical support and visualization affordances that emerged from the narrative analysis of existing literature led to formulation of CuVIS framework LD guidelines for constructive alignment for each identified objective. The synthesis took into account those interconnections that are executable in instructor-mediated classrooms. Also, the analysis results were framed into guidelines using language comprehensible to the instructors and devoid of educational technology jargon. Each guideline was also accompanied by illustrative examples from the instructor’s domain. Currently CuVIS framework is scoped to the domains of EE and CSE. In CuVIS framework, the constructive alignment guidelines are presented stepwise to the instructor through a set of Activity Constructor prompts. The objective of Activity Constructor prompts is to enable instructors to take theory-informed design decisions targeting all the conceptual design impediments. Example of constructive alignment guidelines presented through the Activity Constructor prompts for Prediction objective is presented in Table 5.5. In this table, the column Activity Constructor prompt represents what design decision the instructor has to take like show the system under what multiple condition sets (This is related to covariation stage of prediction objective). The guideline column contains the guidelines that assist them in taking the decision like deciding which variables to vary. It also informs them on why this is important for the prediction objective and how to execute using visualization affordances. The domain example column contains an example implementation of the guideline on a topic from the instructor’s domain.

Table 5.5: Example constructive alignment guideline for objective = Prediction

<i>Activity Constructor prompt</i>	<i>Guideline</i>	<i>Domain Example</i>
Decide what multiple condition sets to show students through visualization	<p>a] Play the visualization to show effect of varying the value (s) of causal variables on the system.</p> <p>b] This will help the students identify the strength and directionality of relationship between different causal variables.</p> <p>c] Therefore, decide which input parameters (variable values) you will vary to show relationship between different variables.</p> <p>d]If you have a video/animation, note the timestamps in your lesson plan where you need to pause to show each condition</p>	<p>Domain = EE</p> <p>Show the simulation output for AM , PM, FM with:</p> <p>a] input all ones b] input all zeros</p> <p>Domain = CS</p> <p>Show the animation output for the Pointer variable y with a] Prefix operator [Timestamp - 00:01:42] b] Post-fix operator [Timestamp - 00:03:42]</p>

5.3.4 Framing CuVIS framework guidelines for meaningful learning with visualization

A subset of Activity Constructor prompts in CuVIS framework also address the meaningful learning dimensions. The dimensions of Active learning and Constructive are incorporated by default as they overlap with constructive alignment principle. To frame guidelines for the Authentic, Intentional and Cooperative dimensions of meaningful learning, we looked at the multiple guidelines available in literature like the rubric for TPACK for meaningful learning (Koh, 2013) and Technology Integration Matrix (TIM) (Hornack, 2011). We chose Koh's (2013) rubric that assesses instructor TPACK levels for designing meaningful learning from their lesson plans. Each cell in the rubric defines different levels (0-3) of design expertise for each of the dimensions. We chose Koh's rubric as basis for framing meaningful learning guidelines in CuVIS framework. However, the guidelines still had to be customized to our context, particularly in terms of instructor mediated setting and visualization affordance. We did not choose TIM since its objective is not to evaluate design expertise but level of technology integration by instructors in the curriculum. It combines levels of technology adoption by instructors with the dimensions of meaningful learning. Given below is description of how each of the five dimensions were made functional in CuVIS framework (Table 5.6).

Table 5.6: Operationalizing meaningful learning with visualization in CuVIS framework

<i>Meaningful Learning Dimension</i>	<i>Definition (Howland et.al, 2012) & Assessment (Koh, 2012)</i>	<i>CuVIS Framework Operationalization</i>
i) Active Learning	Learners actively manipulate the ICT tool & observe the result. It is measured in Koh's rubric in terms of the lesson time spent in working with ICT.	The CuVIS framework LD layout has the columns - 'Which affordances used' for each step with 'Time (mins.)'. These column entries capture the lesson time spent using the visualization.
ii) Cooperative	Learners work with peers to learn. It is assessed in terms of the degree (some/large/ primarily) of divergent knowledge construction promoted by the group activity.	a) Selection of constructivist, cooperative strategy inherently incorporates group activity requiring divergent knowledge expression compared to rehashing the information received. b) For example, CuVIS framework guides prompt instructors to include a group activity component in their design.
iii) Authentic	The activity with visualization is connected to real life application of the topic. It is measured in Koh's rubric by the extent to	CuVIS framework includes an Activity Constructor prompt for this dimension. It gives the instructors 3 options on how to operationalize this dimension in decreasing order of desirability.

<i>Meaningful Learning Dimension</i>	<i>Definition (Howland et.al, 2012) & Assessment (Koh, 2012)</i>	<i>CuVIS Framework Operationalization</i>
	which the students themselves come up with real life application of the topic using visualization	
iv) Intentional	Learners decide their learning pathway themselves. It is measured by the extent to which learners use the visualization to self-diagnose and fix their learning gaps.	<p>a) In CuVIS framework, implementation design of all group activities require learners to articulate their reasoning for discussion within the group. This provides opportunity for self-reflection.</p> <p>b) Self-reflection for each learner is again exercised when they compare their solution with what is shown through visualization.</p> <p>c) CuVIS framework has specific implementation guidelines for instructors to implement synthesis & self-reflection by students like “Ask students to compare their solution with what is shown & underline the errors in their solution, if any.”</p>
v) Constructive	Learners construct, reflect & articulate their understanding of the topic. It is measured in Koh’s rubric as synthesizing the information presented to come up with a solution or articulate their personal reflection of the subject matter to arrive at a solution	<p>a) Both conceptual and implementation level guidelines involve students synthesizing the information obtained through the visualization.</p> <p>Also, the strategies in CuVIS framework database are constructivist, cooperative strategies</p>

5.3.5 Customization of CuVIS framework guidelines to our research context

The CuVIS framework guidelines are contextualized to instructor-mediated classrooms and cover affordances of different types of visualization – video/animation/simulation. This contextualization of CuVIS framework is illustrated with the Prediction objective. From narrative analysis results, we know that learners should ‘experience covariation’ by manipulating the variables themselves (Hennesey et.al, 2007) as a step towards successful achievement of Prediction objective. In instructor-mediated classrooms, it is not possible for the learners to control the variable manipulations. Hence, CuVIS framework guidelines provide an alternative path. It guides the instructor to change the variable value, show the covariation under multiple condition sets and pause after each set to allow learners to discover different aspects of the covariational relationship themselves through a student-centered activity. Again, simulations are not available always for their

chosen topic. For such cases, CuVIS framework guidelines accommodate variation in visualization type by guiding instructors to choose an animation/video that shows the system under multiple condition sets and has the pause button to allow stopping at each condition set. To ensure that the visualization chosen supports the cognitive requirements of the CuVIS framework LD, CuVIS framework provides a visualization checklist right at the initial stage of the LD creation process (Fig. 5.2). Fig.5.2 shows a snapshot of the final CuVIS framework provided to instructors. The conceptual and implementation design guidelines are mapped to a specific combination of objective and activity time duration chosen by the instructor. Table 5.7 zooms into the customized, conceptual guidelines of the framework i.e. set of Activity Constructor prompts for the combination of objective = Prediction and activity time duration = 15 – 20 mins.

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

Conceptual Guidelines

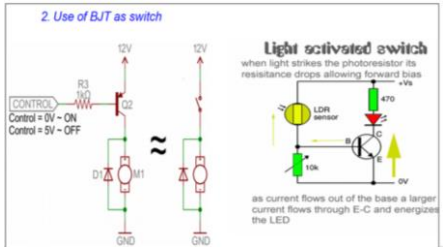
Implementation Guidelines

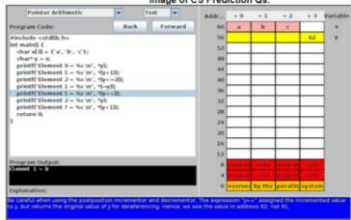
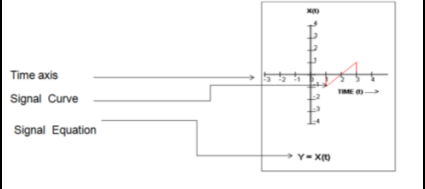

Customized Guidelines

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Figure 5.2: Snapshot of final version of CuVIS Framework

Table 5.7: Conceptual guidelines for objective = Prediction & activity time duration = 15-20 mins.

Activity Construction Prompts	Guidelines	Example
1. Decide the difficult part of the topic to target with visualization	<p>1. Think of aspects of the topic students generally find difficult to understand/ visualize & which is covered in your selected visualization</p> <p>2. Focus the activity with the visualization on this difficult to understand part of the topic you identified.</p>	<p>Domain = EE If topic = Coding Theory Students not able to decide if Position of source coding block & channel coding block in a digital communication block diagram can be interchanged.</p> <p>Domain = CS If topic = travelling salesman problem, Students able to construct a tour but unsure whether the chosen tour is the minimum cost tour.</p>
2. Decide how to connect topic to real-life	<p>You can connect the chosen topic to real-life in any 1 of the following ways (in descending order of desirability):</p> <p>Options :</p> <p>a] Situate the ‘POE’ activity question itself in a real-life context (preferred)</p> <p>b] Make students relate their personal experiences to come up with real-life application of the topic</p> <p>c] You present real-life examples of the topic with/without the visualization</p>	<p>Domain = EE</p>  <p>Domain = CS</p> <ol style="list-style-type: none"> 1. Facebook and Twitter, which is directed and which is undirected? 2. Why Facebook is both directed and undirected? 3. State reason why Facebook is directed. 4. State reason why Facebook is undirected. 5. Why Twitter is directed? 6. How to use BFS on Facebook?
3. Decide what multiple condition sets to show students through visualization	<p>a] You need to play the visualization to show effect of varying the value (s) of causal variables on the system.</p> <p>b] This will help the students to identify the strength and directionality of relationship between different causal variables</p> <p>c] Therefore, decide which input parameters (variable values) you will vary to show output effect on which variables.</p> <p>d] If you have a video/animation, note the timestamps in your lesson plan where you need to pause to show each condition</p>	<p>Domain = EE Show the simulation output for AM , PM, FM with: a] input all ones b] input all zeros</p> <p>Domain= CS Show the animation output for the Pointer variable y with a] Prefix operator [Timestamp - 00:01:42] b] Post-fix operator [Timestamp - 00:03:42]</p>
4. Frame the POE activity question that addresses the difficult part identified	<p>a] Frame questions that addresses the difficult part you had identified</p> <p>b] Question whose solution can be shown through</p>	<p>Domain = EE Topic = Electromagnetic Wave Propagation Show visualization of wave propagation with Ey component only. Ask students to predict</p>

Activity Construction Prompts	Guidelines	Example
	<p>visualization</p> <p>c] Should involve ‘what-if’ type of questions that are not leading.</p> <p>d] Question should prompt students to look for covariation among variables</p> <p>e] The clear deliverable should be student predictions + their reasoning of the causal relationship</p>	<p>what happens if I add Ez component</p> <p>Domain = CS Topic = Pointers Predict output of the code line:</p> <p>Q. Predict what will be the output if the highlighted code line, as shown on-screen, is executed.</p> 
<p>5. Decide what questions to ask to guide reasoning</p>	<p>Ask questions to focus on different aspects of causal relationship like:</p> <p>i) strength of the relationship</p> <p>ii) directionality of the relationship</p>	<p>Domain: EE</p> <ol style="list-style-type: none"> Why do more valves per cylinder increase horsepower? In this case, what was the most direct cause of the bulb blowing up? <p>Domain: CS</p> <ol style="list-style-type: none"> Will the printf statement show an increased value of variable y now? What could be the cause behind increase in value of variable y here?
<p>6. Decide where to pause the visualization</p>	<p>a] Pause just after the input variable values have been changed</p> <p>b] Label & Upload screenshot of the pausing point showing prompts like color codes, text labels or explanation with visuals that will help students predict</p> <p>c] To take screenshot, press 'Prtscr' button in your keyboard. The image will get saved in your PC. Upload this image file.</p>	<p>Domain = EE</p>  <p>Domain = CSE</p> 

5.4 Designing guidelines for group activity question & implementation design

The methodology for formulating CuVIS framework guidelines for both the remaining design impediments – (a) Designing group activity question and (b) Implementation design consists of two steps (Fig. 5.1) : (Step 4a) Choosing an active learning, cooperative strategy which is a classroom ‘instructional method that engages students in learning process’ as they work towards a common goal in small groups (Prince, 2014). The two theoretical bases of CuVIS framework – constructive alignment and meaningful learning lead to the requirement that implementation strategies chosen should support active learning. (Step 4b) Designing guidelines for framing group activity question and implementation. These steps are discussed below.

CuVIS framework suggests an example strategy to the instructors mapped to their specifications of learning objective and activity time duration and appropriate to instructor-mediated classroom context. It is possible to have alternate strategies that could have sufficed as well. But the aim of CuVIS framework is to introduce instructors, who are novice designers, to the knowledge and practice of designing for active learning using visualization affordances within the constraints of their context. Thus, CuVIS framework suggests an example strategy to enable instructors to create a best practice example customized to their own context themselves.

5.4.1 Choosing example active learning strategy

This sub-section details with how the example active learning strategies in CuVIS framework were chosen. The following steps were followed to shortlist example strategies for CuVIS framework – (i) Survey literature for a set of active learning strategies that have empirical evidence of success in face-to-face setting and (ii) Apply a set of filters specific to our research context to further streamline the strategy set. As part of (i), we found there is a multitude of active learning strategies that have been shown to be successful in face-to-face setting like Peer Instruction (PI) (Keller et.al, 2007), Think-Pair-Share (TPS) (Banerjee et.al, 2014), Interactive Lecture Demonstrations (ILD) (Sokoloff & Thornton, 2004), Predict-

Observe-Explain (POE) (White & Gunstone, 1992), Process Oriented Guided Inquiry Learning (POGIL) (Cole et.al, 2007), Think-Aloud Pair Problem Solving (TAPP), Brainstorming, Team Pair Solo (Ogunleye, 2011), Fishbowl (Beck, 1999), Jigsaw (Marhamah & Mulyadi, 2013), Exercise worksheets with visualization (Laakso et.al., 2009), Flipped classroom with visualization (Hansen et.al., 2000), Online quiz (Grissom et.al, 2003), Role play (Naidu et.al, 2000) and many others. The strategy set obtained at the end of (i) is a representative set of active learning strategies since they represent strategies that have proved successful in classroom teaching. We do not claim it to be complete. But it serves our purpose of shortlisting a set of example strategies that have a defined implementation protocol and is successful in classroom setting.

As part of (ii), we shortlisted strategies compatible with our research context from the representative set by applying a set of five filters in sequence. These filters are:

- i) *Setting* – Only active learning strategies executable in face-to-face instructor-mediated classroom setting was chosen. A large set of strategies was obtained after application of this filter.
- ii) *Research-evidence based* – The next filter applied was to narrow down the set of strategies to those which have proved effective in teaching the identified objectives.
- iii) *Conformance to cognitive process (objective)* – The strategy set for CuVIS framework should support the cognitive process outlined in the CuVIS framework guidelines for a particular topic. For example, the procedural understanding objective requires the instructor to break down the activity into modules, sequence them, frame questions on the modules and subsequently give questions that would help students integrate the modules into a whole. Multiple strategies like TPS and Think Aloud Pair Problem Solving (TAPP) were found suitable for such guidelines. But TPS was chosen as the representative strategy for the TPS family of strategies like TAPP, Think-Pair-Square-Share and Think-Write-Pair-Share. Same logic was applied for choosing the strategy of POE from ILD, Predict – Explain – Observe-Explain (PEOE) and POE.
- iv) *Prior use with visualization* – The resultant set of strategies was further streamlined to contain only those that have prior record of being successfully used with visualization. For example, application of this filter led to the choice of TPS over Team-Pair-Solo. This is because successful use of Team-Pair-Solo with visualization

has not been reported before. A possible reason maybe the essential difference between these two strategies. Team-Pair-Solo is used when topics of high complexity has to be taught (Ogunleye, 2011) and visualizations are known to be not effective for topics of high complexity (Urquiza-Fuentes, 2012). TPS, on the other hand, is used when learners need to explore a newly taught topic (Johnson & Aragon, 2003). Thus, the strategy set now contains strategies like Peer Instruction (PI), Think-Pair-Share (TPS) and Predict-Observe-Explain (POE), POGIL that have been shown to be effective in teaching with visualization.

- v) *Instructor effort* - Those strategies were shortlisted for CuVIS framework that require comparatively low instructor effort in execution. This was an important filter since the target audience of CuVIS framework are instructors who are novice designers. For them classroom enactment of these low instructor effort active learning strategies is itself a challenge like framing constructively aligned activity question which is based on visualization, managing the class after group formation and subsequent discussions. Thus, a strategy like POGIL that has been successfully used with visualization for inquiry objective (Cole et.al, 2007) was not included in CuVIS framework. POGIL requires high instructor effort of not only supervising student group formation and managing the class but also supervising the different roles in each group are being carried out properly.

After application of this five-layer of filters, the example strategies chosen for CuVIS framework were PI, TPS and POE. These strategies were mapped to objectives as well as customization parameter of activity time requirements specified by the instructors – ranging from 5-10 mins. (short activity) to 15 -20 mins. (long activity) (Table 5.8). Our objective was to equip instructors to design student-centered activities using visualization themselves. They should become adept at the basic building blocks of active learning so that they can adapt and build on these strategies for their context. To achieve this, we could have given the instructors a basket of 10 active learning strategies that have passed through the set of five filters stated in the thesis. The instructors would have picked and chosen a strategy from a larger set. With this solution instructors are less likely to become adept at mastering the essence of active learning using an ICT tool and customize it to their requirements. The second option was to provide instructors with a smaller subset of 3 strategies (PI, TPS, and POE) – a representative set that encompasses strategies for a variety of customization parameters like different

bloom's level objectives and different time duration specifications. These strategies shortlisted for CuVIS framework contain the basic building blocks of active learning. Instructors are more likely to master the building blocks of active learning through the smaller set and later on build on them and adapt them to their context.

Table 5.8: Active Learning Strategies mapped to objective and activity time requirements

<i>Sr.No.</i>	<i>Objective/Skill</i>	<i>Activity Time</i>	<i>Strategy</i>
1	Conceptual Understanding	5 – 10 mins.	PI
		15 – 20 mins.	TPS
2	Procedural Understanding	5 – 10 mins.	TPS
		15 – 20 mins.	TPS
3	Predicting Process	5 – 10 mins.	PI
		15 – 20 mins.	POE
4	Predicting Phenomenon	5 – 10 mins.	PI
		15 – 20 mins.	POE
5	Multiple Representation	5 – 10 mins.	PI
		15 – 20 mins.	TPS
6	Inductive Reasoning	5 – 10 mins.	PI
		15 – 20 mins.	TPS
7	Multi-process problem solving	5 – 10 mins.	TPS
		15 – 20 mins.	TPS

This mapping is based on conformance of features of the shortlisted strategies with the constructive alignment guidelines for a particular objective as also time customization parameter (Table 5.9). In case of objectives where multiple shortlisted strategies were in contention, CuVIS framework chose that strategy that has a proven track record of being successful with visualization for that objective. For example, for objective = Prediction and time requirement of 15 -20 mins, both POE and TPS conform to CuVIS framework guidelines. But POE has been far more used and with success in contrast to TPS for Prediction objective with visualization. Hence, POE was picked for Prediction objective.

Table 5.9: Illustrating mapping logic between objective, time and strategy

<i>Objective</i>	<i>CuVIS framework guidelines</i>	<i>Justification for choice of strategy</i>
1. Prediction	<ul style="list-style-type: none"> ● Pause visualization before you show the nth condition set. ● Ask ‘what-if’ prediction question involving the nth condition set. ● Ask guiding questions that focus students’ attention on how does the cause & effect occur. ● Conduct class-wide discussion on student prediction & reasoning. ● Highlight important points emerging from the class-wide discussion. Do not provide your explanation yet. 	<p><i>Chosen Strategies: POE (15-20mins.) & PI (5- 10 mins.)</i></p> <ul style="list-style-type: none"> ● POE tailor-made for this objective. The 1st phase of POE – Prediction requires students to frame their hypothesis with reasoning. Instructor can ask guiding questions & discuss.
		<ul style="list-style-type: none"> ● In PI, students respond to ‘what-if’ question posed by choosing a hypothesis from the given options. ● Then they vote individually.
	<ul style="list-style-type: none"> ● Now show the nth condition by resuming the visualization with parallel commentary. 	<ul style="list-style-type: none"> ● In POE, this corresponds to observation phase where students see the phenomenon/ process & rethink their hypothesis.
	<ul style="list-style-type: none"> ● Now provide your explanation of how the cause & effect is happening ● Ask students to compare their prediction with their observation 	<ul style="list-style-type: none"> ● In PI, this corresponds to students observing the phenomenon/ process & rethink their hypothesis. ● They form groups and reason their choice of hypothesis with group members & vote. ● In POE, this corresponds to Explain phase. In both POE & PI, this phase involves instructor providing explanation. Students comparing their prediction with what is shown.
2. Procedural Understanding	<ul style="list-style-type: none"> ● Use the visualization to introduce the problem students have to solve ● Decompose the procedure that students have to follow to solve the problem, into steps ● Arrange the steps in sequence. <p>Give sub-questions mapped to each step of the process.</p>	<p><i>Chosen: TPS (15-20 mins.)</i></p> <ul style="list-style-type: none"> ● TPS activity question requires the activity to be broken down into modules. ● The modules are arranged in sequence. ● Questions mapped to the initial set of modules is given to students in the ‘Think’ phase to solve.
	<ul style="list-style-type: none"> ● The last sub-question should prompt students to integrate the solutions to previous questions 	<ul style="list-style-type: none"> ● Students then group & discuss their solutions of ‘Think’ phase. ● The question of the ‘Pair’ phase prompts students to integrate and build on the ‘Think’ phase answers to arrive at final solution.
	<ul style="list-style-type: none"> ● Do class-wide discussion on the solution ● Highlight the important points in discussion ● Play the visualization with parallel explanation 	<ul style="list-style-type: none"> ● In the ‘Share’ phase students share their group solution with the class, see the solution through visualization & compare their solution with what is shown. ● Other shortlisted strategies like PI & POE do not allow presentation of the problem in chunks.

5.4.2 Designing CuVIS framework guidelines for framing group activity question

Once the example active learning strategies were shortlisted, their implementation protocols were studied. Guidelines were framed for activity question creation as per the cognitive process of the selected objective as also the implementation protocol of the strategy. For example, for objective = Multiple Representation and activity time duration = 15-20 mins, the strategy suggested is TPS. The cognitive process to attain constructive alignment demands the activity question include either relating between two representations or include both relating and translating between representations (van der Meij & de Jong, 2006). To align with the TPS implementation protocol, CuVIS framework gives guidelines to frame the relating stage as ‘Think’ phase question and translating between representations as ‘Pair’ phase question (Fig. 5.3). Hence, the activity question guidelines vary for the combination of objective and the activity time duration specified.

<p>Step 5 – Frame the ‘think-pair-share’ question based on the visualization</p> <p><u>Guidelines for framing ‘Think’ phase questions:</u></p> <ul style="list-style-type: none"> • Frame a question whose solution can be shown through visualization. • Break down the activity into modules or steps • Question should map to the initial module(s)/steps like identifying parameters that need to be changed in given representation from the problem statement • Then start off with the initial steps of construction of the alternate representation (e.g. graph or equation or model) • There should thus be a clear deliverable. 	<p>Step 5 – Frame the ‘think-pair-share’ question based on the visualization</p> <p><u>Guidelines for framing ‘Pair’ phase questions:</u></p> <ul style="list-style-type: none"> • Question should be connected to ‘Think’ phase question but should be of higher difficulty • Question should lead students to build on the ‘Think’ phase deliverable like constructing the final alternate representation • Question should ask students to judge each other’s reasoning and solution to ‘Think’ phase question. • Clear deliverable for the group
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Figure 5.3: Guidelines for ‘Framing activity question based on visualization’ for Strategy = TPS & Objective = Multiple Representation

5.4.3 Designing CuVIS framework guidelines for implementation design

CuVIS framework provides implementation design guidelines through the LD Blueprint template. The template contains the CuVIS framework LD layout (Fig. 1.3) with outline of the execution flow of the activity designed. It is mapped to the cognitive process

corresponding to the selected objective as also the implementation protocol of the selected strategy (Table 5.10). The implementation protocol for a particular strategy, including time allocation for each step in the strategy, is determined through literature survey. The process followed to design LD Blueprint is illustrated with the example of ‘Think-Pair-Share’ (TPS) strategy.

The implementation of TPS strategy starts with the instructor posing the problem to be solved. Students work on the problem individually for a short time (Think), then discuss in pairs (Pair). Subsequently, instructor calls on the student pairs to share their solution and initiate a class-wide discussion (Share) (Borrego et.al, 2013). The components critical for a strategy to be classified as TPS are: (a) discussion of problem in small groups, (b) sharing of group solution with rest of the class before class session can proceed, (c) involves engagement with content through reflection and peer interaction (other than watching/listening/taking notes) (Borrego et.al, 2013). Other research studies specify the time budgeting for the strategy from empirical evidence like TPS typically requires 1-2 minutes of individual thinking followed by 2-3 minutes of Pair phase and 3-5 minutes of Share phase (Larson et.al, 2008). In fact, the time budget is proportional to the student strength. If it is above 60, which is the norm in our target context, the Pair phase is recommended to be of 5 mins. with a share phase discussion of 10 mins. (Bonwell, 1996). These timings for TPS has been also validated in context of instructor-mediated classrooms through implementation in field settings (Banerjee et.al, 2014). The sequence of implementation steps in all ‘LD Blueprint’ for TPS activity adheres to this implementation protocol emerging from literature survey.

However, the content of the steps would change depending on the objective due to differing cognitive process to accommodate. For example, TPS is the example active learning strategy chosen for activity time duration = 15-20 mins. and objective = Multiple Representation/ Inductive Reasoning. Hence, both the ‘LD Blueprints’ will have the group activity executed in three phases – ‘Think’, ‘Pair’ and ‘Share’ phases. But the ‘Multiple Representation’ blueprint will have activity design targeting the phases of relating and translating between two representations (Jonassen & Ionas, 2008). In contrast, the ‘Inquiry-based learning’ blueprint will have activity design targeting the five phases of orientation (observation), conceptualization (questioning, hypothesis generation), investigation (experimentation, data interpretation), conclusion (validating hypothesis) and discussion (communication, reflection) (Pedaste et.al, 2015). Table 5.10 presents a sample LD blueprint.

Table 5.10: Sample ‘LD Blueprint’ for Objective = Multiple Representation & Activity duration = 15 -20 mins. (Instructor design decisions to be inserted in placeholders marked in red & white)

Learning Design for ‘<Topic Name>’ :				
Domain = <.....>; Course Name = <.....>				
Topic Name = <.....>				
Objective = <.....>				
Visualization URL = <.....>				
Setting = <.....>; Time Duration = <.....>; Strategy Suggested = <.....>				
Step No.	Time (mins.)	What Instructor Does	What Student Does	Visualization affordance used, if any
1	2	Play the visualization for the multiple conditions: <Enter the multiple condition sets>	Listens & Observes	Play button
2		Pause the visualization at this point. < Insert screenshot of the point where visualization is to be paused to ask the activity question>	Listens & Watches	<ul style="list-style-type: none"> Pause button Slider bar Dynamic linkage Simultaneous representation
3	3-5	Pose the activity question : <Insert parent question>		<ul style="list-style-type: none"> Pause button Slider bar
4		Show Think phase: <Insert Think phase question>	<u>Individual Activity</u> • ‘Thinks’ about the answer for 2 – 3 mins.	
		Ask students to think individually & write down their answer with reasoning	Writes down the answer with reasoning	
5	5- 10	<ul style="list-style-type: none"> Ask students to form groups of 2-3. Ask students to discuss their answers of ‘Think’ phase question Pair Phase: Show question <ul style="list-style-type: none"> - Discuss your answer + reasoning if you do not agree with your friend’s answers - You can also change your answer - Together agree on a final answer - <Insert Pair phase question> 	<u>Group Activity</u> <ul style="list-style-type: none"> Teams up & discusses their ‘Think’ phase answers with group members Discusses & writes down solution to ‘Pair’ phase question as a group 	
6	12 -15	• Ask random student groups to share their solutions with the class. Highlight important points of each answer.	<u>Group Activity</u> Presents their group solution to the class.	
7		<ul style="list-style-type: none"> After 5-10 mins., show the ‘Share’ phase question a) Compare your answer 	<u>Group Activity</u> Compares their solution with what is shown on-	

		with what is shown <ul style="list-style-type: none"> • b) <u>Underline the errors</u> you found in your solution 	screen	
		<ul style="list-style-type: none"> • Run the visualization with the given input value. 	<ul style="list-style-type: none"> • Notes the difference, if any, with their solution • Receives instructor feedback on their errors 	<ul style="list-style-type: none"> • Play-Pause button • Slider bar • Dynamic linkage • Simultaneous representation
8		End the session by connecting the topic to Real-life, if activity question itself was not place in real-life context: <p style="color: red;"><Insert real-life connection></p>		

5.5 Developing the CuVIS framework

The development phase of CuVIS framework comprises of three steps (Fig. 5.1) - (5) Developing the CuVIS framework prototype (Section 5.5), (6) Testing of CuVIS framework prototype (Section 5.5.1) and (7) Final CuVIS framework (Section 5.5.2). The design and development phases progress in iteration with each other leading up to the final CuVIS framework. The objective of this phase is to (i) develop the framework prototype by integrating the guidelines at appropriate steps of the LD creation process and (ii) evaluate the prototype iteratively with instructors leading up to the final CuVIS framework. The guidelines are presented to the instructor in steps of the LD creation process based on the ADDIE model of instructional designing (Fig. 5.4). This provides the needed structure to the LD creation process that is required for novice designers (Kali, Y. & Ronen-Fuhrmann, T., 2011).

Thus the CuVIS framework guides the instructor through the steps of – Resource Analysis (via visualization selection checklist, strategy selection), Learner and Content Analysis, Design constructively aligned, meaningful activity, Design group activity question (via Activity Constructor prompts) and Design activity implementation for the classroom (via LD Blueprint). The context analysis is by default built into the CuVIS framework guidelines. The conceptual and implementation design guidelines are integrated into CuVIS framework through Activity Constructor prompts and LD Blueprint respectively. Examples of Activity

Constructor prompts are like Deciding which part of the topic to target with visualization depending on learners' difficulty, Deciding what and how to present real-life application of the topic, Deciding which variable values to change to show the system under multiple condition sets, Deciding where to stop the visualization to launch the activity etc. (Table 5.7). Each prompt represents a design decision and is accompanied by an illustrative example of the guideline from the instructor's domain for better comprehensibility. Instructors then plug in their responses to the prompts at appropriate steps in the LD Blueprint template. The domain examples are generated in consultation of ET researchers who are also college instructors. The number of prompts and their content as also the blueprint content varies with the combination of the selected objective and activity time duration required.

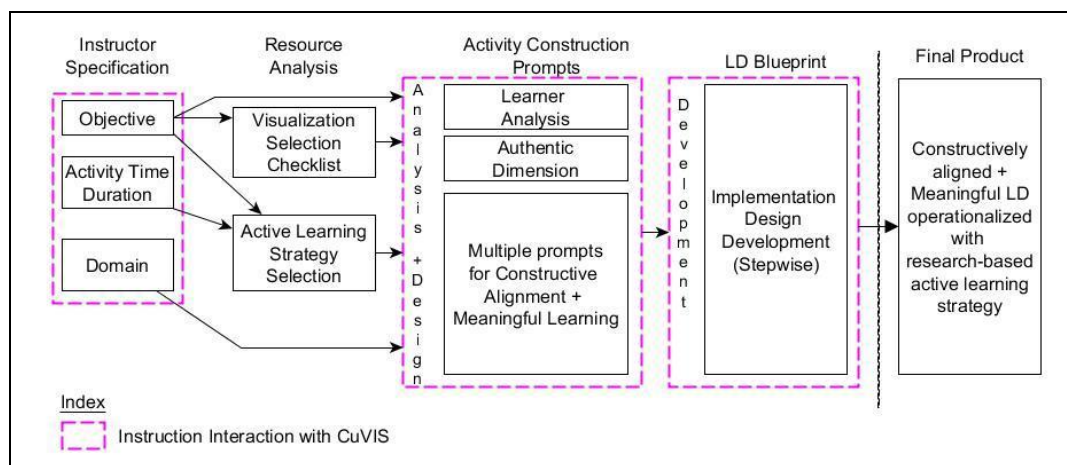


Figure 5.4: Block Diagram of CuVIS Framework functioning (Fig. 1.1 repeated)

5.5.1 Prototype testing of CuVIS framework

Different versions of the CuVIS framework prototype was tested in four iterations with the target user population i.e. instructors who are novice designers. In each iteration instructors used the CuVIS framework to generate an LD for teaching with visualization for their chosen topic. Instructor feedback was then collected on the design of the conceptual and implementation level guidelines. In iteration – 1, instructor feedback was gathered on comprehensibility of the conceptual guidelines presented through the Activity Constructor prompts. Focus group interviews were conducted with ten instructors from the domains of EE

and CSE. The interview feedback recommended more detailed instruction for some of the conceptual guidelines like those on framing group activity questions.

Iterations 2, 3 and 4 were conducted to gather feedback on the usability of the implementation level guidelines presented through the LD Blueprint. In each of these iterations semi-structured interviews were carried out with individual instructors. In iteration 2, the usability of LD Blueprint ver.1 is tested for comprehensibility. This version was a generic interaction diagram between instructor and students representing the implementation protocol of the chosen strategy (Fig.5.5). Instructors were expected to adapt it to their context. However, instructors wanted more detailing in the blueprint like time duration specification for each step.

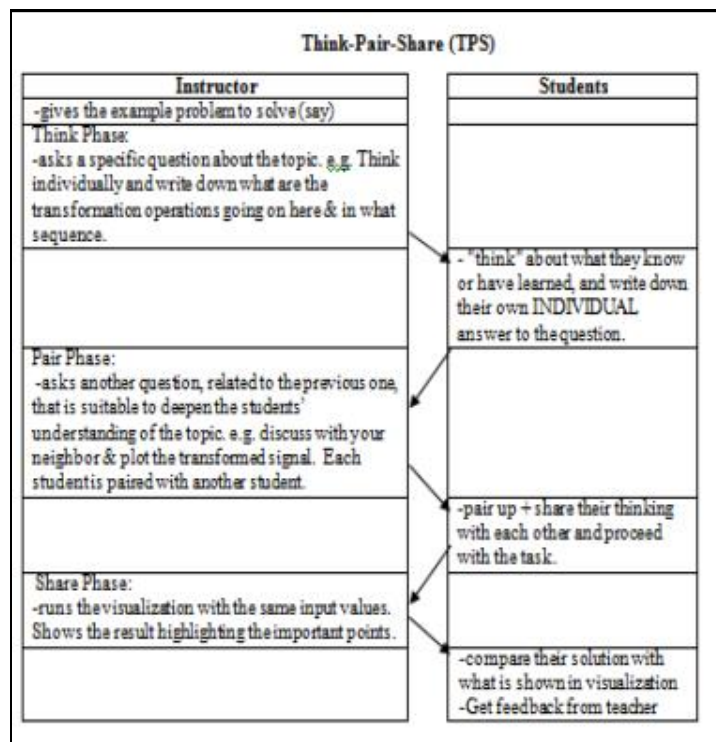


Figure 5.5: LD Blueprint Ver.1

This led to the development of version 2 of the blueprint (Fig. 5.7). In this version, color coding was introduced in the 'LD Blueprint' to clearly point out which visualization affordance to use, at what step and to depict the implementation flow. Also, two rows were added to the blueprint. One row contained activity design tips for each step of the chosen active learning strategy. The second row contained a best practice example from the domain

for the same objective. Feedback received at end of prototype testing of blueprint ver.2 was that instructors still faced problems in applying it to their requirements. They wanted a ‘fill-in-the blank’ template where many of the implementation guidelines for conducting group activity in their context would already be encoded.

'MR' Learning Design						
Instructional Objective with visualization		Visualization should :				
Write/Draw alternate representations from the given visualization or vice-versa.		i) Show all multiple representations simultaneously on-screen ii) Take user input to modify a representation iii) Simultaneously reflect modification done in 1 representation in all the other representation (s) iv) Reflect modification stepwise when multiple modifications done				
STEP	Step 1		Step 2		Step 3	
Phase	Think		Pair		Share	
Time	3-5 minutes		5-10 minutes		12-15minutes	
Who	Instructor	Student	Instructor	Student	Instructor	Student
What	A. Write an initial (seed) question where students will relate both representations themselves. For e.g. Refer below. B. Pause the visualization to show initial state of both representations on-screen	INDIVIDUAL Activity A. 'Thinks' about what they know B. Writes down answer to seed question i.e. relating corresponding variables in both representations	A. Ask follow-up question wherein students will write or draw the alternate representation as per the modification specified in question	GROUP Activity A. Teams up & shares their answers to seed question with team members B. Proceeds with answering follow-up question as a group	A. Invite few student groups to share their answers with class B. Run the visualization with same input values as in Step 1. C. Highlight important objects/ actions in the system & the causal relation between them D. Summarize & move on	GROUP Activity A. Compares their solution & notes the difference with solution shown through visualization B. Gets instructor feedback on their solution
Activity Design Tips	A. Question should be broad enough for every student to attempt. B. There should be a clear deliverable like students relating corresponding variables across representations.		A. Make student groups of 2-3. B. Question connected to seed question but of higher difficulty like students drawing the alternate representation. C. Clear deliverable for the pair D. Question specific enough to lead into the discussion you want to carryout later.		A. Anticipate a few likely responses B. Give about 1 min. to each group to explain their answer C. Highlight important points of each answer D. Invite answers that are conceptually different from previous ones E. Measure of success: Many of the points you wanted to convey got covered already	
Example	Relating with viz. If $y(t) = (x - 4t/2)$, where $x(t)$ signal curve is shown on-screen: a) Identify the transformation operations. b) Identify their sequence		Translating a) Identify errors, if any, in each other's 'Think' phase answer b) Together draw stepwise the final transformed signal.		Dynamic feedback from visualization a) Share your solution with class. b) Now compare your solution with solution shown in visualization c) Mark out the errors in your solution & reflect why	

Figure 5.6: LD Blueprint Version 2

This led to the version 3 i.e. the final version of LD Blueprint (Table 5.10). This version was tested with six instructors from the target user population and from the domains of EE and CSE using the same methodology as in previous rounds. Instructors indicated satisfaction with the third version of the blueprint. In each of the three rounds there was no overlapping between the instructor sets to avoid any bias in judgment.

5.5.2 Output: Final CuVIS framework

In this chapter the Design and Development phase followed to build the CuVIS framework was described. The final CuVIS framework emerged after four rounds of prototype testing with the target user population of science and engineering instructors. The CuVIS framework attempts to strike a fine balance between being open-ended and a rigid template, yet be usable and useful to instructors who are novice designers. At every step in the development phase instructor feedback is taken and they are co-participants in developing the framework. The framework walks the instructors through the steps of Analysis, Design and Development of the LD creation process through the Activity Constructor prompts and the LD Blueprint.

A snapshot of the CuVIS framework is given in Sec. 5.3.5 (Fig. 5.2). The CuVIS framework guidelines address each of the four identified design impediments. The guidelines are at both conceptual and implementation levels. The customization is captured through variation in guidelines in terms of domain, objective and activity time duration. The objective selected forms the centerpiece of CuVIS framework. A change in objective changes the entire set of CuVIS framework guidelines – conceptual as well as implementation. The customization to domain is in terms of the illustrative examples that accompany each guideline. In the current version of CuVIS framework, such domain examples have been generated in two engineering domains – Computer Science and Engineering (CSE) and Electrical Engineering (EE). These two engineering domains are chosen since CSE addresses computational systems while EE represents dynamical natural systems. The guideline set also changes with the activity time duration specified. The combination of objective and activity time duration determines which active learning strategy will get chosen. Accordingly, the guideline for framing group activity questions and the implementation design guidelines change. Complete version of the CuVIS framework is given in Appendix A.

Chapter 6

Impact of CuVIS framework on instructors' design expertise

6.1. Introduction

In the current and following chapter we present the summative evaluation phase of the CuVIS framework (Fig.6.1). In this chapter we focus on the impact of CuVIS framework on instructor's design expertise. Design expertise is defined as the knowledge and skill required to 'enact a design process' as well as the knowledge of content, learner and context (Huizinga, 2014). For CuVIS framework, this means CuVIS framework guides instructors through the LD creation process by assisting them in taking appropriate design decisions related to Analysis (learner, content, context), Design (activities using visualization affordances and formative assessment designs) and Development (integrating the design decisions into an implementation plan) phases of the process. CuVIS framework functions by guiding

instructors to themselves create a best practice example for teaching using visualization customized to their context. Research has shown that learning occurs while designing, particularly when designing artefacts for others to learn with (Papert, 1991). We wanted to harness this learning and explore if CuVIS framework can be used to have a long-term effect in developing instructor’s design expertise.

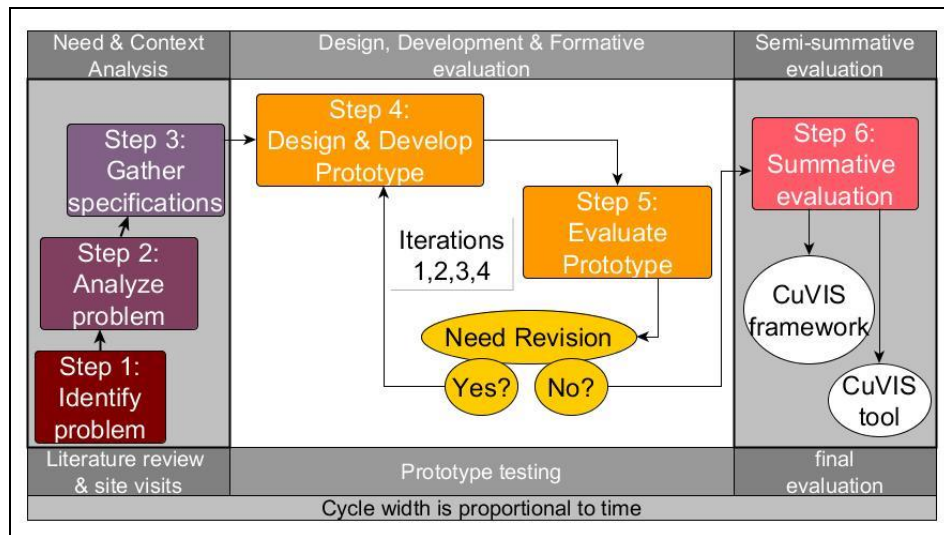


Figure 6.1: Design & Development Research (DDR) phases (Fig.3.2 repeated)

In Section 6.2 existing instructional models/frameworks that target instructor’s design expertise are discussed. In Section 6.3, existing training models for developing instructors design expertise with ICT tools are presented. In Section 6.4, we present an instructional pathway using the CuVIS framework and its effectiveness in developing instructor’s design expertise is documented. In Section 6.5, we present the rubric that was used to assess instructors’ design expertise for constructive alignment and meaningful learning from analysis of their LDs. In Section 6.6, analysis of interviews with instructors who used the CuVIS framework are analyzed and features of CuVIS framework are identified that instructors found useful in contributing to the development of their design expertise. Section 6.7 concludes the chapter by discussion on the impact of CuVIS framework on instructor design expertise.

6.2. Developing instructors' design expertise

Instructors' design expertise refers to the knowledge and practice needed for executing the design process composed of the following phases - analysis, design, development, implementation and evaluation. It also includes instructor's knowledge of their learners, content and context (Huizinga et.al, 2014). 21st century instructors are expected to design such instruction using affordances of the chosen ICT tool like visualizations, wikis, mobile apps etc. Thus they need to acquire technological pedagogical content knowledge (TPACK) as well as the practical skills needed to apply this knowledge to effectively incorporate new technology tools in their teaching. In recent times teaching has been positioned as design science (Laurillard, 2012) because like in other fields of design, here too reflective instructors go through the stages of design science starting from need analysis of the learners to design and development of instruction to address that need to implementation and evaluation stages of how the instruction needs to be further tailored to better satisfy learners' requirements.

Some researchers have used learning by design approach to develop instructors' design expertise for technology enhanced learning (TEL) (Kali & Ronen-Fuhrmann, 2011; Mor & Mogilevsky, 2013). In this approach student-instructors learn through designing artefacts for teaching their students. One such training model is the Learning Design Studio (Mor & Mogilevsky, 2013) that adopts an open-ended, reflective studio approach wherein learners design artefacts in groups, receive formative feedback from peers and refine their design. Effectiveness evaluation of this model has been tested through three case studies. The findings suggest this training model can be successful when there is instructor commitment of carrying out the entire studio approach given that it places substantial time demand on learners.

Research in instructors' design expertise recommends the ideal training model should be a blend of open-ended and structured approaches (Kali & Ronen-Fuhrmann, 2011). Kali & Ronen-Fuhrmann (2011) developed such a training model that integrated three elements - a) open-ended studio approach, b) ADDIE model and c) a repository of expert design knowledge. The study found the step-by-step structure of the ADDIE model helped concretize novice instructors' design ideas. However, expert design knowledge is also required so that instructors do not end up with LDs that lack sound pedagogy (Brown, 1992). Both

concretization and bridging the knowledge gap between expert and novice designers is facilitated by the open studio method.

6.2.1 Design of training workflow with CuVIS framework

The training workflow of CuVIS framework contains three rounds with instructors receiving varying degrees of support at each round. The rounds are – ‘Warm up’, ‘Scaffold’ and ‘Transfer’ with a time interval of an average of three-four months between the last two rounds (Fig. 6.2). Each round is split into ‘Visualization Selection’ and ‘Visualization Integration’ sections. In the ‘Visualization Selection’ round instructors choose the topic to teach, the instructional setting (Lecture/Tutorial), the visualization and the learning objective with visualization. In all three design rounds the learning objective with visualization remains a constant i.e. if an instructor chooses Prediction objective in ‘Warmup’ round they will carry forward the same objective in the two subsequent rounds. In the ‘Visualization Integration’ section instructors design student-centered, constructively aligned, meaningful LDs for their chosen scenario.

The design of the training workflow in CuVIS framework incorporates elements from Kali and Ronen-Fuhrmann’s (2011) instructional model. Their model consists of three elements – a. ADDIE structure, b. use of design principles database (DPD) and c. studio approach to instruction. These elements were applied to the CuVIS framework context of self-learning, individual design activities, to create the training workflow. Fig. 6.2 below shows how the ADDIE structure has been used in the training workflow. The database of the theory-informed, research-evidence based CuVIS framework design guidelines play a role similar to that of the DPD. The third element is the studio approach to instruction. It consists of multiple open-ended design activities involving feedback from mentors and peers. In the context of CuVIS framework training workflow, this third element had to be modified into the self-learning scenario involving multiple open-ended design activities (‘Warm up’ and ‘Transfer’ rounds) but with feedback from mentor only. Peer feedback was not logistically feasible.

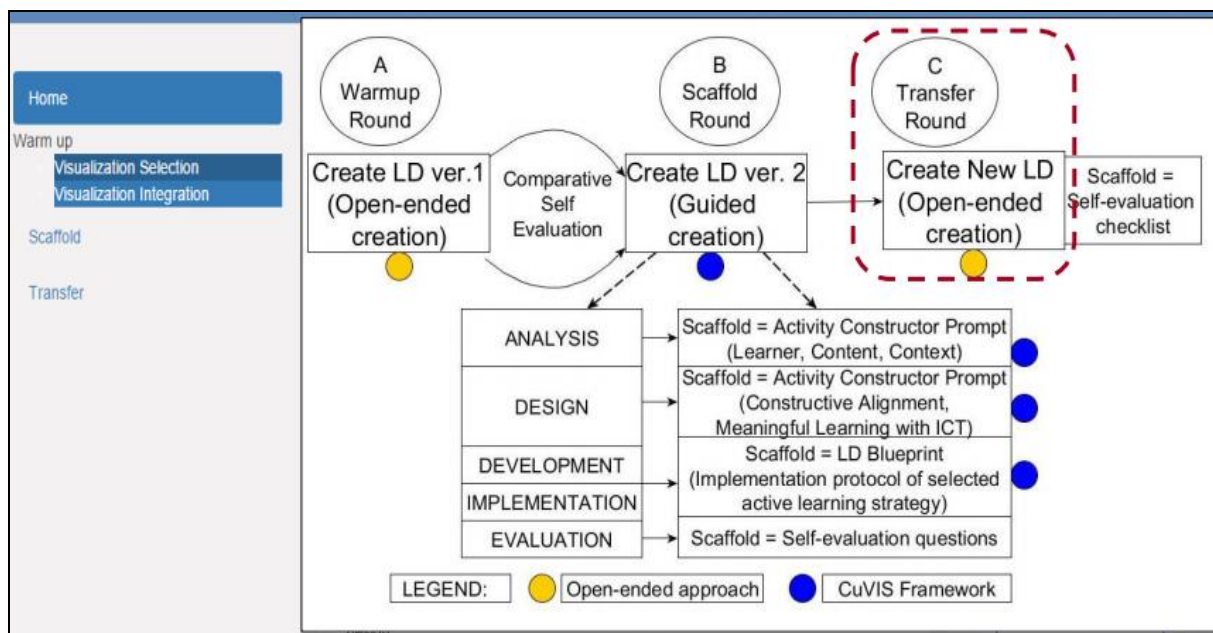


Figure 6.2: Training workflow with CuVIS framework

6.2.2 Functioning of the CuVIS framework training workflow

In the ‘Warm up’ round, instructors create an unguided LD for a classroom learning scenario of their choice. The instructors draw on their teaching experience to execute the open-ended design activity. They apply their technological pedagogical content knowledge (TPACK) to create an LD by filling up the LD table (Fig. 4.3). The only guidance available to them are the column headings of the LD table which act as prompts for instructors on what specifications to provide within the LD.

In the ‘Scaffold’ round they use the CuVIS framework to re-design their LD of the ‘Warm up’ round. The CuVIS framework guidelines provide instructors with access to expert knowledge that is required to achieve constructive alignment and meaningful learning in the LD. The ‘Activity Construction’ prompts of CuVIS framework walks the instructor through the step-by-step flow of the ADDIE model – Analysis (Learner, Content, Context), Design (design of learning activity with visualization and framing activity question mapped to objective) , Development (implementation plan of designed activity) and Evaluation (Fig. 6.1). At each stage of the ADDIE model, instructors are provided with guidelines and illustrative examples from their domain. In the Evaluation phase, instructors are provided with

guiding questions as scaffolds to do a self-reflection activity of comparing the LDs created in the first two rounds to articulate how the two differ and what they have learnt through the comparison activity. This reflection activity is guided by a set of questions like Q1) Can you list what new things you have learnt going from your first learning design (unguided) to the second (guided)?; Q2) For the benefits you have identified above, can you list what features/guidelines provided in CuVIS framework have helped you achieve the positive change/learning stated above? This activity prompts the instructor to reflect on the gap between their knowledge and the expert knowledge. This is a manifestation of the research finding that development of instructor's design expertise is aided by instructor's reflection of their own practice (Davis & Varma, 2008).

In the 'Transfer' round they create an LD on a new learning scenario of their choice but for the same objective without using CuVIS framework. They are provided scaffold of a self-evaluation checklist that reminds them of the six dimensions that should be incorporated – five dimensions of meaningful learning and the dimension of constructive alignment. It does not tell them how to operationalize it. The conjecture is they should have acquired the requisite knowledge of how to operationalize the theoretical guidelines after their interaction with CuVIS framework.

6.2.3 Scaffolds used in the training workflow

A number of scaffolds have been designed to help instructors to develop their design expertise (Fig. 6.1). Scaffolds like the Activity Constructor prompts and the LD Blueprint come as part of the CuVIS framework. The CuVIS framework guidelines with illustrative examples from the instructor's domain enables instructors to gain knowledge of how to operationalize the teaching principles of constructive alignment and meaningful learning. While Activity Constructor prompts provide conceptual guidelines, the LD Blueprint provide implementation level guidelines about the implementation protocol of the selected research-evidence based active learning strategy like Peer Instruction, Think-Pair-Share and Predict-Observe-Explain.

The additional scaffolds developed for the training workflow system are the reflection scaffolds that are provided during open-ended design activity rounds – (i) Guiding questions

that support the activity of comparative evaluation between LDs of ‘Warmup’ and ‘Scaffold’ rounds. (ii) The other reflection scaffold is the self-evaluation checklist used in the ‘Transfer’ round (Table 6.1). The purpose of the checklist is to remind instructors of what pedagogical dimensions should be included to make their LDs effective without telling them how to design for them. The pedagogic points column in Table 6.1 correspond to the five dimensions of meaningful learning, constructive alignment and implementation protocol of chosen active learning strategy. The reflection questions column in Table 6.1 includes questions on two themes. (i) It specifies the level of detailing to include in implementation design to guard against implementation errors. This is important since instructors are not accustomed to planning in detail (Lim & Hang, 2003) and often revert back to instructor-directed teaching even while professing to use constructivist teaching methods (Borrego et. al, 2013). The specifications for the detailing level evolved from the common errors we spotted during our analysis of unguided instructor LDs and instructor interviews thereof. (ii) Some of the reflection questions also raise a flag for common design errors committed by instructors like the activity designed incorporates active learning but not based on visualization. The self-evaluation checklist was tested with instructors to improve its comprehensibility in two iterative cycles. Given below is the final version of the checklist.

Table 6.1: Checklist for self-evaluation of LD with visualization

<i>Sr. No.</i>	<i>Pedagogic points to include in your learning design</i>	<i>Reflection questions: Check if you are able to answer yes to below questions. If you get a single ‘No’ answer, please modify your learning design</i>
1	Active learning with visualization	i) Is learning design is given in chunks in range of 2 – 5 mins. ? ii) Are students doing an <u>activity with the visualization</u> for more than half of the lesson time? Enter Your response [i.e. an example of how you have included this in your learning design]:
2	Cooperative	i) Is it clearly mentioned which step of the learning design is going to be a group activity & which will be an individual activity? ii) Is it clearly mentioned what group work students will do together (e.g. Discuss/Draw/ Model/ Solve)? Enter Your response [i.e. an example of how you have included this in your learning design]:

<i>Sr. No.</i>	<i>Pedagogic points to include in your learning design</i>	<i>Reflection questions: Check if you are able to answer yes to below questions. If you get a single 'No' answer, please modify your learning design</i>
3	Constructivist	i) Does the learning activity designed with the visualization need students to <u>apply</u> what they have been taught by the instructor? Is the learning activity an extension of what the instructor has just taught? ii) Are <u>specific</u> instructions given to students to reflect on the solutions they have come up with? Enter Your response [i.e. an example of how you have included this in your learning design]:
4	Intentional	Is there specific instruction from the instructor that makes students self-diagnose their errors & try to fix it themselves? Enter Your response [i.e. an example of how you have included this in your learning design]:
5	Real-life connection	Has the instructor included a real-life application of the topic like the activity question is based on a real-life problem related to the topic? Enter Your response [i.e. an example of how you have included this in your learning design]:
6	Alignment to objective	i) Is your activity question based on the visualization? ii) Is your activity question student-centered and involves group activity? iii) Is your activity question mapped to your objective? iv) Does your activity design follow the CuVIS framework guidelines for mapping to your objective? Enter Your response [i.e. an example of how you have included this in your learning design]:
7	Implementation Design	v) Does the learning design follow the implementation steps specific to your chosen active learning strategy for proper impact? Enter Your response [i.e. an example of how you have included this in your learning design]:

6.3. Assessing development of instructor's design expertise

Instructor's design expertise has been assessed in previous research studies in multiple ways like surveys and qualitative studies. For example, in the 'Learning Design Studio' (LDS) model, the effect on design expertise was captured through instructor survey and anecdotal evidence (Mor & Mogilevsky, 2013). Kali & Ronen-Fuhrmann's (2011) evaluated the impact of their training model on design expertise through content analysis of instructors' design artefacts, their reflective journals, surveys and online discussions. Again, Koh (2013) used a rubric to assess the impact on design expertise in terms of instructor's TPACK for designing activities for meaningful learning with ICT from instructor lesson plans. In this thesis, we measure the impact of CuVIS framework on design expertise by (i) assessing the TPACK levels for designing effective learning activities with visualization and (ii) capturing

the change in pedagogical practice through established techniques of time allocation analysis (Kong et.al, 2011) and temporal sequence of activities (Laurillard & Ljubojevic, 2010) (Section 6.5).

In this subsection we present the rubric that is used to measure the change in TPACK levels from ‘Warmup’ to ‘Transfer’ round. It is based on Koh’s (2013) rubric and extended to include the criterion of constructive alignment (Table 6.2). Therefore, this rubric has six criteria with a scale of 0-4 measuring TPACK levels for design expertise in terms of meaningful learning and constructive alignment. The different levels for the alignment criterion is described in terms of the extent to which the CuVIS framework guidelines for alignment are operationalized. The rubric allows us to quantify the evolution of each instructor’s design expertise through the three design rounds of ‘Warmup’, ‘Scaffold’ and ‘Transfer’. The rubric has been tested for inter-rater reliability. Instructor LDs from the domains of EE and CSE were evaluated by the researcher and two other Educational Technology experts from the two domains. The rubric went through two rounds of iterations with each expert before the Cohen’s kappa value of 0.80 to 0.81 was obtained in both cases. The final version of the rubric is given below.

Table 6.2: Modified rubric to assess TPACK for creation of effective Learning Designs
(adopted from Koh, 2013)

<i>Dimension</i>	<i>0 (Missing)</i>	<i>1 (Inadequate)</i>	<i>2(Developing)</i>	<i>3 (Proficient)</i>	<i>4 (Skilled)</i>
1. Active	Students passively receive subject matter from the media or ICT all the time	There is sporadic use of ICT by students to work with the subject matter	Students using ICT to work with subject matter half the time	There is substantial use of ICT by students to work with subject matter	Almost all lesson time involves students using ICT to work with the subject matter
2. Constructive	ICT tools used for transmission of subject matter rather than meaning-making	ICT tools to support reproduction of subject matter or convergent knowledge expression by students	ICT tool used to support some degrees of divergent knowledge expression by students with respect to the subject matter	ICT tools used by students to synthesize information in order to construct verbal, written, visual, conceptual or product oriented expressions of the subject matter	ICT tools used by students to articulate their personal reflections of the subject matter in form of verbal, visual, written, conceptual or product oriented expressions
3. Authentic	No representations of real-world phenomenon or	ICT tools used to present examples of real-world phenomena or	ICT tools support students to investigate real-world	A problem associated with a real-world phenomenon	Students represent their personal experiences of the real-world

	problems related to subject matter are presented with ICT tool	problems related to subject matter	phenomenon or problems related to subject matter	related to subject matter is used to anchor the activity & investigate	phenomenon/problem related to the subject matter with ICT tools
4. Intentional	Students do not use ICT tools to support them in diagnosing, strategizing about or improving their learning gaps of the subject matter	Students' learning gaps of the subject matter are being diagnosed by instructors/ peers	Students self-diagnose their learning gaps of the subject matter by using ICT tools/resources	Students use ICT tools/ resources to self-diagnose their learning gaps of the subject matter. Thereafter, they are to fix those learning gaps.	Students continually use ICT-based tools/resources to self-diagnose & fix their learning gaps of the subject matter
5. Cooperative	No cooperative activity over ICT platforms/ tools or ICT platforms/ tools are used to share information and resources related to the subject matter but no online discussion occurs	Students work together either around the computer or through the computer in convergent knowledge expression of the subject matter	Students work together either around the computer or through the computer in activities that require some degree of divergent knowledge expression of the subject matter	Students work together either around the computer or through the computer in activities that require a large degree of divergent knowledge expression of the subject matter	Students work together either around the computer or through the computer in activities that require primarily divergent knowledge expression of the subject matter
6. Alignment	None of the CuVIS framework alignment guidelines, for the given objective, have been operationalized with the ICT tool	An attempt has been made but majority of the CuVIS framework alignment guidelines for the given objective, have not been operationalized with the ICT tool	Almost half of the CuVIS framework alignment guidelines specified for the given objective, have been operationalized with the ICT tool.	More than half of the CuVIS framework alignment guidelines for the given objective, have been operationalized with ICT tool.	All of the CuVIS framework alignment guidelines for the given objective, have been operationalized with the ICT tool.

6.4. Study 3 - Effectiveness of CuVIS framework training workflow in developing instructors' design expertise

The focus of Study 3 was to evaluate the effectiveness of CuVIS framework in developing instructors' design expertise. It was captured through evolution of instructors' TPACK for designing (Section 6.4) and change in the instructors' pedagogical practice

through ‘Sequence of activities’ and ‘Time allocation analysis’ techniques. ‘Sequence of activities’ is defined as detailed description of all teaching activities that form part of the teaching method along with their temporal sequence (Laurillard & Ljubojevic, 2011). This is the crucial part of a LD that captures the pedagogical practice of the instructors (Laurillard, 2012). ‘Time allocation’ analysis measures the percentage of time allocated in the LD for different type of activities (Kong et.al, 2011).

A. Research Questions

The research questions answered by this study were:

- RQ2.1: What is the effectiveness of CuVIS framework in improving instructor's TPACK to create effective & customized LDs with visualization?
- RQ2.2: What is the impact of CuVIS framework on instructors' pedagogical practice exhibited through LD?
- RQ2.3: What features of CuVIS framework scaffolds do instructors find effective in developing their design expertise for effective and meaningful LDs with visualization?

B. Participant characteristics

The participants of the study were sampled from within EE and CSE sample units (Refer Section 3.5). These instructors had attended a two-week blended pedagogy workshop, prior to this study. Thus they were exposed to various constructivist teaching strategies like Peer Instruction and, Think-Pair-Share. Participation in the research study was a voluntary activity for the instructors, not a part of any official training program supported by their institute. At the end of the study they got a certificate for participating in this research study. These instructors were shortlisted based on medium to good quality of their LDs submitted during the pedagogy workshop. A subset of seventy instructors were approached for the study. Out of these seventy, sixteen instructors volunteered to participate in the study. Finally, six instructors (Female = 5, Male = 1) completed all the three rounds of ‘Warmup’, ‘Scaffold’ and ‘Transfer’. The average teaching experience was twelve years and their age was in the range of 35 - 45 years. Three instructors were from Tier- II cities and the other three were from Tier-I cities. They have taught UG level courses with visualizations in medium-sized instructor-mediated classrooms of 70 – 100 students.

C. Procedure

CuVIS framework training workflow was tested for effectiveness in a semester long study spanning 6 months. The CuVIS framework training workflow explained in detail in Section 6.3 was applied. A cohort of six Engineering instructors was tracked through the three time points. The LDs produced in the ‘Warmup’ round was treated as pre-test sample i.e. TPACK levels at pre-CuVIS framework stage. The CuVIS framework intervention was introduced in the ‘Scaffold’ round. The ‘Transfer’ round was taken as post-test i.e. TPACK levels after CuVIS framework intervention was withdrawn.” The ‘Transfer’ round LD was evaluated for transfer of expertise acquired in designing constructively aligned and meaningful learning activities with visualization.

D. Data analysis technique

Two data sources were used – the LDs produced by each instructor at each time point and their interviews post the study. The LDs produced by each instructor were evaluated along two axes. Along one axis, they were evaluated to track instructors’ TPACK in terms of their competency in designing meaningful learning activities. The TPACK rubric by Koh (2013) with a grading scale of 0-4 was chosen for this purpose. This rubric was chosen because each of its criteria represented each dimension of meaningful learning. Also validity of the rubric has been established. We added the constructive alignment criterion to this rubric (Table 6.2). These criteria measured if all the alignment guidelines have been operationalized through proper implementation of an active learning strategy. The inter-rater reliability of this rubric was found to be Cohen’s kappa = 0.81.

The other axis was tracking the evolution of the sequence of activities in the LD through time allocation analysis methodology, adopted from Kong et al., (2011). Content analysis of the eighteen (6x3) LDs was done to identify various categories of teaching activities designed. The content validity of the categories was established through discussing the activity categories with another researcher before the final set of categories emerged. For each instructor, the variation in time allocation for each category was recorded. The percentage of allocated time gives a measure of effectiveness of CuVIS framework in terms of degree of student engagement and the extent of student-instructor dialog (Kong et al., 2011). The temporal ‘Sequence of activities’ analysis clearly depicted how the sequence of

the different types of activities varied and new type of activities got incorporated in the LD as the instructor progressed from ‘Warmup’ to ‘Transfer’ phases.

E. Results

(i) Assessment of TPACK for meaningful & effective learning with visualization

The LDs produced by each instructor at each round were evaluated for the instructor’s TPACK. Analysis of the total TPACK scores (Fig. 6.2) for each instructor showed that use of CuVIS framework training workflow resulted in increase in TPACK levels for all the instructors. They were able to retain their higher TPACK levels in the Transfer phase, even after withdrawal of CuVIS framework. The scores in the Transfer phase for all the instructors were in the range of 19-23 out of 24. An instructor-wise analysis of scores (Fig. 6.3) helped us identify the impact of CuVIS framework training along each of the rubric criteria. We found CuVIS framework use increased scores along Constructive, Intentional, Cooperative and Constructive alignment dimensions for all instructors. Active learning score for all instructors except T4 showed an increase. T4 remained at his starting score for active learning which was high at the start itself (Fig. 6.4). CuVIS framework was however, not able to substantially improve the Authentic dimension score for instructors T2, T3.

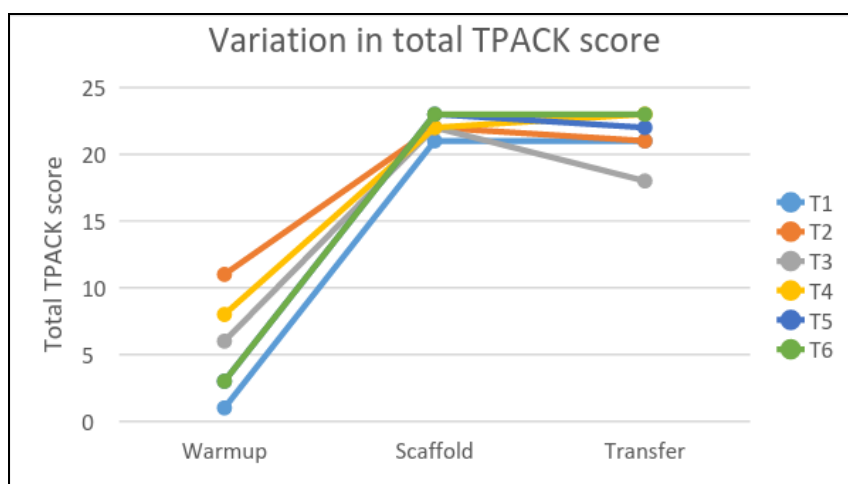


Figure 6.3: Impact of CuVIS on individual instructor’s total TPACK level

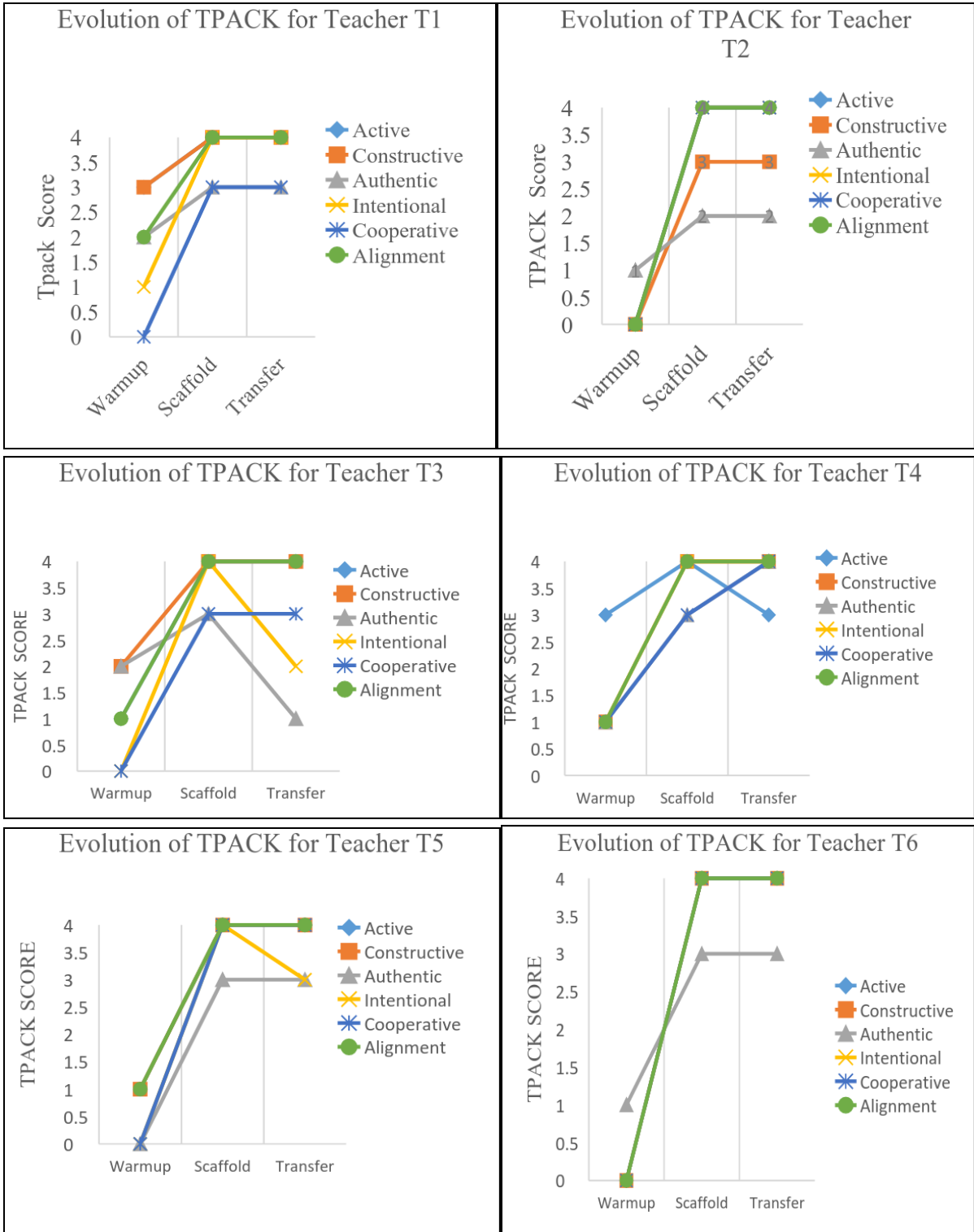


Figure 6.4. Impact of CuVIS framework on individual instructor’s TPACK levels along each rubric criteria

(ii) *Analysis of time allocation and sequence of activities in LDs*

Time allocation analysis and analysis of the sequence of activities in each instructor’s LDs were done to understand the impact of CuVIS framework on their pedagogical practice. Three categories of teaching activities were identified through content analysis: Category 1 - Lecturing without student interaction (with or without visualization), Category 2 - Guided interactive activity with visualization (Individual activity, Group activity, Feedback through visualization) and Category 3 – Guided interactive activity without visualization.

Category 1 included teaching activities where students were passive recipients of information. Time allocation analysis results showed a sharp reduction in this activity from pre-test to transfer phase for all instructors. Category 2 included student activity with visualization. It included sub-categories of individual and group activities with visualization and feedback activities through visualization (Table 6.3). This category gave a measure of active student engagement with visualization planned (Kong et. al., 2011). It showed the maximum increase in time allocation among all the categories. The subcategory of group activity with visualization showed the highest increase (mean increase of 32.06% across instructors) (Table 6.3). Category 3 comprising of activities like class-wide discussion not involving the visualization, showed a reduction in time allocation from pre-test to transfer phase.

Table 6.3: Time-allocation analysis of Category 2: Student engagement with visualization.

Category 2	Sub-category	Instructor	Percentage of time allocated (%)			
			Warmup	Transfer	Increase	Mean Increase (%)
Guided interactive activity with visualization	Individual activity based on visualization	T1	13.79	24	10.21	14.70
		T2	10	20.4	10.4	
		T3	0	22.86	22.86	
		T4	0	20	20	
		T5	0	14.7	14.7	
		T6	0	10	10	
	Group activity based on visualization	T1	0	36	36	32.06
		T2	10	38.6	28.6	
		T3	0	30.3	30.3	
		T4	0	20	20	
		T5	0	14	44.11	
		T6	0	33.33	33.33	

Guided interactive activity with visualization	Feedback through visualization	T1	3.45	24	20.55	16.84
		T2	0	22.7	22.7	
		T3	20	28.57	8.57	
		T4	0	10	10	
		T5	0	5.9	5.9	
		T6	0	33.33	33.33	

Fig. 6.5 shows the change in the sequence of activities from ‘Warmup’ to ‘Transfer’ phases for each instructor. It captures the change in pedagogical practice of the instructors caused by CuVIS framework along the teaching activity categories identified. All the instructors migrated from lecturing with visualization to doing series of activities weaved around the visualization. All the instructors reduced, if not completely removed, lecturing with visualization. Instructors T1, T2 and T3 retained lecture activity for a small proportion with the purpose of setting the context for the visualization activity. T4 in fact dropped lecturing with visualization in favor of a guided discovery strategy with static images prior to visualization activity. This was in sharp contrast to his pre-test LD involving passive lecturing with visualization. The interview results in the next Section 8.6 with discussion and limitation of the study presented in Section 8.7.

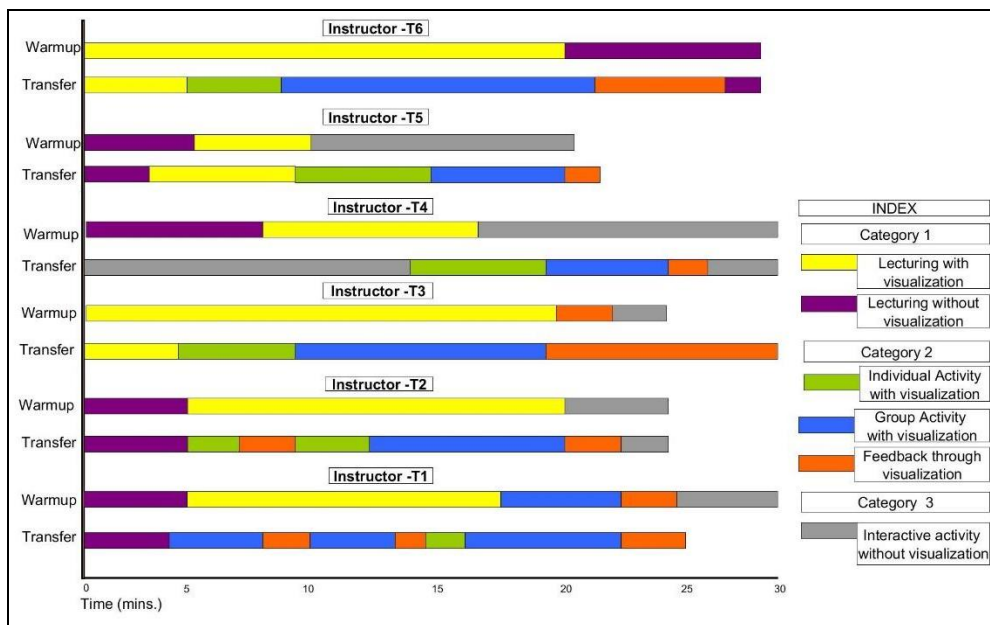


Figure 6.5: Impact of CuVIS framework on Sequence of activities with visualization

6.5. Identification of effective features of CuVIS framework

Each of the six instructors was interviewed twice for 15-20 minutes – after the ‘Warmup’ round and after ‘Transfer’ round. The interview transcripts were analyzed through the 6-step thematic analysis methodology (Braun & Clarke, 2006). Thematic analysis was chosen since the objective was to understand the impediments instructors face in the design process and how successful CuVIS framework had been in resolving them.

Each sentence in the interview transcripts were taken as the unit of analysis. The similar codes that emerged from the transcripts were grouped into an overarching theme. Thus four themes were obtained – a) Design Problems resolved, b) Scaffolds that helped, c) Benefits of using CuVIS framework LDs and d) Design Problems unresolved. The theme of ‘Design Problems resolved’ is defined by the points in the LD creation process that instructors identified as design challenges that instructors could overcome through the use of CuVIS framework. These include designing Constructive alignment, framing active learning questions that exploit visualization affordances and designing field implementation. Instructors were able to overcome these impediments by using the following ‘Scaffolds that helped’ - LD blueprint with minute level sequencing of teaching activities, domain examples to illustrate guidelines, self-evaluation checklist with list of common design errors committed by instructors. The ‘Benefits of using CuVIS framework LDs’ were identified as facilitating field implementation, increasing student engagement and imparting skills needed by students to make the transition from academics to the professional world. However, instructors listed the following as ‘Design Problems unresolved’ after use of CuVIS framework - a) designing activity question anchored in real-life as well as based on visualization (Authentic), b) time overrun during field implementation and c) more time required in planning the class.

6.6. Discussion & Implications

Design expertise of instructors refers to instructor’s knowledge and skill to effectively execute the different phases of the design process like Analysis, Design, Development and Evaluation. It also incorporates instructor’s knowledge about learner, content and context

(Huizinga, 2014). Prior research has shown that design expertise can be built through learning that takes place while designing artefacts for others to learn with (Papert, 1991). There are training models like Learning Design Studio (Kali & Ronen-Fuhrmann, 2011; Mor & Mogilevsky, 2013) which have harnessed this learning by design approach to develop instructor's design expertise. The design guidelines that have emerged for such training models for novice designers are: there should be (i) a blend of open-ended design projects and a structured approach like ADDIE (Kali) and (ii) access to relevant expert knowledge. Accordingly, we have designed a self-regulated training workflow for instructors using CuVIS framework. Instructors execute three design projects across different time points – Warmup (pre-CuVIS framework, open-ended), Scaffold (CuVIS framework, guided, brings in ADDIE structure + database of expert knowledge), and Transfer (post-CuVIS framework, open-ended). Self-reflection scaffolds like reflection questions and checklist are provided after scaffold and transfer rounds to concretize the learning. We have implemented this module with six engineering instructors to test the impact of CuVIS framework on instructor design expertise.

The first research question targeted impact of CuVIS framework on instructor's TPACK for designing meaningful and constructively aligned LDs. The evaluation of the LDs generated by six in-service engineering instructors across the three time points was evaluated based on a modified version of an established rubric. The results showed that all the instructors except T1 were at similar low TPACK levels in the pre-test phase. Only T1 had a high score along the Constructivist dimension in the initial phase itself. A possible reason for this, as identified by T1 herself, was her objective to equip students in learning by doing to smoothen their transition from academics to the workplace. Instructors T2 and T3 reported difficulty with the Authentic dimension. The probable cause for the problem as identified by instructors was that the visualization chosen did not support creation of a real-life based activity involving the visualization content. This is borne out by the fact that for instructor T2, the Authentic dimension score in Transfer round actually fell below that of the Warmup round (Fig. 6.3). The reason given by the instructor was that the visualization chosen in the Transfer round did not support creation of a real-life based activity. Overall, the training workflow with CuVIS framework was successful in increasing instructors' TPACK in terms of their ability to design effective and customized LDs where effectiveness is defined as incorporating the dimensions of constructive alignment and meaningful learning with visualization.

The second research question was on impact of CuVIS framework on the sequence of activities in the LDs from Warmup to Transfer phase. Three categories of teaching activities were identified from the LDs – Lecturing without student interaction, Guided interactive activity with visualization and Guided interactive activity without visualization. The time-allocation analysis of the LDs revealed maximum increase occurred in guided interactivity with visualization. Within this category, there was a 28.7 % increase in planned group activity based on the visualization. Analysis of sequencing of these activity categories captured the change in instructors’ pedagogy from pre-test to transfer. Every instructor brought in Active learning, Constructive, Intentional and Cooperative activities weaved around the visualization and aligned to their objective. In fact, instructor T4 transformed from lecturing to guided discovery with visualization in the classroom. Another positive output of CuVIS framework noted in the Transfer phase was that instructors came up with their own sequencing of activity steps yet retained the learning from CuVIS framework in terms of Meaningful and effective learning. This proved that training workflow with CuVIS framework was able to do the fine balance between being open ended and being a rigid template as recommended in literature (Laurillard et.al, 2013; Bennett et al., 2015).

The third research question seeks to provide answers to some of the pertinent questions in current LD research. Questions on points in the LD process instructors need help in and what type of scaffolding should be provided for this. From analysis of instructor interviews we identified 4 points in the LD process where instructors needed scaffolding. They required support in designing for constructive alignment, framing active learning activity questions based on visualization, implementation design and creating activities with visualization anchored in real-life. CuVIS framework was able to successfully scaffold instructors in framing activity questions by providing illustrative examples from their domains alongside the theoretical guidelines. CuVIS framework was able to help in designing the implementation plan by ‘micro planning’ the steps for the chosen active learning strategy in the LD blueprint. However, CuVIS scaffolding for incorporating the Authentic dimension was partially successful. Thus, the current study contributes to LD research by identifying some of the points where instructors require scaffolding and the scaffolding features that were successful in addressing the difficulty. Thus CuVIS framework is a useful resource for instructors to translate the theoretical knowledge of teaching with visualization into practice. Besides, it gives them a tangible theory- informed, research based product to implement in the

classroom. It also serves as a valuable training resource for teacher-educators at the tertiary level to cement the learning from training workshops. The time duration of this training workflow came to a semester due to the instructors doing the LD creation activities simultaneously with their regular college duties. The actual man hours estimate given by the instructors during their interviews was three hours for the warmup round that came down to one and half hours in the scaffold round. Thus, the training workflow is expected to take around eight hours if instructors are dedicated to doing only this activity.

The main limitation of the current study was that CuVIS framework offers limited number of Active learning strategies from the vast array that has proved successful in teaching with visualization for a particular objective. However, CuVIS framework did not deter instructors in coming up with active learning strategies of their choice in the transfer phase. The current study has been restricted to Engineering instructors and that too to a sample size of 6. Also, classroom observation of the implementation of the LDs could not be done due to difficulty in getting permission from the college administrations. Hence, the dissonance if any, between the LD planned and its actual implementation could not be studied.

Chapter 7

Impact of CuVIS framework on student learning

7.1 Introduction

In this chapter we assess if LDs created using CuVIS framework guidelines and their subsequent implementation in the classroom are effective in student achievement of the targeted learning objective. Thus the research question addressed is: What is the effectiveness of the CuVIS framework LDs in student learning with visualization? (RQ3). Two field experiments, each using a quasi-experimental research design were conducted. The characteristics of the student sample (N =375) in these experiments were in accordance with the requirements of our research context. They were college students from EE or CSE domains who were taught in instructor-mediated classrooms. The domain specification is because illustrative examples in CuVIS framework are currently limited to these domains. One topic each from Computer Science and Engineering (CSE) (Pointer) and Electrical Engineering (EE) (Signal Transformation) were chosen. Three instructors (one from CSE and

two from EE) used CuVIS framework to generate LDs using visualization for their chosen topic. They then implemented the LDs with their students. Experiment – 1 on ‘Signal Transformation’ (Banerjee et.al, 2014) and Experiment - 2 on ‘Pointers’ (Banerjee et.al, 2015) were conducted by the instructors in presence of the researcher to ensure implementation fidelity. Sections 7.2 and 7.3 present details of each of the experiments. Section 7.4 concludes the chapter by discussing implications of the results of the field experiments.

7.2 Experiment 1 – Signal Transformation

7.2.1 Sample Characteristics

We chose a sample of 144 first-year undergraduate students of EE from Mumbai University, India since they satisfied the sample characteristics outlined above. Also, these students were accessible to us since we were able to obtain requisite permission from their college authorities to conduct field experiments in their classrooms. Hence the sampling technique used was convenient sampling. The students were enrolled for the course on ‘Signals and Systems’. None of the students had prior knowledge of problem solving in the topic of ‘Signal Transformation’.

7.2.2 Learning materials & Instrument used

The topic chosen by instructors for this experiment was ‘Signal Transformation’ which satisfied the topic characteristics outlined in the Weiss graph (Weiss et.al, 2002). This topic involved abstract concepts whose comprehension would be facilitated by use of visualization. The visualization chosen was an interactive animation on ‘Transformation of continuous time signals’ (<http://oscar.iitb.ac.in/onsiteDocumentsDirectory/ContinuousSignalTransformation/ContinuousSignalTransformation/index.html>) (Fig.7.1) that satisfied the visualization selection checklist provided by CuVIS framework. It allowed users to manipulate the amount

of transformation change and visualize the output for various combinations of transformation operations like time scaling, time reversing and time shifting along time and amplitude axes (Fig. 7.1). Both signal representations – graph and equation were dynamically linked on-screen.

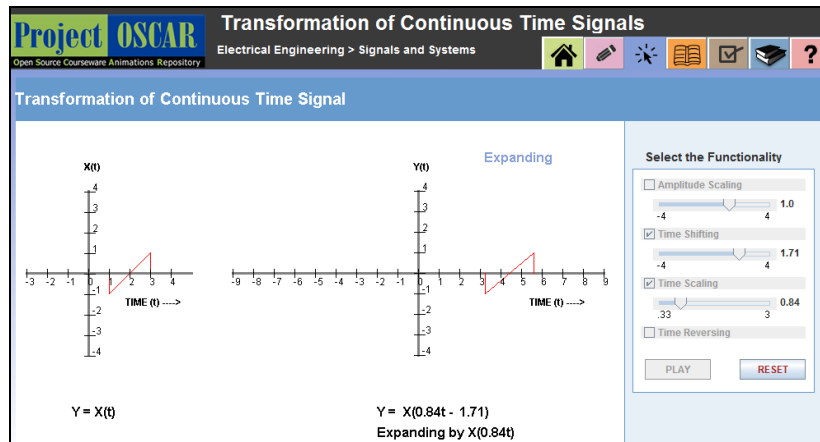


Figure 7.1: Screenshot of visualization for Experiment 1

A post-test was designed by both the instructors together to ensure content validity and pedagogical inputs were provided by the researcher. It contained four questions based on the problem solving activity done using visualization. The questions involved identifying the transformation operations and their sequence from the given mathematical expression, relating and translating between graphical and mathematical representations of the given signal, drawing/writing the transformed version of the given signal involving single or multiple transformation processes. A sample of two of these questions is given in Table 7.1. Each question was mapped to a particular objective type (Table 7.2).

Table 7.1: Sample post-test questions from Experiment 1

Sr. No.	Question	CuVIS framework objective
1	If $x(t)$ is the given signal, to obtain $x(4-2t)$ from the given signal, identify which operations should be carried out on the independent variable (time) and in what sequence.	Visualize to explain a specified concept
2	A continuous time signal $x(t)$ is shown on screen. Sketch the signal $x(1 - 3t/4)$ & write mathematical expression for each transformation.	Write/Draw alternate representations from the given visualization or vice-versa.

7.2.3 Procedure

The research design was post-test only 2-group controlled experiment. The students were divided into two sections by the institute for scheduling reasons. We had to work with these predetermined groups. So, randomizing or matching the two groups was not possible. However, we ensured the groups were equivalent on basis of previous university test marks ($p= 0.19$). The experimental group had a sample size of 70 and control group a sample size of 74. Assignment of treatment to the two groups was however done on a random basis.

The experimental group underwent a 30 minute problem solving activity, involving multi-process transformation and multiple representation, based on the visualization. The activity question given was - A continuous time signal $x(t)$ is shown on screen. Sketch the transformed signal $y(t) = x(4 - t/2)$. The active learning strategy suggested by CuVIS framework was Think-Pair-Share. The corresponding CuVIS framework LD created proceeded in the following way - In the Think phase, students individually identified the transformation processes, their sequence and the transformation units from the given $y(t)$. In the Pair phase, the student pairs drew each transformation step together to arrive at the final graphical representation. In the Share phase, each group shared their answers with the class and received instructor feedback. The instructor finally showed them the solution in steps through the visualization. The control group did the same problem solving activity for the same duration. But here the instructor himself solved the problem on the blackboard, responded to students' doubts and concluded by running the visualization with the relevant input parameters, giving parallel commentary. This LD was chosen for the control group since it is the one commonly used by instructors for teaching using ICT tools like visualizations (Angeli & Valanides, 2009).

The visualization used, the instructor and the post-test questions were same for both groups. Thus the only thing that differed between the groups was the LDs (Fig.7.2). The setting was instructor-mediated classroom where resources available to the instructor was a LCD projector and laptop. Student interaction with the visualization for both the groups was mediated through the instructor as students did not have access to laptop in the class. After the visualization activity both groups solved the same post-test questions for the same duration (40 mins.). The achievement of learning objectives from the visualization activity was measured through the post-test scores.

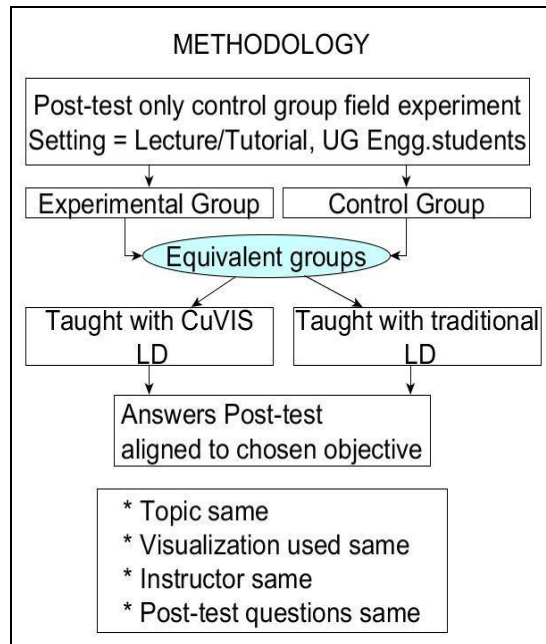


Figure 7.2: Common methodology of field experiments with students

7.2.4 Data Analysis & Results

Non-parametric Mann-Whitney U test was done to compare the post-test results of the two groups, since the test scores showed non-normal distribution as per Shapiro-Wilk test of normality. Analysis of post-test results showed that experimental group did statistically significantly better ($p = 0.00$; $p=0.001$) than the control group for three of the four objectives (Table 7.1). This points toward effectiveness of CuVIS framework guidelines in achieving the intended learning objective. For the fourth objective of problem solving with a single process, there was no significant difference between the groups. This was expected because this particular objective required surface-level knowledge of simple reproduction of a process. Hence, non-constructivist, instructor-directed LD like the one followed for control group is sufficient for such objectives (Garside, 1999). We included this guideline for validation in our experiment because we wanted to verify that a non-constructivist LD was sufficient for surface-level objectives in our research context also.

Table 7.2: Mann-Whitney U test results for post-test for Experiment 1

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

7.3 Experiment 2 – Pointer Arithmetic

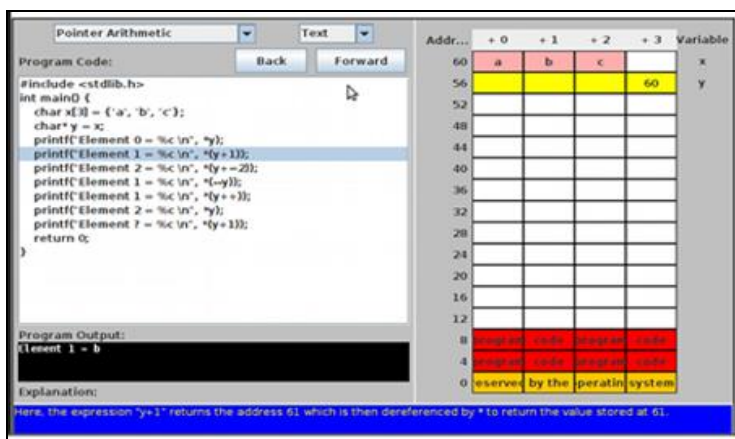
7.3.1 Sample Characteristics

In this experiment sample selection parameters and technique were the same as in Experiment 1. A sample of 231 students was taken who were enrolled in a mandatory introductory course in computer programming at an engineering institute in Mumbai, India. They were first year undergraduate students from Mechanical, Electrical, Aerospace and Chemical Engineering who had to take this compulsory course. They had self-declared no prior knowledge of the topic chosen for the experiment.

7.3.2 Learning Materials & Instrument used

The topic chosen by the instructor was Pointers. This topic was chosen since it required visualization to make the invisible memory address manipulations visible to the students. The visualization chosen was an animation on basic and pointer arithmetic with user-controlled navigation (Fig. 7.2). It demonstrated stepwise the change in memory map in response to execution of each line of code and also the output of the printf () function. The reason for choosing this visualization was it satisfied the visualization checklist of CuVIS framework for Prediction objective by having features like the presence of explicit feedback and additional narrative or text explanations of what is happening in steps.

The post-test contained three post-test questions related to students' prediction skill. The topics were pointer basics and pointer arithmetic which were taught using visualization. The post test questions asked the students to predict the output of a code segment or predict the value of the pointer variable at a certain point in the code (Fig. 7.3). The questions were generated by the instructor who was also an educational technology (ET) expert and validated by another ET expert.



Sample post-test question:
 Predict the output of the following program:

```

int main () {
int A[4], *p;
for (int i = 0; i < 4; i++) A[i] = i;
p = &A[0];
printf (" %d %d %d /n" , *p , *(p +
=2) ,*(p + 1) + *(p-1));
return 0;
}

```

Figure 7.3: Screenshots of visualization and sample post-test question of Experiment 2

7.3.3 Procedure

The instructional setting and the procedure followed for Experiment 2 (Fig. 7.4) were similar to the one in Section 7.2.3 for Experiment 1. As in Experiment 1, the students were already divided into two predetermined groups by their institute. However, we tested the two groups for equivalency in programming skills based on a prior quiz using independent samples t-test ($M_{\text{experimental}} = 16.96$ (SD = 5.86); $M_{\text{control}} = 15.72$ (SD = 6.09); $p > 0.05$). The experimental group had a sample size of 136 (Male = 120; Female = 16) and the control group had a sample size of 95 ($N = 95$; male = 85; female = 10). The treatment assignment to the two groups was randomly done.

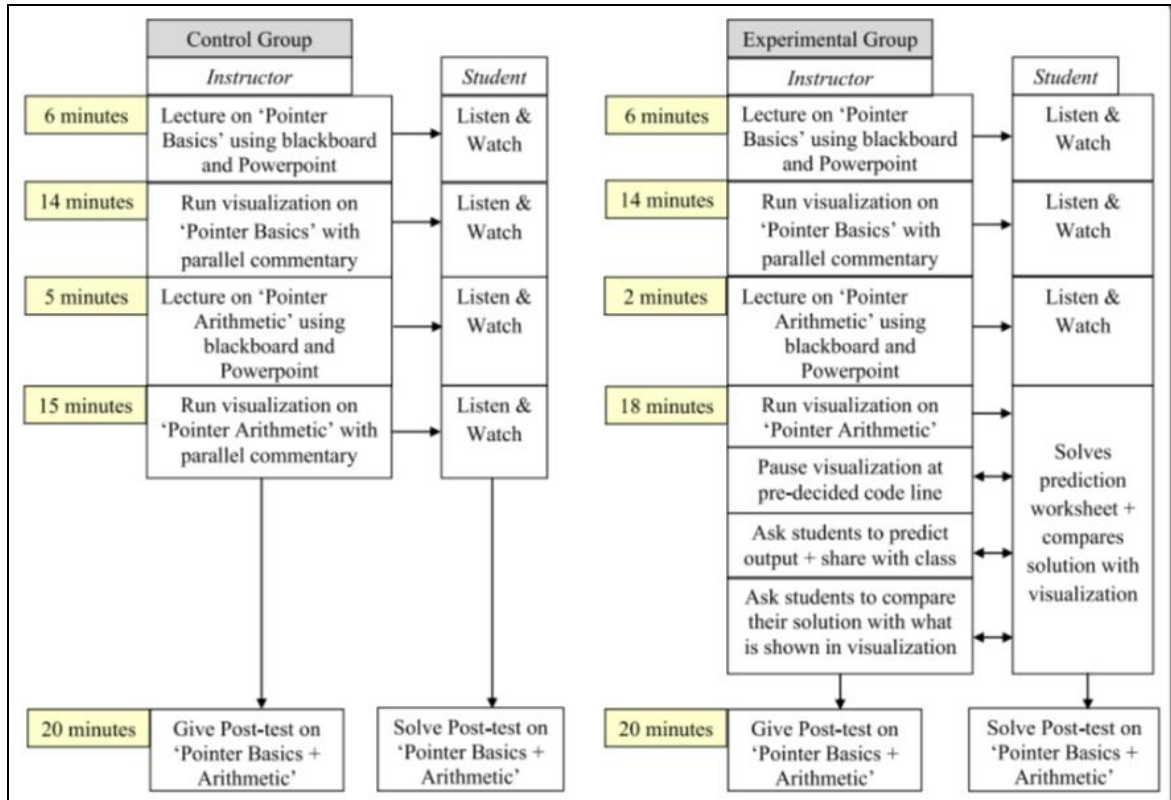


Figure 7.4: Learning Designs (LDs) used for control and experimental groups in Experiment 2 (Banerjee et.al, 2015)

The learning objective for this experiment was students should be able to predict the change in pointer variable values on execution of specific code lines (Prediction). The activity duration required by the instructor was 15 - 20 mins. Thus, the strategy suggested by CuVIS framework was Predict-Observe-Explain (POE) for the experimental group. The instructor started with lecture on Pointer basics using the visualization. In the topic of Pointer arithmetic, the instructor conducted the POE activity. Students predicted the value of the pointer variable if the next code line is executed. The feedback to the prediction activity was given through the visualization with explanation by the instructor. The control group was taught the same content. They were shown the variation in pointer values using the visualization with parallel instructor commentary for approximately the same duration. As in Experiment 1, the visualization used, the instructor, the topic taught remained the same. Only the LD implemented differed (Fig. 7.5). After the activity, both groups were given 20 mins. to solve the same set of post-test questions.

7.3.4 Data Analysis & Results

Since the distribution of post-test scores was non-normal, non-parametric Mann-Whitney U test was done to compare the median post test scores of the two groups. We did not get any significant difference in post-test scores. But we found the experimental group took half the time (10 min) than the control group to complete solving the post-test paper (20 min). There was a statistically significant difference in the rate of problem solving ($p = 0.00$) in favor of the experimental group (Table 7.3) with an effect size of 1.46 where the rate of problem solving was computed as the average time taken to solve the post-test paper for the entire group. The rate of problem solving is defined as the number of correct responses given to problem solving questions in unit time. To calculate the rate of problem solving for each student (R), we divided the post-test score (C), representing the number of correct responses of each student in a group, by the average time taken by the group to solve the post-test (t), i.e., $R = (C/t)$. The average time of the group was taken since it was not possible to get solving time taken by individual students. Since the distribution of R was found to be non-normal by the Shapiro-Wilk test, the non-parametric Mann-Whitney U test was done to compare the medians of the two groups.

Table 7.3: Mann-Whitney U test results for post-test of Experiment-2

<i>Dimension</i>	<i>Group</i>	<i>Standard Deviation</i>	<i>Mean</i>	<i>U-value</i>	<i>p-value</i>
Rate of problem solving	Prediction (N= 136)	0.26	0.62	966.5	0.00
	Viewing (N=95)	0.13	0.32		
Average post-test score	Prediction	2.55	6.18	6435	0.96
	Viewing	2.52	6.35		

7.4 Discussion

In this section we discuss the implications of the results of the two field experiments with students. The research question explored in this chapter was ‘What is the effectiveness of CuVIS framework in student learning with visualization?’ The effectiveness was measured in

terms of students being able to achieve the chosen learning objective when taught using LDs designed with CuVIS framework guidelines. The field experiments with students presented in this chapter provided empirical evidence of effectiveness of the CuVIS framework guidelines in aligning LDs to objectives.

The two experiments with students showed that experimental group taught using CuVIS framework LDs achieved the selected objectives significantly better in terms of post-test score/rate of problem solving than those taught using non-CuVIS LDs. The post-test score in Experiment 1 captured the difference in performance due to the CuVIS framework intervention. In Experiment 2 post-test scores of both groups did not show a significant difference. The possible reason could be the questions in the post-test were not able to capture the difference in learning. Hence, we took an alternative metric of rate of problem solving to quantify the learning difference between the groups. We found the experimental group took significantly less time to solve the post-test questions.

The topics involved in the two experiments had the common characteristics of being difficult to visualize and involved dynamic change in the system with time. So, CuVIS framework LDs for topics with such characteristics can lead to successful achievement of learning objective with visualization in our research context. Also, engineering instructors who were novice designers were able to use CuVIS framework to create these LDs customized to their requirements of objective, setting and activity time duration. This points towards comprehensibility of CuVIS framework guidelines and their success in enabling instructors to translate existing theory into practice to create effective LDs.

All the instructors were informally interviewed after the experiment sessions to record their reflections on teaching with CuVIS framework LDs. All the instructors reported that the micro-planning to the minute level given in CuVIS framework LDs helped them in executing the active learning activities in the classroom. They also perceived an average of 50% reduction in number of doubts asked by students in the experimental group than control group though nature of doubts remained the same.

There are however certain limitations. We have tested the effectiveness of CuVIS framework with only two topics, one each from the domains of EE and CSE. Experiments with more topics and from other science and engineering domains are required to be able to generalize the findings from our field experiments to student learning with CuVIS framework LDs. Also, of the three instructors involved in the experiments, one was an ET expert while

the second one had attended our pedagogy workshops and thus had knowledge of the active learning protocols. The third instructor had never attended a pedagogy workshop and had no prior knowledge of active learning protocols. But he had a teaching experience of ten years. Our experience with these instructors showed that all of them were able to use CuVIS framework guidelines to create effective LDs in their chosen topic. However, the difference occurred in the implementation phase of the LDs. The instructor who had some level of awareness of active learning was able to execute the LD maintaining the implementation fidelity without our help. But the third instructor with no awareness of active learning had to be mentored about implementation protocol of the chosen strategy in two face-to-face meetings by the researcher prior to the actual experiment. This points to the fact that CuVIS framework LDs can potentially guide against violation of implementation fidelity if the instructor has basic knowledge of active learning implementation protocols.

Chapter 8

From CuVIS Framework to CuVIS tool

8.1. Introduction

In the previous chapters we have presented the CuVIS framework. It enables instructors to create constructively aligned, meaningful LDs for teaching with visualization in instructor-mediated classrooms. Effectiveness of CuVIS framework has been assessed in terms of (i) development of instructors' design expertise and (ii) student achievement of targeted learning objectives on implementation of CuVIS framework LDs. During prototype testing of CuVIS framework, we received instructor comments to enhance the usability like “a digital learning design system should be implemented” or “I think it is too much work to do the selection through a lookup table. It will be good if some sort of guided wizard is designed”. Hence, we built the CuVIS tool as a digital interface to interact with the framework. This is a semi-automatic tool that takes the instructor through a series of design

decision prompts akin to a wizard and outputs the LD based on instructor responses to the prompts.

The tool is based on the CuVIS framework. The tool functions in the following way: (i) the instructor specifies the input parameters – objective, domain and activity time duration, the tool automates retrieval of the relevant guidelines from the CuVIS framework lookup table at the backend and (ii) automates filling up of the appropriate LD Blueprint. In Section 8.2, a comparative analysis of the current crop of LD tools is presented to show where the CuVIS tool fits in the scenario. In Section 8.3 the design and development of the CuVIS tool is described. The description includes the design, development and prototype testing of the tool. In Section 8.4 the functionality of the tool is given with Section 8.5 documenting usefulness and usability evaluation of the tool. The chapter ends with summary and discussion of what the tool achieves, its limitations and future work (Section 8.6).

8.2. Comparative analysis of existing LD tools

Some existing LD frameworks have led to development of LD tools. For example, the Conversational Framework forms the foundation of Learning Designer tool (Laurillard, 2013), ISiS framework leads to ScenEdit (Emin & Aguirre, 2010). Other than these, a host of LD tools have been built with the purpose of assisting instructors in authoring LDs like CADMOS (Katsamani & Retalis, 2011), OpenGLM (Derntl et.al, 2011), Webcollage (Villasclaras-Fernández et. al, 2011).

A comparative analysis of a subset of five such LD tools that have empirical evidence of their usability is presented in Table 8.1. The analysis is based on Prieto et.al's (2013) analysis but presented along the focus area of CuVIS tool i.e. on the pedagogy of teaching using visualization in our research context. The focus of CuVIS tool is currently not on the technological aspects like IMS-LD compliance or exporting to an LMS. Thus, the purpose of comparative analysis of LD tools is to explore relevance of existing tools in the context of enabling instructors who are novice designers to create student-centered LDs using visualization affordances in instructor-mediated setting. Thus, existing LD tools are compared along the following dimensions: target user characteristics, granularity i.e. unit of learning targeted is an entire course (macro) or an individual lesson (micro), the instructional

setting, the LD representation (layout), type of scaffolds provided, if ICT tool affordances are accommodated and the pedagogical contribution of the tool. This comparative analysis also informs the design specifications of the CuVIS tool.

A discussion along these dimensions is presented below:

- i) Target Audience – Ranges from teacher-educators to instructors who are expert designers to instructors who are novice designers. The educational level targeted ranges from secondary school instructors (ScenEdit) to University instructors (Learning Designer; CADMOS).
- ii) Instructional Setting – Majority of the tools, especially the ones incorporating IMS-LD specifications are designed for the online setting. Very few like the ScenEdit accommodate a different setting like the blended format. Currently no existing LD tools target the face-to-face setting (Prieto et.al, 2013).

Table 8.1: Comparative analysis of existing LD tools

<i>LD Tool</i>	<i>Target user</i>	<i>Granularity</i>	<i>Setting</i>	<i>LD Representation</i>	<i>Scaffold type</i>	<i>Degree of scaffolding</i>	<i>Tool Affordance</i>	<i>Pedagogical contribution</i>
Learning Designer	Instructor who wants to develop strategic thinking	Macro level	Online/ Blended	Visual analytics in form of pie chart showing percentage time devoted to different types of pedagogy	Conceptual & Reflection	i) Intelligent guidance through wiki that instructor can consult ii) Visual analytics of LD	Generic (no role of ICT tool affordance)	Aims to develop instructors' design expertise through reflection & intelligent guidance
CADMOS (Katsamani & Retalis, 2011)	Instructor with basic computer skills & know-how of learning standards	Macro level - Activities mapped to objectives	Online	Graphical: a) At conceptual level shows multiple activities with resources required like whiteboard, email, videos, b) At flow level, vertical swim lane of activities with resources used & instructor-defined time duration at activity level	Conceptual + Flow models + Reflection	i) Instructors guided to generate metadata. ii) Then they drag and drop to create the two models iii) Shows statistics of different kind of activities used	Generic	No pedagogical guidance on how to achieve the mapping
Open GLM (Derntl et.al, 2011)	Instructor who is LD expert	Macro level	Online	Graphical: Swim lane of color-coded activities for three actors - instructor, student, and group. Resources required can be specified but not timing. IMS-LD compliant.	Flow model	Open to instructors to model learning activities as they want	Generic	No pedagogical guidance
Web Collage (Villasclaras-Fernández et. al,	Instructor who are not experts in creating computer-	Macro level - Activities mapped to objective where	Online	Graphical, IMS-LD compliant. But does not allow time duration specification nor adding resources to the chosen pattern. Uses natural	Conceptual + Flow models	Semi-guided tool that presents a set of collaborative learning flow patterns (CLFP) like Brainstorming	Generic	Instructors can select multiple objectives from a drop-down menu (procedural, attitudinal, problem solving, complex). Tool suggests a research-evidence based CLFP mapped to objective. On clicking

2011)	supported collaborative LD	objectives touch on cognitive, affective & psychomotor domains		language making LD description complex		CLFP to instructors to choose from. Also suggests assessment design patterns for rubric, peer review etc.		help, it advises on when to use it, what are the benefits of the CLFP. But no guidance on customization to instructor's context
ScenEdit (Emin, Pernin, & Aguirre, 2010)	Instructor-designers & Instructor trainers	Micro Level	Blended	Visual tree structure with geometric shapes denoting different intention, strategy, interactional situation	Instructor intentions (target competency) + Teaching Strategies + Interactional Situations (model orchestration of intention & strategy)	Medium, Instructor selects a scenario like PBL scenario. Tool prescribes a set of intentions, strategies & situation model	Generic	Instructor role specified in detail but does not specify either student role or role of the particular ICT tool
CuVIS tool	Instructors who are not experts in designing constructively aligned LDs with visualization.	Micro level	Face-to-face instructor-mediated classroom	Stepwise detailing at minute level. Contains time duration for each step, role of instructor, student & visualization at minute level.	Conceptual & Implementation	Medium, semi-guided tool. Instructor input (taken in stages), determine what scaffolds to be presented.	Specific to Dynamic Visualizations (Video, Animation, Simulation)	Enables instructors in creating constructively aligned LDs for visualization that support all 5 dimensions of Meaningful Learning with ICT.

iii) *Granularity* – Majority of the LD tools assist in LD generation at the macro level i.e. for a course or module. None of the tools focus on guiding instructors on how to align their activity and formative assessment questions to the learning objective at the granularity of an individual objective (Boyle, 2010).

iv) *Representation* – Many of the tools like CADMOS, OpenGLM provide graphical representation like a vertical swim-lane that is IMS-LD compliant and can be exported to an LMS. The representation defines the roles for three actors – instructor, student and group but does not provide any pedagogical guidance. In contrast, the Learning Designer tool provides graphical representation in form of a pie chart representing the various types of pedagogical strategies incorporated to promote reflection among instructors.

v) *ICT tool targeted* – Majority of the tools, like ScenEdit and CADMOS, assume that the generated LDs are applicable across the spectrum of ICT tools. They ignore the role played by affordances of various ICT tools. But, the ICT tool affordance is important in constructing effective LDs since the tool needs to be aligned to objective as well (Hammond, 2010).

vi) *Pedagogical Contribution* – Some tools like CADMOS and OpenGLM puts the spotlight on technical aspects of LD rather than pedagogical ones. Others are focused on the pedagogical aspects. Some like Learning Designer address development of instructors' design skill while others like Web Collage target scaffolding instructors to create a theory-informed activity. Some of them like ScenEdit and Web Collage suggest a collaborative flow pattern (CFLP) that is mapped to the objective. However, ScenEdit do not address aligning assessment questions to objective. Web Collage addresses assessment designs mapped to objective in terms of rubric, peer feedback etc. and provides macro-level guidance. There is no guidance available on customizing the flow patterns. Also, none of the LD tools leverage the learning impact of affordances of different ICT tools.

vii) *Scaffolding* – The tools provide scaffolding at either conceptual or implementation levels or both. In the conceptual level, instructors decide type of activities to do for a particular module, resources to use and the role of instructor, student and group. The implementation level scaffold assists the instructor in sequencing these activities. The degree of scaffolding ranges from being open-ended like in CADMOS to medium like Web Collage where instructors can choose from an array of pedagogical patterns to prescriptive like in ScenEdit. Other tools like Learning Designer provides intelligent guidance through a wiki that instructors may consult.

The major gaps emerging from comparative analysis of existing LD tools (excluding CuVIS tool) are similar to the gaps found for LD frameworks (Sec.2.4). The existing tools do not provide guidance to instructors in our research context for (Table 8.1):

- i) Customization to instructor-mediated classroom setting
- ii) Designing constructively aligned, meaningful LDs that support collaborative active learning
- iii) Customizing LD implementation design to instructor's activity time requirement
- iv) Accommodating pedagogical utility of ICT tool affordances

Thus the existing LD tools do not mitigate the design impediments identified (Chapter 4) for instructors who teach using visualization in instructor-mediated classrooms.

Also, LD research in recent times has come up with design recommendations for LD tools (Laurillard et.al, 2013; Bennett et.al, 2015) extracted from interviews with university instructors. These recommendations are that LD tools should accommodate domain influences, should be flexible for instructors to customize as well as accommodate changes 'within the design', and should be a balance between open-ended, unsupported design and rigid templates (Bennett et.al, 2015). Laurillard et.al. (2013) identified additional tool features that would make the tool effective for instructors as designers of technology enhanced learning. The features recommended were links to existing LDs and research findings, a stepwise default design process and evaluation feedback on the LD created. However, empirical studies are required to test the effectiveness of these recommendations on the instructors' design practice (Bennett et.al, 2015). A re-analysis of existing LD tools in light of the design recommendations show further gaps in the existing tools. They do not (iv) accommodate domain influences nor do they (v) provide any evaluation mechanism to instructors on their LDs (except for Learning Designer which uses a pie-chart to show distribution of type of activities planned in the course).

8.3. Design and Development of the CuVIS tool

The CuVIS tool is based on the CuVIS framework and hence addresses some of the gaps obtained from analysis of existing LD frameworks like providing guidelines customized

to instructor-mediated setting. It also incorporates the design guidelines existing for LD tools. Table 8.3 shows the extent to which each of these guidelines have been operationalized in the CuVIS tool. The last two guidelines in Table 8.2 are not yet incorporated in the CuVIS tool though the resources required has been created like the LD evaluation rubric, self-evaluation checklist for instructors (Chapter 6) and database of example LDs created by instructors from various science and engineering domains as part of our studies with instructors.

Table 8.2: Operationalizing existing design guidelines in CuVIS tool

<i>Sr. No.</i>	<i>Design guidelines for LD tool</i>	<i>Operationalized in CuVIS tool through</i>
1	Flexible for instructors to customize (Bennett et.al, 2015)	The final LD is editable with the instructor allowed to insert additional activities or affordances
2	Balance between being open-ended vs. rigid template (Bennett et.al, 2015)	Balance determined through instructor feedback. Instructors are co-designers of the tool.
3	Domain influence (Bennett et.al, 2015)	Illustrative examples from instructor's domain provided with each of the conceptual guidelines
4	Stepwise default design process (Laurillard et.al, 2013)	The set of Activity Constructor prompts takes the instructor in steps through the ADDIE design process
5	Access to existing LDs & research findings (Laurillard et.al, 2013)	Access to research findings given through the CuVIS framework guidelines.
6	Evaluation feedback (Laurillard et.al, 2013)	Rubric created for manual evaluation of instructor LDs by experts (Chapter 6). But not yet included in tool.

In the development phase, the prototype of the CuVIS tool was tested with instructors (N = 10) in three iterative cycles for usefulness and usability. In each cycle, instructors used the CuVIS tool to create LDs for a learning scenario of their choice and then responded to pilot survey on usefulness. They were also interviewed individually for 10- 15 mins. to gather their feedback and enhance the usability of the tool. The usefulness survey used was based on the standard instrument of Technology Acceptance Model (TAM) (Davis, 1989). TAM was chosen because it has been widely used to predict user adoption of new technological tools including educational tools (Curlango-Rosas et.al, 2009). The pilot usefulness survey contained 8-items on a 5-point Likert scale and contained questions addressing the TAM constructs of perceived ease of use and perceived usefulness. Perceived ease of use is defined in TAM as the degree to which the user believes using the tool will be free of effort while

perceived usefulness is defined as the degree to which an user believes the tool will help in improving his/her job performance. Analysis of survey responses revealed high percentage of agreement among the instructors on both the constructs, implying the CuVIS tool prototype was perceived to be a useful tool by instructors. Interview analysis provided pointers on improving usability of the tool. For example, instructors wanted the final LD output to be editable and instructors allowed to insert new rows at the beginning and end of the table.

8.4. Functioning of CuVIS tool

It is a semi-automatic tool that assists instructors, who are novice designers, in authoring effective, customized LDs with visualization for instructor-mediated setting. The CuVIS tool presents the conceptual guidelines of the CuVIS framework in steps as a set of Activity Constructor prompts. It then helps the instructor by automating the generation of the final LD by integrating instructor responses to the prompts into the appropriate LD Blueprint template. Each Activity Constructor prompt corresponds to a design decision that instructors need to take in the LD creation process. Examples of these design decisions include what part of the chosen topic do learners find difficult to understand (learner analysis), how to connect the topic to real life, what multiple condition sets to show (if objective = conceptual understanding) or what variable values to vary to show causality (if objective = prediction), what active learning group activity question to design so that it is mapped to objective (content analysis). Each of these Activity Constructor prompts contains a conceptual level guideline accompanied by an illustrative example from the instructor's domain. As can be seen above, the set of Activity constructor prompts vary with variation in learning objective and activity time duration. Table 8.3 demonstrates how the set of Activity Constructor prompts vary with objective. Variation in objective changes the set of design decisions that needs to be taken. In Table 8.3, this variation is shown in red as the objective changes from prediction to multiple representation to procedural understanding.

Table 8.3: Illustrating change in the set of Activity Constructor prompts with objective (marked in red)

Activity Constructor Prompts:		
<i>Objective = Prediction</i>	<i>Objective = Multiple Representation</i>	<i>Objective = Procedural Understanding</i>
1. Decide the difficult part of the topic to target with visualization	1. Decide the difficult part of the topic to target with visualization	1. Decide the difficult part of the topic to target with visualization
2. Decide how to connect the topic to real-life	2. Decide how to connect topic to real-life	2. Decide how to connect topic to real-life
3. Decide which multiple condition sets you want to show through visualization	3. Decide which variables in representation you want to vary.	3. Breakdown the process into 'individual components' or modules
4. Frame the POE activity question such that it is mapped to your objective	4. Frame the TPS activity question mapped to Multiple Representation objective	4. Frame the TPS activity question mapped to Procedural Understanding objective
5. Design the Prediction worksheet [optional]	5. Decide where to pause the visualization	5. Decide where to pause the visualization
6. Decide what questions to ask to guide reasoning		
7. Decide where to pause the visualization		

The LD Blueprint is a template where the implementation steps are sequenced as per the cognitive process for that particular objective and the implementation protocol of the chosen active learning strategy (as per the activity time duration requirement). The layout of the blueprint template contains a tabular representation that specifies the role of the instructor, students and the visualization affordances, if any for each step at minute-level resolution. The design of this scaffold is explained with illustration in Table 5.10 (Chapter 5).

The theoretical basis for CuVIS tool is same as that of the CuVIS framework i.e. constructive alignment (Biggs, 1996) and meaningful learning with ICT (Howland et.al, 2012). It follows the ADDIE model of instructional designing to provide the structural support to the design process as recommended by Laurillard et.al (2013). In a nutshell, the CuVIS tool captures the variation in instructors' domain, objective and activity time requirements and assists them in creating a theory-informed and research-evidence based LD customized to their requirements.

The CuVIS tool proceeds through the Analysis, Design and Development stages of ADDIE model in four steps (Fig. 8.1): (1) Specification step - Instructor inputs customization specifications into CuVIS tool like domain, objective, activity time duration (2) Analysis step – Instructors takes design decisions through guided analysis of resource, learner and content,

(3) Design step - Instructor takes design decisions guided by CuVIS tool and (4) Development step - CuVIS tool integrates the design decisions into an effective LD as per the implementation protocol of the chosen active learning strategy.

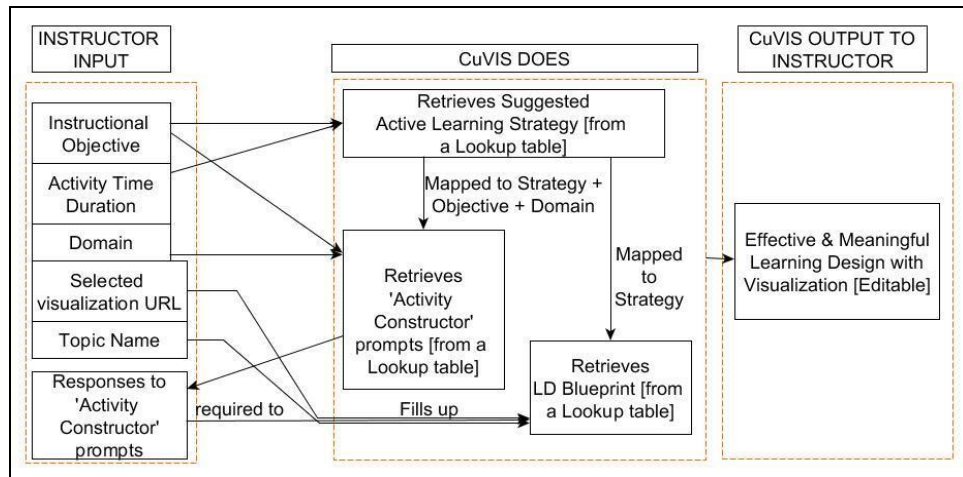


Figure 8.1: Overview of working of CuVIS tool

A. Specification step (step – 1)

The instructor-mediated classroom is taken as the default teaching-learning environment. CuVIS tool takes the instructor's specifications in terms of their objective, instructional setting (lecture/tutorial), domain, topic name and activity time duration. Instructors specify their learning objective with the visualization from the list of seven objectives identified from instructor interview analysis (Section 4.4.1) (Fig. 8.2). Each objective is accompanied with an illustrative example from the instructor's domain for better comprehensibility. Currently, CuVIS tool examples are restricted to the domains of EE and CSE. In fact, guidelines at every stage is illustrated through a domain example for better comprehensibility. This is how CuVIS tool accommodates the domain influence recommendation of LD tool design guidelines. Depending on the activity time duration and the objective specified, CuVIS tool suggests a sample research-evidence based active learning strategy (Fig. 8.3). This mapping algorithm has been explained in detail in Section 5.4.1.

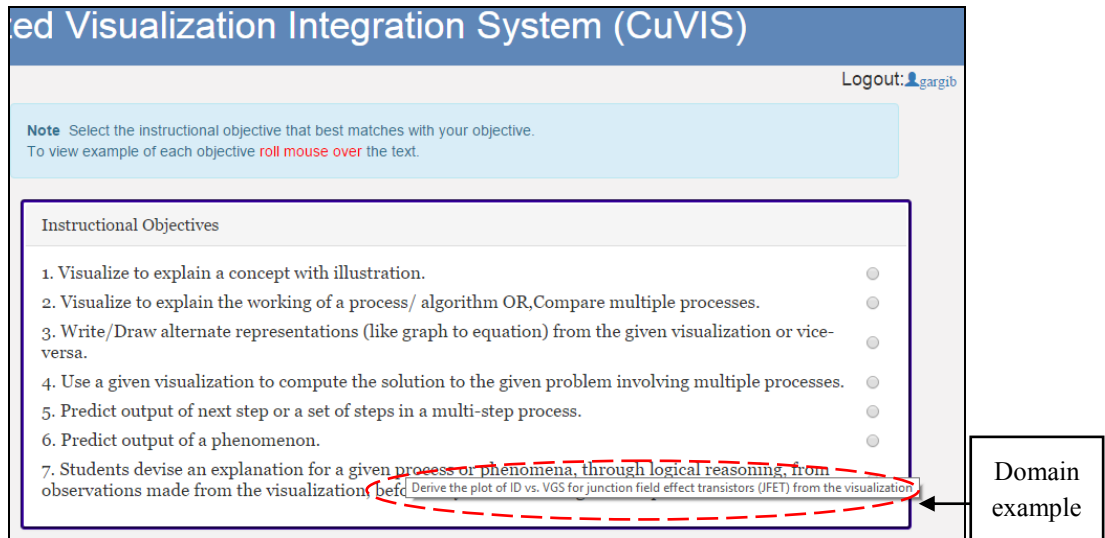


Figure 8.2: List of objectives with visualization for instructors to choose from

B. Analysis step (step – 2)

In this step, CuVIS tool guides the instructor through analysis of content, resource and learner.

(i) Content Analysis – Instructors are asked to choose those topics for teaching with visualization that requires the Weiss graph (Weiss et.al, 2002). This was to ensure that the topic chosen requires visualization use. Also, content analysis is revisited when instructors respond to some of the Activity construction prompts like framing activity question.

(ii) Resource Analysis - Depending on the objective specified, CuVIS tool presents a checklist of visualization affordances that are required in the selected visualization to support the pedagogy of CuVIS LD for that objective (Fig. 8.3). The checklist accommodates visualizations of different types – videos, animations and simulations and is incorporated to address the design impediment of instructor not being able to perceive the pedagogical utility of the tool affordances (Lim & Hang, 2003).

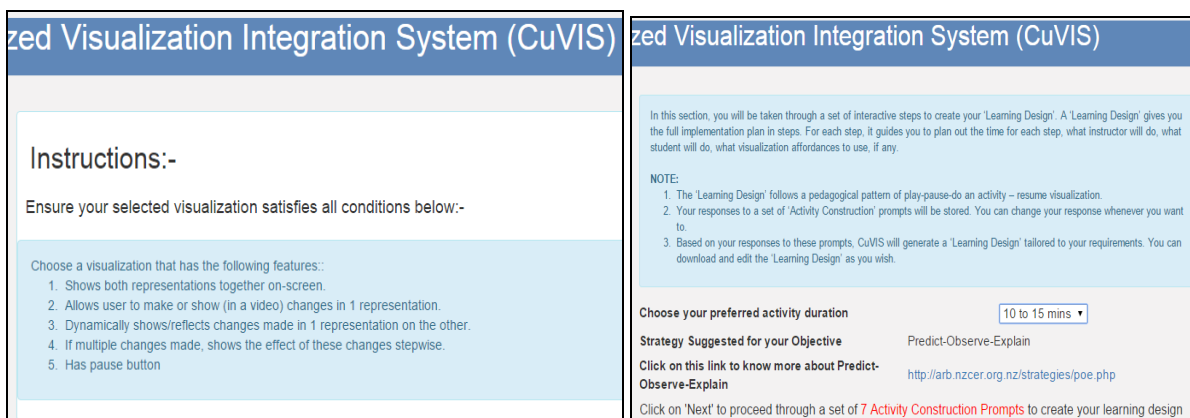


Figure 8.3: Resource analysis in CuVIS tool: Visualization Selection Checklist (for Objective = Multiple Representation (Left), Strategy selection (Right))

(iii) Learner Analysis – Instructors are guided to think about aspects of the chosen topic that they have seen their students generally find difficult to understand/ visualize. Thereafter, the LD needs to address this aspect. This was incorporated since this is where an in-service instructor’s teaching experience makes the LD richer and effective (ICT-TPACK, Angeli & Valanides, 2009).

C. Design step (step – 3)

In this step the sequencing and design of the CuVIS tool components like Activity Constructor prompts and LD Blueprint are done. Each Activity Constructor prompt contains three components – (i) the design decision to take, (ii) the guideline and (iii) the example from the instructor’s domain (Fig.8.4). For a particular objective and activity time duration, instructors are presented with a specific set of Activity Constructor prompts in steps. The sequencing of the prompts is done as per the ADDIE steps. On the other hand, the LD Blueprint template (Table 5.10, Chapter 5) outlines the implementation design. The layout contains a tabular representation in steps specifying the role of instructor, student and visualization at each step. The steps are sequenced as per the implementation protocol of the chosen active learning strategy. The template is editable for the instructors.

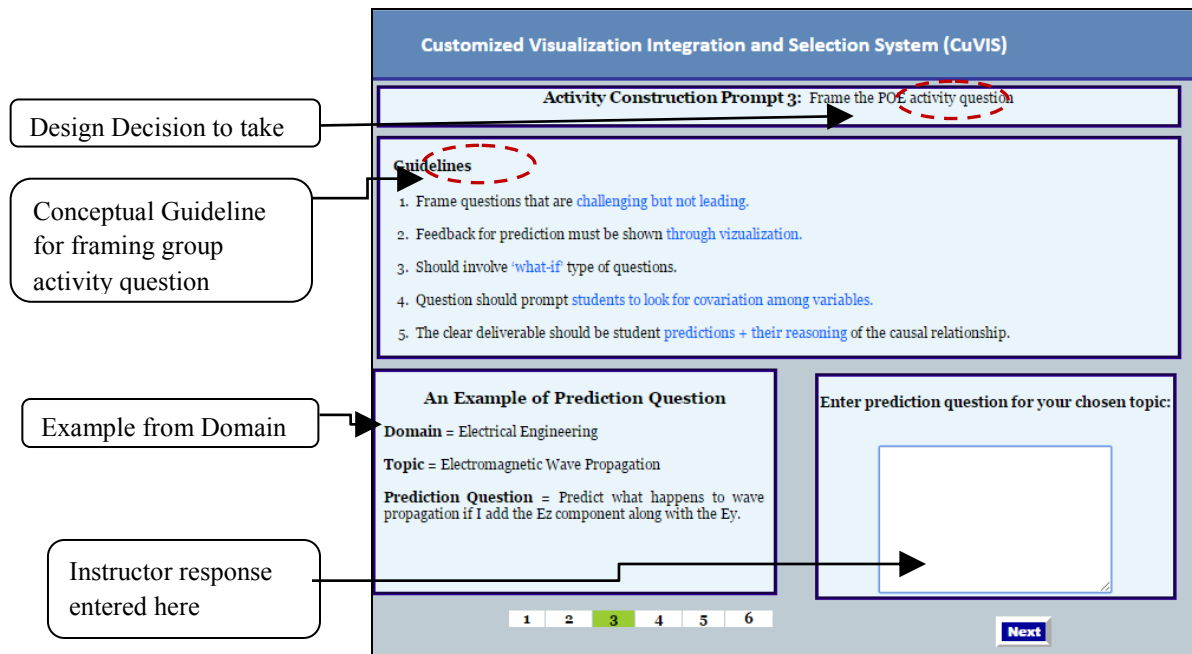


Figure 8.4: Example of components contained in an Activity Constructor prompt

D. Development step (step – 4)

In this step, CuVIS tool captures instructor responses to the Activity Constructor prompts and integrates them into the implementation design as per implementation protocol of the selected sample strategy. This process is automated in the CuVIS tool with the tool retrieving the appropriate LD Blueprint from the backend as per the objective and activity time duration requirement of the instructor. The final LD generated is editable allowing the instructors to add rows at the beginning (setting the stage for the activity with visualization) and at the end of the session planning and add any additional visualization affordances used at a particular step. This feature was incorporated to conform to the design guideline that LD tools have to maintain a fine balance between being open-ended and being rigid templates.

8.5. Usefulness & Usability Testing of CuVIS tool

This testing is part of the Summative Evaluation phase of DDR methodology (Fig.3.2, Chapter 3). The research question addressed in this section is: What is the instructor perception of the usefulness and usability of the CuVIS tool? (RQ4). The usefulness and

usability testing of the final CuVIS tool was done through large-scale surveys with science and engineering instructors.

A. Sampling and Sample Characteristics

The sampling strategy employed to draw sample from our accessible population was stage sampling (Refer Section 3.5). In stage 1, those instructors were shortlisted who satisfied the parameters for representativeness – (i) science and engineering instructors who have taught using visualizations in their instructor-mediated classrooms, (ii) who have attended pedagogy training workshop focusing on active learning, (iii) but are novice designers. In stage 2, these instructors were grouped into sample units based on their domains. After checking for data validation in terms non-blank LD submissions, we sampled all the responses from all the domain units. These science and engineering instructors had undergone our two-week blended pedagogy workshop for teaching with ICT tools. Hence, these instructors were aware of pedagogical principles but were novices in applying the principles to design student-centered teaching-learning activities using visualization. The instructors (N = 1200 +) hailed from nine different domains like Electrical (N= 202), Civil (N = 30), Computer Engineering (N= 778), Mechanical (N= 121), Biotechnology (N= 15) as also science domains like Physics (N= 23), Chemistry (N= 18), Earth Science (N=9) and Mathematics (N=20). The teaching experience was in the range of 0-30 years with its detailed distribution given in Table 8.4.

Table 8.4: Distribution of instructor teaching experience in sample taken for effectiveness testing of CuVIS tool

<i>Sr. No.</i>	<i>Teaching Experience</i>	<i>Frequency</i>
1	<1 year	21
2	1-5 years	336
3	6 – 10 years	466
4	11-15 years	272
5	16 – 20 years	85
6	More than 20 years	36

B. Instruments used

We took established survey instruments for testing usefulness and usability of CuVIS tool. To capture instructor perception of usefulness of CuVIS tool, we used the survey based on Technology Acceptance Model (TAM) (Davis, 1989). The survey instrument contained 10- items on a 5-point Likert scale (Table 8.5). The reason for choosing TAM instrument was that it has been widely used to predict user adoption and use of new technological tools including educational tools (Curlango - Rosas, 2009). This instrument captured instructor perception of usefulness in terms of whether CuVIS tool enhances their teaching effectiveness with visualization and makes the process of creation of LDs less time consuming. For usability testing, we used the 10-item System Usability Scale (SUS) (Brooke, 1996) widely used for assessing the usability of wide variety of products and services. We asked an additional question in each survey to capture instructor perception on gross usefulness and usability of the CuVIS tool (Fig. 8.6). For usability testing, the additional question (Q.11) included was – ‘Overall, I rate the usability of the CuVIS tool as Excellent, Good, OK, Poor, Awful.’

C. Procedure

Instructors first used the CuVIS tool to generate LDs with their selected visualization for their chosen topic and objective. They then uploaded their CuVIS-LDs in Moodle as part of their assignments for the blended pedagogy online workshop they were undergoing. Once their assignment was uploaded, they were requested to respond to the two surveys on usefulness and usability of CuVIS tool. There was a total of 4389 participants in the blended online course, out of which 1780 submitted their LDs. The number of respondents to usefulness survey was N = 1422 and for usability survey was N = 1290. To safeguard against conclusion validity threat, we did a random check of the LDs uploaded by the respondents. We checked for blank LDs uploaded with the objective of rejecting the survey responses of the corresponding instructor. Every 10th LD submission was randomly checked where they were arranged alphabetically. A total of 142 (10%) of the submissions were cross-checked and found to be not blank.

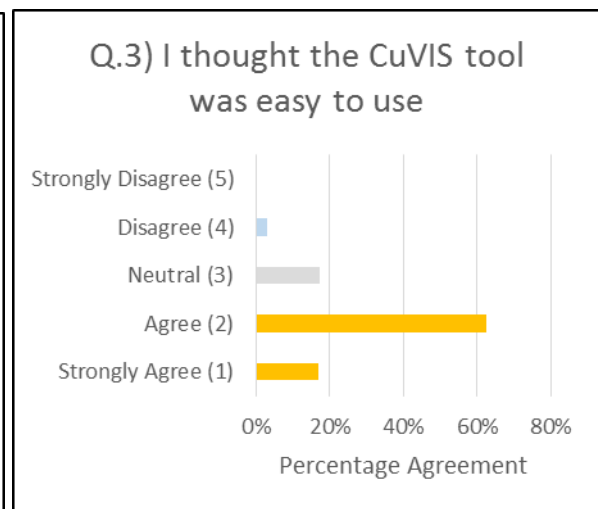
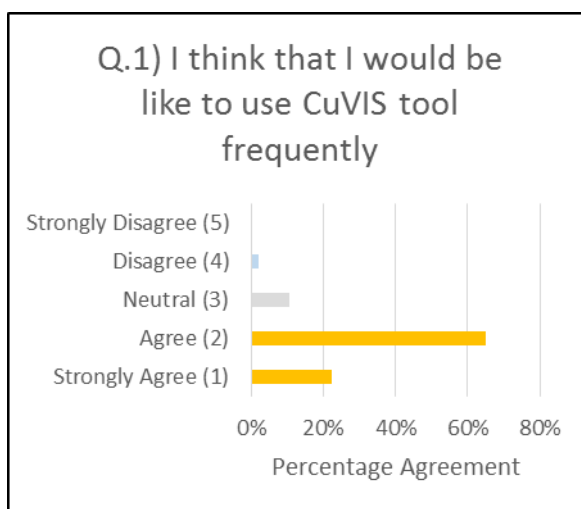
D. Results

Analysis of the survey data revealed that 90.13% of respondents perceived CuVIS tool to be a useful resource for creating LDs with visualizations (Table 8.5). The SUS survey

responses were used to calculate the SUS score as per standard method (Brooke, 1996). The SUS score came to 78.86 indicating the product is usable. Also, 92.18% of respondents (to Qs.11 in the usability survey) perceived usability of CuVIS tool as good to excellent. In the tables below the response analysis for each question in usefulness and usability survey is given. The Agree (%) in Table 8.5 is the total of Strongly agree and Agree.

Table 8.5: CuVIS tool usefulness survey results

Qs. No.	Question	Agree (number) %
1	I was able to use the CuVIS tool for my objective with the visualization.	92.11 (1120)
2	Using the CuVIS tool will improve the quality of my teaching with visualization	91.53 (1113)
3	Using the CuVIS tool will give me greater control over my teaching with visualization.	85.11 (1035)
4	CuVIS tool will enable me to accomplish learning design creation with visualization more quickly.	79.94 (972)
5	CuVIS tool supports critical aspects of creating a learning design with visualization	80.84 (983)
6	Using the CuVIS tool for visualization will increase my productivity	84.37 (1026)
7	Using the CuVIS tool for visualization will improve my job performance	81.5 (991)
8	The CuVIS tool for visualization will allow me to accomplish more work than would otherwise be possible.	73.69 (896)
9	Using the CuVIS tool will enhance my teaching effectiveness	89.97 (1094)
10	The CuVIS tool will make it easier for me to plan integration of visualization in my teaching	86.59 (1053)
11	Overall, I find the CuVIS tool to be a useful resource for my teaching (5-point scale)	90.13 (1096)



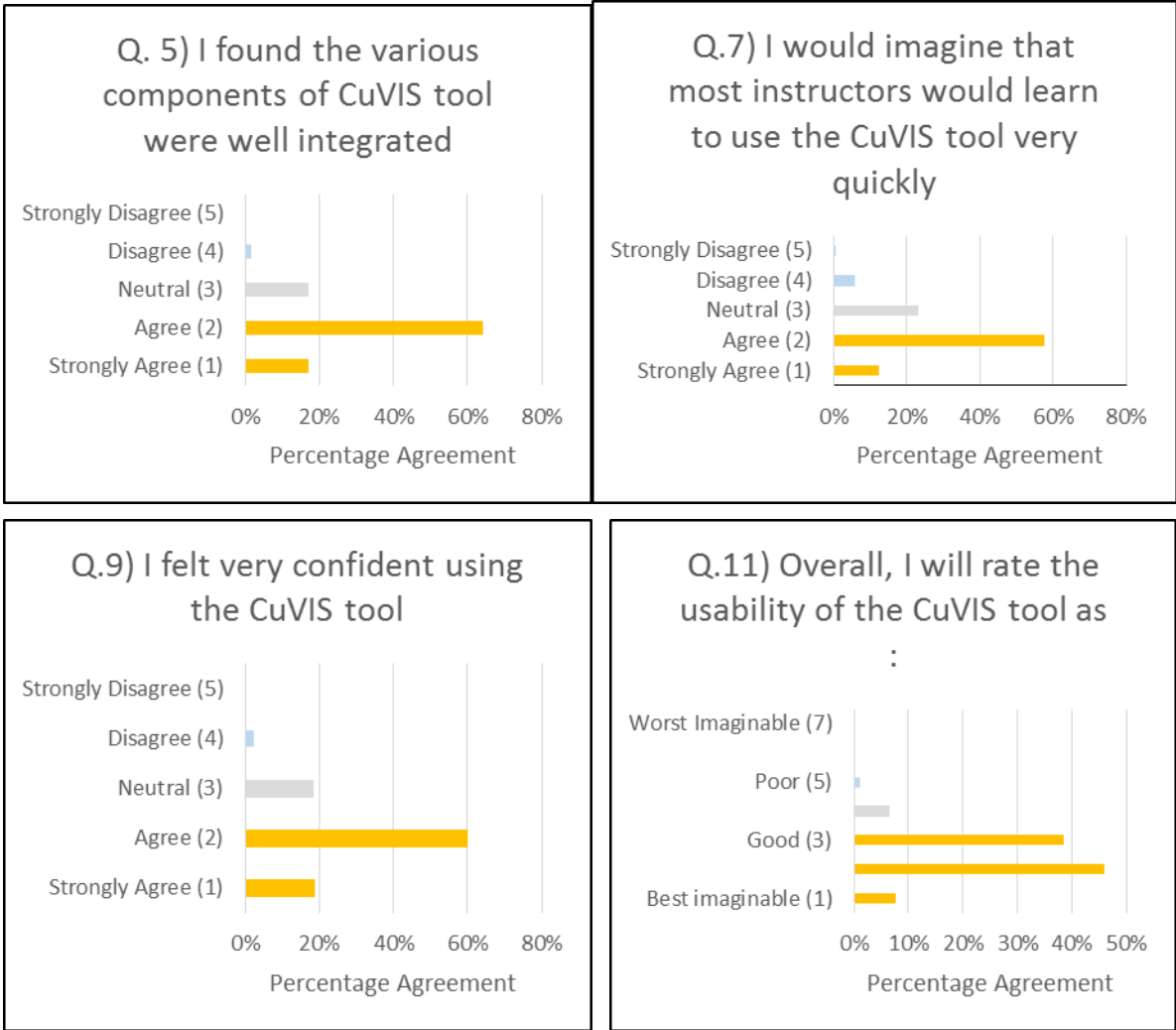


Figure 8.5.1: User response to positive questionnaire items in SUS survey

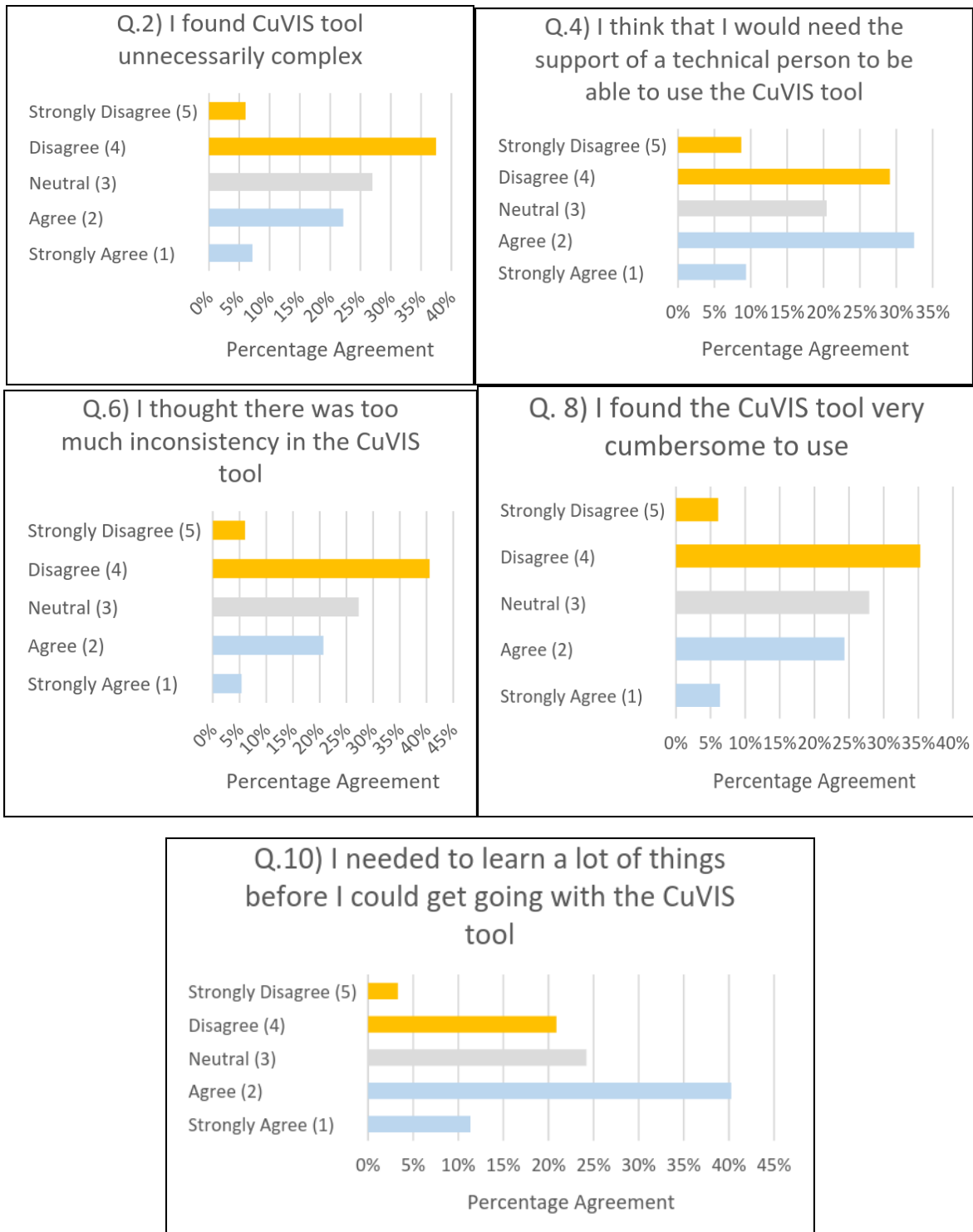


Figure 8.5.2: User response to negative questionnaire items in SUS survey

8.6. Summary & Discussion

CuVIS tool enables novice instructor-designers to create customized, constructively aligned, meaningful LDs with visualization for face-to-face instructor-mediated classroom setting. CuVIS framework provides guidelines at both conceptual (Activity Constructor prompts) and implementation levels (LD Blueprint). These guidelines have evolved from existing theory and addresses the four design impediments identified in Chapter 4 (Table 4.2). The CuVIS tool is a semi-automatic tool where the conceptual guidelines are presented to instructors as a stepwise series of Activity Constructor prompts. The tool automates the generation of the final LD by placing the instructor responses to the prompts at appropriate places within the LD Blueprint template.

The design of the CuVIS tool was informed by the existing design guidelines for LD tools (Table 8.2). The tool addresses the gaps identified in existing LD tools with respect to our research context (Section 8.3). The Activity Constructor prompts contain conceptual level guidelines that exploits the pedagogical utility of visualization affordances. Both the prompts and the LD Blueprint are customized to instructor-mediated setting. Also, the active learning strategy suggested by the tool is mapped to the instructor's objective and activity time duration requirements. The final LD generated is constructively aligned and support meaningful learning through collaborative active learning strategies.

The usefulness and usability of this tool was tested through large-scale surveys of more than 1200 instructors from nine different domains of science and engineering. Around 90% of the instructors perceived the tool to be useful and the SUS score obtained was 78.86 marking the CuVIS tool as a usable product. An analysis of the graphs in Fig.8.5.1 shows that majority of the instructors are confident of working with the CuVIS tool to create effective LDs. They have found the tool easy to use and are likely to continue using the tool in future. However, a study of the negative questions is SUS show that majority of the instructors are unsure of their application of the conceptual guidelines in their chosen topic. Hence, Q4 (Fig. 8.5.2) show 40.5% of the instructors felt they needed the help of a technical person (ET expert) in addition to the tool. This deficit in confidence is also shown in their response to Q10 where 52% of them felt they needed to know a lot of things before they could start using the tool. The probable reason for this perception is that the instructors were novice designers and had used

the CuVIS tool for the first time. Repeated use of the tool is likely to boost their confidence in application of the guidelines. Another reason that may have contributed to this survey result is 19.4% of the instructors were from non-EE/non-CSE domains and did not receive illustrative examples from their domains.

The above reasons point towards the limitations in the CuVIS tool. The tool currently does not provide feedback to the instructors on their operationalization of the conceptual guidelines. Also, the illustrative examples with the guidelines are restricted to EE and CSE domains. Thus, as part of future work examples from other science and engineering domains need to be included in CuVIS tool. Also, a feedback component needs to be built into the tool like a rubric or self-evaluation checklist that will spot the faulty operationalization and hint at corrective measures.

Chapter 9

Conclusion and Discussion

9.1 Overview of problem and proposed solution

Information and communication technologies (ICT) in education has been shown to lead to achievement of important teaching-learning objectives, especially in science and engineering domains like improving students' prediction and reasoning skill, increasing conceptual and procedural understanding (Rutten et.al, 2012). However, these objectives remain unrealized when the instructor simply lectures with ICT in the classroom (Tsai & Chai, 2012). For successful attainment of objectives, instructors need to design effective student-centered learning designs (LDs) that involving active learning and exploit affordances of the chosen ICT (Angeli & Valanides, 2009; Tsai & Chai, 2012). However, instructors are unable to design such effective LDs (Angeli & Valanides, 2009; Laurillard, 2012). This lack of instructors' design thinking has been identified as an important barrier to effective ICT integration in teaching (Tsai & Chai, 2012).

In this thesis, the problem is targeted within the context of instructor-mediated classrooms which is a reality in India and many parts of the developing world. This context poses additional challenge towards creating student-centred learning activities since students do not have 1:1 access to the ICT tool. Their interaction with ICT is necessarily mediated through the instructor (Banerjee et. al., 2015). Also, in this thesis we target that aspect of design thinking that deals with the knowledge and skill required to ‘enact a design process’. The knowledge required includes knowledge of content, learner, context (Huizinga, 2014) and pedagogical affordances of ICT (Angeli & Valanides, 2009). This is referred to as instructor design expertise. Thus the specific problem targeted in this thesis is: instructors’ lack of design expertise in creating student-centred learning activities for teaching using visualization in instructor-mediated classrooms.

As a solution to this problem, we have built the CuVIS framework that provides guidelines to enable instructors to design constructively aligned, meaningful LDs for instructor-mediated classroom setting. The CuVIS framework guidelines are aimed at the four design impediments we have identified from our studies with instructors (Chapter 4). They guide instructors stepwise through the LD creation process and equips them with pedagogical know-how to design theory-informed, research-evidence based LDs with visualization customized to their context. CuVIS framework captures the variation in instructor’s learning objectives, domain and activity durations and accordingly provides the requisite support. The CuVIS framework takes customization input from the instructor in terms of their domain (EE/CSE), objective and activity time duration. The domain specification leads CuVIS framework to present examples from the instructor’s domain to illustrate application of each framework guideline. The combination of objective and activity time duration determines the set of activity construction prompts and eventually the LD blueprint that is provided to the instructors. The output from the framework is a student-centered LD with visualization customized to the instructor’s requirements and to instructor-mediated setting.

The effectiveness of CuVIS framework in improving instructors’ design expertise has been shown through increase in their TPACK and change in pedagogical practice towards student-centered collaborative LDs (Chapter 6). CuVIS framework effectiveness has also been tested through success of CuVIS LDs in achieving targeted learning objectives on implementation with students (Chapter 7). The CuVIS tool was developed to aid instructor interaction with the CuVIS framework.

9.2 Delimitations of CuVIS framework

The CuVIS framework has been designed to assist instructors in designing student-centered activities using visualizations in instructor mediated classroom setting. This setting was chosen since it is common in Indian college classrooms and in many parts of the developing world (Banerjee et.al, 2015). In such a setting it is the instructor who controls the play of the visualization and the students interact with the visualization via the instructor. Thus, the pedagogical expertise of the instructor becomes even more crucial to override the constraints of the instructional setting. The CuVIS framework guidelines guide the instructor to create effective student-centered learning designs (LDs) within the constraints of such a context.

Among the various ICT tools that exist today, CuVIS framework has been built for teaching with dynamic visualizations like videos, animations and simulations. Visualizations were chosen as the ICT of choice since we found through our pre-workshop survey with 2410 science and engineering instructors that visualization was the commonly used ICT in classrooms. Thus, the LDs generated based on CuVIS framework focus exclusively on teaching-learning activities that use the visualization to teach. The CuVIS framework targets three different types of visualization - videos, animations and simulations. Within videos, only videos of experiments in science and engineering fall within the purview of the framework. Lecture videos are clearly out of scope. The variation in affordances provided by the three different visualization types is accommodated within CuVIS framework guidelines. The framework provides a common core design mapped to a particular objective and activity time duration specified. At relevant points, the guidelines deviate to inform instructors on the ways to operationalize the guideline based on the affordances of the available visualization type (Refer Appendix A: CuVIS Framework). Also, the CuVIS framework guidelines address teaching of science and engineering topics at the tertiary educational level. Therefore, the target audience of the framework are instructors from science and engineering domains.

9.3 Answering the research questions

The research objective of this thesis is to develop a framework that will enable instructors to create effective, customized LDs with visualization in context of instructor-mediated classrooms (Fig. 9.1). The research methodology followed to address this goal was Design and Development Research (DDR) that proceeds through the following phases of Problem Analysis, Design and Development and Summative Evaluation (McKenney, 2001). Science and engineering instructors were involved at each phase of CuVIS development. The research questions (RQs) addressed in each phase are shown in Fig. 9.1. There are no RQs addressed in the Design and Development phase since the goal of this phase was to build the framework based on the findings of RQ1 in the preceding Problem Analysis phase.

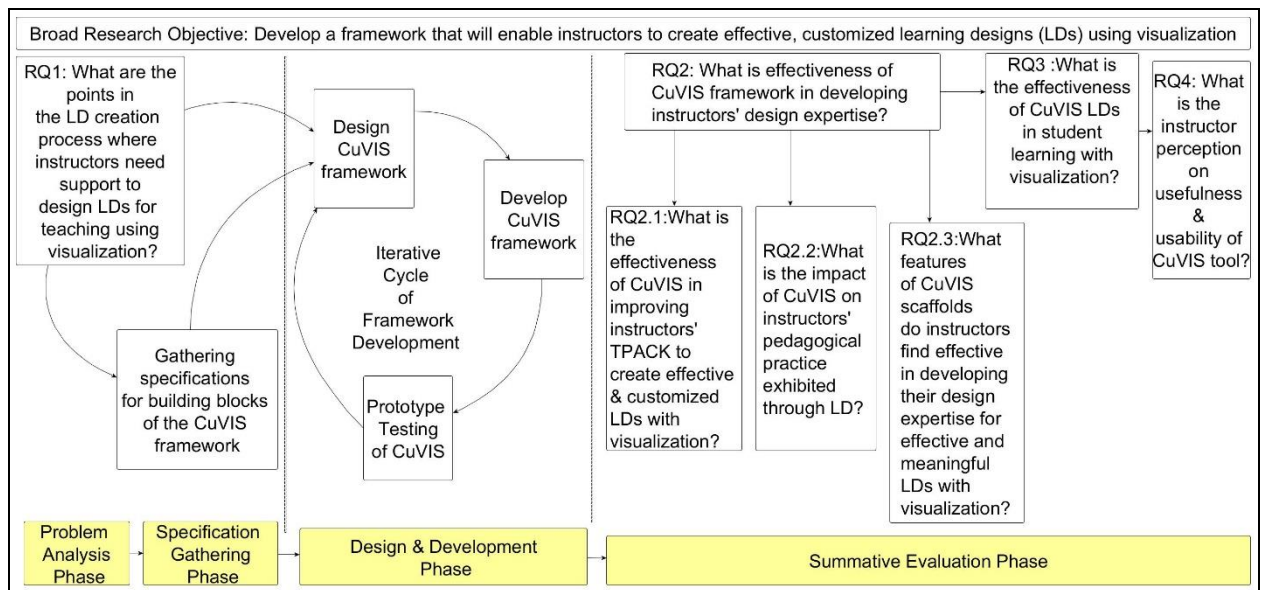


Figure 9.1: Overview of thesis research questions (RQs) at different phases of DDR

9.3.1 Problem analysis phase

The research question explored in this phase is ‘What are the points in the LD creation process where instructors need support to design LDs with visualizations? (RQ1) (Fig. 9.1) This is currently an open question in LD research (Bennett et.al, 2015). We wanted to identify the design impediments faced by instructors in our research context. This RQ was answered through inductive content analysis of unguided instructor LDs. The instructors (N = 30) in

this study had attended a two-week blended pedagogy workshop but were novices in designing effective LDs with visualization (Chapter 4). We identified four design impediments, both at conceptual and at implementation level. These were:

(i) Conceptual level impediments

- Operationalizing constructive alignment
- Operationalizing meaningful learning with ICT
- Framing group activity question with visualization

(ii) Implementation Level impediments

- Designing implementation for chosen active learning strategy

The CuVIS framework guidelines were designed to address these four impediments as part of the Design and Development phase (Chapter 5).

9.3.2 Summative Evaluation phase

The objective of the third phase of Summative Evaluation is to evaluate effectiveness of the CuVIS framework in teaching with visualization in instructor-mediated classrooms. The effectiveness was tested in terms of (i) improvement in instructors' design expertise (Chapter 6), (ii) success in achieving learning objectives on implementation of CuVIS LDs with students (Chapter 7) and (iii) usefulness and usability of the CuVIS tool (Chapter 8). Each of these corresponds to an RQ (Fig. 9.1).

The effect on design expertise is explored through RQ2: What is effectiveness of CuVIS framework in developing instructors' design expertise for LDs with visualization? This effectiveness is measured along the following axes: (i) instructors' TPACK scores for their design expertise (RQ 2.1) and (ii) change in their pedagogical practice (RQ 2.2). We also interviewed instructors to identify which features of CuVIS framework scaffolds they found helpful in developing their design expertise. Thus, the three sub-RQs are:

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

RQ2.2: What is the impact of CuVIS framework on instructor's pedagogical practice as exhibited in their LDs?

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

The first two sub-RQs were answered through a semester long qualitative study with six engineering instructors (EE & CSE). Each instructor created LDs on their chosen learning scenarios across three different time points (Warmup: pre-CuVIS framework, Scaffold: CuVIS framework use and Transfer: post-CuVIS framework) with varying degrees of support. In the Transfer round, instructors chose a new learning scenario and were expected to apply their learning from the Scaffold round to design effective LDs. To answer RQ2.1, the three LDs of each instructor were evaluated using a rubric to track the variation in TPACK scores from Warmup to Transfer. The rubric measures design expertise along six criteria – five dimensions of meaningful learning plus constructive alignment with a scale of 0 - 4. The evaluation results showed increase in total TPACK scores for all instructors from 2 - 4 in the Warmup round to 20-23 (out of 24) in the Transfer round. An upward swing in TPACK scores was found along each dimension from Warmup to Transfer except for the Authentic dimension. For two of the six instructors there was in fact, a drop for the Authentic dimension. Interviews with these instructors revealed that they found it difficult to frame a group activity question based on real-life since the selected visualization did not have affordances to support creation of such an activity.

To address RQ2.2, the pre and post-CuVIS LDs of each instructor were analyzed using the techniques of time allocation analysis (Kong et.al, 2011) and temporal sequence of activities analysis (Laurillard, 2012). These two techniques were chosen as they have been used by researchers to capture instructor's pedagogical practice from analysis of their LDs. We found that the activity category that showed the maximum mean increase in time allocation (32%) was 'Group activity with visualization' going from Warmup to Transfer. Additionally, the percentage of time allocated for activities like 'Lecturing without student interaction' and 'Interactive activity but without visualization' showed a drop. The analysis of sequence of activities revealed instructors migrated from lecturing with visualization to doing a series of student-centered activities with visualization.

Thus the above findings indicate CuVIS framework use resulted in increase in instructors' design expertise. The fact that they were able to retain their high TPACK scores

in the Transfer round even after withdrawal of CuVIS framework points to development in their knowledge of learner, content and context analyses. Also, they developed the ability to design student-centered activities with visualization and frame group activity questions exploiting the pedagogical utility of visualization affordances.

The third sub-question (RQ2.3) was answered through thematic analysis of semi-structured instructor interviews. This helped identify features of design expertise scaffolds that instructors found helpful – (i) illustrative examples from the instructor’s domain for each guideline, (ii) guidelines on learner analysis that triggered them to think from point of view of students’ difficulties, (iii) guidelines on how to frame group activity question based on the visualization and also aligned to their objective, (iv) the ‘microlevel’ detailing in the implementation scaffold (LD Blueprint) where each step is of 5-10 mins. duration and role of instructor, student and visualization affordance specified for each step and (v) the self-evaluation checklist that reminds them of the dimensions to include in their LDs.

The effectiveness of CuVIS LDs in achieving the targeted learning objective is explored through RQ3: What is the effectiveness of CuVIS framework on student learning with visualization? It is answered through control-group field experiments conducted with students (N = 375). The experimental group was taught based on the CuVIS framework LD and control group was taught based on the LD traditionally followed by the instructor. Thus, the only parameter that differed between the groups was the LD used. All other parameters like the learning material and visualization used, the instructor and the topic remained the same for both groups. The experimental group students in each experiment performed statistically significantly better ($p < 0.05$) on the selected objectives with visualization compared to the control group. Thus we can claim that student achievement of the targeted learning objective is higher when instructors teach with CuVIS LDs.

To improve the ease of use of CuVIS framework, the CuVIS tool (<http://www.et.iitb.ac.in/cuvis>) was built in response to instructors’ recommendation. It is a digital interface for instructors to interact with the framework. It automates the generation of the implementation design (LD Blueprint) incorporating instructor’s responses to the Activity Constructor prompts. This tool was tested for usefulness and usability with 1200 + science and engineering instructors from nine domains. The instructors used the CuVIS tool before responding to usefulness survey based on TAM (N = 1216) and SUS (usability, N = 1290).

90% of the instructors surveyed perceived CuVIS tool to be a highly useful tool. It had a SUS score of 78.86 marking it as a usable product.

Thus, from the evidence presented above we can claim use of CuVIS framework leads to development of instructors' design expertise. This claim is further supported by two factors: (i) the increase in instructors' TPACK scores and improvement in their pedagogical practice was noted in the Transfer round. In this round instructors designed for a new learning scenario without the help of CuVIS framework. (ii) Post-study interviews with instructors revealed that though it was a semester-long study, they had not participated in other pedagogy workshops or read up relevant research articles during this period. So improvement in instructors' design expertise can be attributed to the knowledge and skill gained through their use of CuVIS framework in the Scaffold round. While designing in the Transfer round, they may have referred to their CuVIS LD of the Scaffold round. This would in fact point towards crystallization of their learning from CuVIS framework. However, to strongly establish the claim we need to test with larger number of instructors and in more number of domains. Also, we can claim that students' achievement of targeted learning objectives is higher when instructors teach with CuVIS LDs. This claim is based on the evidence from field experiments with a sample of 375 engineering undergraduate students for topics that involved dynamic systems that were invisible and changed with time. However, the number of topics involved was restricted to two, one each from EE and CSE domains. Further testing with larger number of topics and from different domains is required to substantially establish the claim. Further, we can claim that the CuVIS tool is highly useful and usable tool for science and engineering instructors.

In light of these claims, we discuss to what extent we have been able to meet our research objective. Our objective was to develop a framework that would enable instructors to create effective customized LDs for teaching using visualization in instructor-mediated classrooms. To create effective LDs, instructors need to develop their design expertise. Design expertise involves knowledge and skill of the design process as also knowledge about learner, content and context (Huizinga, 2014). The findings of RQ 2.1 show that CuVIS framework use has increased their TPACK in terms of their conceptual knowledge of constructive alignment and meaningful learning. This knowledge requires knowledge about learner, content and context. This increase in knowledge is reinforced by the findings of RQ 2.2 which shows CuVIS framework use resulted in a change towards constructivist pedagogic

practice. All the findings of RQ2 show that CuVIS framework was able to resolve the four design impediments identified. Since conceptual knowledge is known to be intertwined with procedural knowledge in problem solving (Jonassen, 2000), we can assume successful creation of effective LDs would involve development of the instructors' knowledge of the design process. However, we have not explicitly evaluated the development of this component of instructors' design expertise. The findings of RQ3 provide evidence for effectiveness of CuVIS framework guidelines that were synthesized from narrative review of existing literature. This confirms that use of CuVIS guidelines leads to creation of effective customized LDs where effective implies constructively aligned, meaningful and exploits affordances of visualization (Sec.2.4). The positive instructor perception recorded for usefulness and usability of the CuVIS tool (RQ3) affirms that instructors can use the tool to interact with the CuVIS framework with ease. However, we have received instructor feedback on further improvement of usability like including illustrative examples from more number of domains. Overall the CuVIS framework developed is able to assist instructors in creating effective customized LD with visualization for instructor-mediated classrooms.

9.4 Implications

The two main stakeholders of CuVIS framework and tool are the instructors and the teacher trainers. The primary stakeholders of CuVIS framework are science and engineering instructors who teach in instructor-mediated classrooms with a student strength of 60 -100. They are novices when it comes to designing activities using visualization. These instructors can use the CuVIS framework/tool to create a theory-informed research-evidence based LD using visualization that is customized to their requirements. Such effective LDs when implemented with students will ensure achievement of the intended teaching-learning objectives. These instructors have been involved as co-designers of the CuVIS framework in all the three DDR phases. For example, we identified the design impediments to target through analysis of instructors' unguided LDs. Thus, we attempted to ensure the practical viability of the CuVIS framework. However, the prerequisite for productive use of CuVIS framework is that instructors should be aware of constructivist pedagogy and active learning strategies. Also, the illustrative domain examples that CuVIS framework provides to facilitate

translation of the guidelines to their context is currently restricted to EE and CSE domains. We have found majority of instructors from other domains have been able to transfer CuVIS framework guidelines to their context. But they have felt the need to have examples from their domains too. The secondary stakeholders are the teacher trainers. They can use CuVIS framework in the training workflow outlined in Section 6.3 along with the additional resources created like the self-reflection scaffolds to develop instructor's design expertise in self-paced mode. Thus CuVIS framework can be used as a post-workshop training resource to crystallize the learnings from the workshop. However, the teacher trainers need to provide expert feedback on the instructor LDs created in training phase.

The other group of secondary stakeholders for the research findings in this thesis are the learning design (LD) researchers. The identification of design impediments in the LD creation process is an open question in current LD research (Bennett et.al, 2015). This thesis contributes to LD research by identifying four design impediments both at the conceptual and implementation levels such as operationalizing constructive alignment or meaningful learning. The thesis also identifies a set of features that design scaffolds should have to be effective in developing instructors' design expertise. This would help researchers involved in designing scaffolds for instructors' design expertise.

The three gaps in existing literature we had identified in Chapter 2 for our research context were: (i) current LD frameworks/tools do not address the context of instructor-mediated classrooms, (ii) they do not focus on guidelines for exploiting affordances of a specific ICT tool and (iii) the level of support provided by existing guidelines to facilitate translation of theory into practice was inadequate for instructors in our context. The CuVIS framework guidelines were designed to address the context of instructor-mediated classrooms. The guidelines also incorporated the pedagogic utility of visualization affordances. Further, CuVIS LDs based on these guidelines were successfully implemented by instructors teaching using visualization in such classrooms. However, CuVIS framework guidelines are mapped to the seven learning objective categories identified from interviews with our target instructors (Chapter 4). Hence, the gaps (i) and (ii) have been addressed in this thesis but for the particular set of objective categories. The target audience of CuVIS framework includes tertiary level instructors who are novice designers and do not have the provision of semester-long training programs. Such instructors were able to use the CuVIS framework guidelines to

translate theory into practice. The level of detailing required in CuVIS framework guidelines evolved from our studies with instructors who were co-designers of the framework.

9.5 Generalizability

The research goal of the thesis was to develop a framework that would enable instructors to create effective LDs with visualization customized to their requirements. The instructional setting chosen was instructor-mediated classrooms. The framework was developed in iterative cycles involving feedback from science and engineering instructors. CuVIS framework incorporates illustrative examples for each guideline from the domains of EE and CSE currently. Hence, its effectiveness on instructor design expertise and student learning was tested with instructors from these domains. The instructors who were part of the experiments were novice designers. They had exposure to benefits of student-centered, active learning pedagogy by attending a two-week blended pedagogy workshop. With this backdrop, the plausibility of extending the applicability of CuVIS framework to other settings, domains and instructor population is discussed in this section.

9.5.1 Setting:

Experiments (Chapters 6, 7 & 8) with instructors have shown that they have been able to use CuVIS framework successfully to create constructively aligned, meaningful LDs when setting is instructor-mediated classroom. This success was measured in terms of (i) increase in instructors' TPACK for designing meaningful learning and constructively aligned LDs (Chapter 6) and (ii) successful achievement of the targeted student learning outcomes (Chapter 7). Therefore, the question is: Can the effectiveness of CuVIS framework be extended to instructors in other settings?

We analyze the setting dependency of the CuVIS framework in this subsection. There are two levels of CuVIS framework guidelines, the conceptual level and the implementation level. The conceptual guidelines were formulated through synthesis of cognitive model of learning a particular objective (Chapter 4). Hence, the CuVIS framework guidelines at this level is largely independent of setting. It were the examples from the domain that illustrated

customization to the setting (Fig. 1.1). Also, the implementation design scaffold (LD Blueprint) is customized to the constraints of instructor-mediated classrooms. To test the degree of setting dependency in CuVIS framework, the framework was given to 2 teaching assistants in a MOOC course on Signals and Systems (EE) to create effective LDs with visualizations. They were able to use CuVIS framework conceptual guidelines to create constructively aligned and meaningful LDs with visualizations for the topics of Convolution and Fourier transformation (Table 10.2). But they were not able to use CuVIS framework implementation level guidelines to design the implementation of group activity (like Pair phase in Think-Pair-Share strategy) through discussion forums in MOOC. Therefore, it may be concluded that instructors can use the conceptual guidelines of CuVIS framework to create constructively aligned, meaningful learning activities with visualization for their chosen setting. CuVIS framework can help instructors overcome the following design impediments, irrespective of their instructional setting –

- (i) Operationalizing constructive alignment
- (ii) Operationalizing meaningful learning dimensions
- (iii) Framing group activity question with visualization

However, CuVIS framework guidelines cannot help instructors in ‘Designing implementation for chosen active learning strategy’ in settings other than face-to-face classrooms.

9.5.2 Domain:

CuVIS framework has been shown to have an impact on student learning in topics like Pointer Arithmetic (Programming course, CSE) and Signal Transformation (Signals & Systems course, EE). The topics were chosen through the Weiss graph (Weiss et.al, 2002) and hence dealt with systems/phenomenon that are difficult to visualize (like change in variable values within the computer on program code execution) or are dynamic, changing in time/space (Signal Transformation). These characteristics were also true for the topics that instructors (N = 1216) selected for their design activity (Study 1, Chapter 4 and Study 3, Chapter 6) like bubble sort, stack operations, breadth first search (CSE), resistive circuit, bipolar junction transistor, digital signal modulation (EE). A subset of such topics is given in Table 9.1 to give an essence of the multi-domain applicability of the CuVIS framework with

respect to science and engineering. The nine domains covered include Mechanical, Civil, Biotechnology, Chemistry, Physics, Mathematics, Earth Science besides EE and CSE. Also, during specification gathering phase we gathered the specifications for different types of objectives from this subset of science and engineering domains. However, arts and commerce domains like History or Accountancy are outside the purview of CuVIS framework.

Table 9.1: Topics selected for generating LDs with CuVIS framework

<i>Domain</i>	<i>Topics Selected</i>
1. Computer Science & Engineering (N=778)	Database normalization, Algorithms: Binary Search, Fetch->Decode->Execute cycle in CPU operation, Insertion into binary search tree, Conversion of Infix to Postfix Expression using stack, Replacement Policies in Cache Memory, Arrays in C, Merge Sort, Dijkstra's algorithm, Diffie Hellman Key Exchange, Fuzzy Logic Control, Logic Gates, Stack operation, Insertion sort, Selection sort, Sequence alignment, OSI model, Functioning of 8085 microprocessor, IP Addressing and Subnetting, K-means clustering, Programming 8051 Microcontroller, Process Scheduling, Virtual memory
2. Electrical Engineering (N= 202)	Convolution, MOSFET, PN junction diode, Creation of an Electric Dipole, Bipolar Junction Transistor, CMOS fabrication, Types of control valves, VLSI Chip Testing DFT & BIST, Magnetostatics and electromagnetic theory, Wave Propagation along a transmission line, Homomorphic Filtering, Linear Block Code, Effect of variation of gate and drain voltages on JFET I-V characteristics, Frequency Modulation, Fourier series, Operation of a semiconductor junction diode, Thevenin Theorem, Electromagnetic radiation from a transmitter antenna, Q-point, Electromagnetic wave propagation, Amplitude modulation, Pulse code modulation, Resistivity circuit, Faraday's law of electromagnetic induction, Hydroelectric power generation, Electrostatics
3. Mechanical Engineering (N=121)	Liquid motion within a centrifugal pump, Continuous casting, Working of Internal Combustion Petrol Engine, Flipflop, Damping in spring mass system of mechanical vibration, Basics of IC Engine, Principle of transformer operation, Fundamentals of Turbomachines, Lathe machine, Working of wind turbine, Stress strain behavior of an axially loaded bar, Whitworth quick return mechanism, Rotational flow inside the Boundary Layer, Heat exchanger working principle, Carnot cycle, Transmission of power using belt and rope drives, TM Waves in rectangular waveguide, Operations of thermal power plant, Hall-effect sensor, Mechanics of metal removal process, Working of petrol engine, Tidal energy conservation, Friction Stir Welding, Iron carbon diagram, Assembly drawing, PID Controller, Differential
4. Civil Engineering (N = 30)	Streamline & Pathline flow, Type of Bond Corner in brick masonry, Manufacture of cement, Working principle of points and crossings

<i>Domain</i>	<i>Topics Selected</i>
5. Chemistry (N = 18)	Manufacture of nylon 6,10, Causes of environmental pollution, Green Chemistry, Nernst equation in electrochemistry, Beer-Lambert's law, Electrochemical corrosion, Nucleophilic substitution reactions (SN1, SN2), Gel filtration chromatography, CO ₂ CRC adsorption process, Crystal defect
6. Biotechnology (N=15)	Phagocytosis, BloodTyping, Structure of DNA, Enzyme-substrate binding, enzyme activity in sample reaction, DNA replication
7. Physics (N = 23)	Introduction to laser, Electrical resistivity in superconductors, Bouyant force, Boyle's law, Newton's Law of Viscosity, Simple harmonic motion, Moment of a force, Crystallography, Superconductors
8. Mathematics (N = 20)	Linear algebra – eigenvalues, Non-linear equation using N-R Method, Transportation problem
9. Earth Science (N = 9)	Seismic waves, Folding

An analysis of CuVIS framework was carried out to gauge the degree of domain-specificity supported by it. Of the framework guidelines, the implementation guideline (LD Blueprint) is domain neutral since it deals with implementation design of the chosen active learning strategy in the context of large classes (student strength = 60 -100) in instructor-mediated setting. It also contains the basic cognitive structure particular to that objective. The conceptual guidelines (Activity construction prompts) aim to provide the requisite knowledge and skill required for instructors to design effective activities with visualization. These guidelines give the generic set of cognitive sub-goals to target for the particular objective selected. For example, if objective is multiple representation the cognitive sub-goals to target are students relating and then translating between the alternate representations. This part of CuVIS framework guidelines is domain-generic.

It is the illustrative examples accompanying each guideline that brings in the domain-specificity (Fig. 1.1). Currently, it is restricted to the domains of EE and CSE. The assumption was that since these two domains between themselves cover both dynamic natural systems (EE) as well as algorithmic, modular systems (CSE), instructors from other domains would be able to find an analogy in these examples. They would then be able to transfer the CuVIS framework guidelines to their specific domain. To test this conjecture, CuVIS framework was tested with 236 instructors from other domains like Civil Engineering, Mechanical, Chemistry, Biotechnology, Physics, and Earth Science. They used the CuVIS

framework to create LDs for their chosen topic and then responded to a usefulness and usability survey. Content analysis of these LDs revealed they were able to overcome the four identified design impediments similar to their colleagues from EE and CSE domains. They also gave positive response to usefulness of CuVIS framework and a SUS score of 60.2 (N = 236). In response to the open-ended question in the survey, we found (5/236) i.e. 2.1 % of respondents gave recommendation for including examples from their domains also. An analysis of the LDs of these five respondents revealed that except for one, all others could apply the guidelines satisfactorily in their domains. It is however assumed that they would have had to invest more time and effort to make the transfer to their domains compared to EE or CSE instructors. A study of the comments received (given below) appears to allude to this fact:

- “would like to suggest to add more lesson plan templates for the domain like Civil Engineering as it was really difficult for us to prepare the proper lesson plan for it”
- “It was helpful but need more clarity specific to the stream”
- “In order to answer the above questions (usefulness & usability) also to implement in my teaching process, I need to learn a lot more as in how to use the lesson plan resource in my domain.”
- “Please mention examples of all the domain i.e. chemistry, biotech”
- “Slides that mentions the guidelines and examples need to be modified as it does not include guidelines and examples for Civil Engineering domain properly.”

9.5.3 Instructor characteristics:

Instructors (N = 1200+) who were part of the CuVIS framework effectiveness experiments had prior exposure to benefits of active learning and constructivist pedagogy through a two-week online pedagogy workshop. They had an average teaching experience of seven years. They were able to successfully implement the CuVIS framework guidelines to create constructively aligned and meaningful LD with visualization for their learners. CuVIS framework was also tested with ten instructors among them had teaching experience of up to one year. We analyzed the LDs generated by ten instructors, picked at random. While this is a small subset of total instructors, we found that they were able to override the four identified design impediments with the support of CuVIS framework. Thus, CuVIS framework appears

to be effective for instructors irrespective of their teaching experience if they have attended a pedagogy workshop focused on teaching with visualization before. However, it is difficult to predict effectiveness of CuVIS framework for instructors who have not attended any pedagogy workshop. Their insufficient prior knowledge about learning objectives or benefits of active learning might prove a hindrance to the effective use of CuVIS framework. This can however be mitigated through self-study with online course videos.

9.6 Limitations

In this sub-section we present a list of limitations of the CuVIS framework:

(i) *Prescriptiveness*: CuVIS framework is prescriptive to a certain degree like giving a set of objectives to choose from or suggesting a strategy to design the LD. Critics can argue from research perspective that this prescriptive nature of CuVIS framework will hinder the development of instructors' design expertise. However, we wanted to build a framework that will be practically relevant for tertiary level instructors who are novice designers and do not have the provision of attending long-term training programs. The current design of the framework in terms of the level of detailing required in guidelines evolved through our studies with instructors (e.g. Study 1, Chapter 4). Even though CuVIS framework is prescriptive to some extent, it serves our research objective of providing a viable starting point to instructors to create effective LDs with visualization for instructors who are novice designers.

(ii) *Strategy choice*: CuVIS framework takes the decision of which active learning strategy is suitable for creating the LD based on objective and activity time duration selected by the instructor. Designing effective learning activities with visualization is an ill-defined problem (Mishra & Koehler, 2006). It can have multiple possible solutions, especially with respect to the choice of active learning strategy to implement the LD. In CuVIS framework, a set of three active learning strategies (PI, TPS, POE) were chosen based on a set of five filters mapped to our research context. These strategies were simply vehicles to exemplify the operationalization of CuVIS framework guidelines customized to the instructor's requirements with least instructor effort. Other active learning strategies could have been used

like role play or flow chart for procedural understanding objective or concept map for conceptual understanding objective. These strategies are likely to have had an equivalent impact on instructor's design expertise and student learning with CuVIS LD.

(iii) *Completeness of objective list*: CuVIS framework presents a list of seven objective categories with visualization for the instructor to choose from. This objective list was prepared after interviews with 28 instructors drawn from our sample population, to identify objectives that science and engineering instructors generally have while teaching using visualization. However, discussions with instructors who were also Educational Technology (ET) experts revealed that Create level objectives like Visualize the bank scenario and design an appropriate solution (Simulation Modeling course, CSE) or, design a system using appropriate data structure for a given real-world scenario in Data Structure course, are not covered by CuVIS framework. However, we had 92% of instructors (N = 1216) in the usefulness survey agreeing that the CuVIS framework objective list covered the objective they had targeted with visualization.

(iv) *Assessing effectiveness*: Further to this, the two control-group field experiments to evaluate the impact of CuVIS LDs on implementation in student learning involved 375 students from the domains of EE and CSE. However, the experiments involved teaching of one topic each from EE and CSE. Also the qualitative experiment to evaluate the development of instructors' design expertise with CuVIS framework involved six instructors and twelve topics from EE and CSE. Thus the results of these experiments point to positive impact of CuVIS framework, both on instructor design expertise and student learning. But the number of topics and the number of instructors need to be increased to strongly establish the current effectiveness results.

(v) *IMS-LD specification*: The LDs created with CuVIS framework currently do not conform to IMS LD specifications that would lead to increased interoperability of the LDs and easy import into an LMS. This is so because technical aspects were not the focus areas of CuVIS framework. The focus is more on the pedagogy of teaching using visualization.

Chapter 10

Thesis Contributions & Future Work

10.1 Contribution of thesis

The major contributions of this thesis are:

- The CuVIS framework - It enables instructors to create effective customized LDs using visualization in instructor-mediated classrooms. Here effective LDs refer to constructively aligned, meaningful LDs that use active learning strategies and exploit the visualization affordances. The framework, when used in the training workflow outlined in Chapter 6, has also been shown to contribute towards developing instructors' design expertise. Use of CuVIS framework has been shown to lead to increase in instructors' TPACK scores in terms of designing for constructive alignment and meaningful learning. It also led to change in pedagogical practice with instructors moving from instructor-directed lecturing with visualization to doing a series of student-centered group activities using visualization

affordances. However, the sample size of LDs analyzed were eighteen (6X3) with each of the six instructors creating three each at different time points across a semester.

- Design scaffolds: Scaffolds like Activity Constructor prompts, LD Blueprint, Self-evaluation checklist have been developed which can be used by instructors or teacher trainers to facilitate development of instructors' design expertise. Instructors (N=6) from domains of EE and CSE have identified these as helpful in developing their expertise as revealed through thematic analysis of their interviews.
- Design impediments: Identified four design impediments for designing effective LDs using visualization for instructor-mediated classrooms: (i) operationalizing constructive alignment, (ii) operationalizing meaningful learning, (iii) frame group activity questions based on visualization and (iv) design implementation of active learning strategies. This was done through content analysis of unguided LDs created by 30 instructors from the domains of EE and CSE. We found design impediments at both conceptual and implementation levels. These impediments contribute to LD research on identification of design impediments.
- Framework evaluation: CuVIS framework was evaluated with instructors for effectiveness along two axes: (i) impact on design expertise and (ii) achievement of targeted objective. The impact on developing instructor design expertise was evaluated through a semester-long study with six instructors from EE and CSE. The effectiveness of CuVIS LDs in achieving the targeted learning objective on implementation was tested in field setting with 375 engineering undergraduate students on one topic each from EE and CSE involving three instructors. The usability and usefulness of CuVIS tool was evaluated with 1200 + science and engineering instructors from nine domains.

The minor contributions of this thesis are:

- CuVIS tool: It serves as the digital interface to the instructors to interact with the framework. A large-scale survey of usefulness and usability was done with 1200+ instructors with 90% of them perceiving CuVIS tool to be a highly useful tool. The SUS score of CuVIS tool was computed to be 78.86 marking it as a usable tool.
- Design recommendations for scaffolds targeting development of instructors' design expertise like inclusion of illustrative examples from instructors' domains. These

recommendations were obtained from the instructors from EE and CSE themselves (N = 6) through thematic analysis of their interviews.

10.2 Future Work

10.2.1 Expanding CuVIS framework to other instructional settings

The CuVIS framework can be expanded for teaching using visualizations in different instructional settings like MOOC, laboratory and others. The conceptual guidelines of CuVIS framework provide the generic cognitive structure for constructive alignment as well as operationalization of the cognitive structure for instructor-mediated classrooms. These guidelines were easily adapted to a MOOC setting by two teaching assistants in a ‘Signals & Systems’ MOOC course for the topics of ‘Fourier Transformation’ and ‘Signal Convolution’. For example, one CuVIS framework guideline for conceptual understanding is ‘Students should be shown the system under multiple condition sets’. For MOOC, this guideline was operationalized as ‘Ask students to see the Fourier transformation of signals by varying the frequencies and periods through the slider bars’. However, CuVIS framework implementation design guidelines (LD Blueprint) needed substantial modifications for this change of setting. For example, when strategy suggested by CuVIS framework was ‘Think-Pair-Share’ (TPS), CuVIS framework guidelines for ‘Think’ and ‘Share’ phases could be transferred to MOOC with slight modifications (shown in red in Table 10.1). But the CuVIS framework guidelines were not sufficient to address the ‘Pair’ phase small-group activity implementation design in MOOC. In fact, designing collaborative LDs is currently a popular research area in MOOC pedagogy. Thus, researchers can take the CuVIS guidelines for visualization to create constructively aligned and meaningful LDs in MOOC. However, to extend CuVIS framework to other instructional settings, researchers need to design a new set of implementation level guidelines specific to the setting.

Table 10.1: ‘Fourier Transformation’ CuVIS LD for objective = Multi-process problem solving & setting = MOOC (modifications in red)

Step No.	<i>Time (mins.)</i>	What teacher will do	What student will do	Which visualization feature used, if any
1	NA- Could not be specified as MOOC is self-paced	Give students a Prologue document that (i) introduces the topic, (ii) have small individual activity on coming up with real life application of Fourier series	Student will read that document and give their answer wherever a question is asked, and then he will be shown the correct answer.	NA
2	NA	Analogy from real life presented in learning material	Student go through the metaphor	NA
3	NA	Introduce the visualization at this point. Give detailed description of various interactivities in visualization. URL: http://mathlets.org/mathlets/fourier-coefficients/	Student select the target waveform	Radio button
4	NA	Introduce the activity question: Select the waveform Target A by clicking the corresponding radio button. You now will see a square waveform. Answer the following questions: A) Think phase (individual activity): Think and decide whether target waveform A will be approximated using Sine terms or Cosine terms? B) Pair phase (group activity) Step – i) Find corresponding Fourier Series coefficients (b_1, b_2, \dots, b_6 or a_0, a_1, \dots, a_6) and report the Distance result. Step- ii) Justify why you have chosen Sine or Cosine and why do you think your coefficients are correct? Step iii) Post your answers to both Think and Pair phase questions in the discussion forum using the button below. Step iv) Look at the answers and reasoning posted in the forum by your classmates. Do you want to change your answer? If yes, re-post your new answers with the reason why you made the change.	i) Students select the Target waveform ii) Students find the coefficients while they try to approximate by varying the slider bars. iii) Students debate with reasoning which 1 is correct and why in the forum. iv) Uploads final answer v) Student read the distance number by clicking on the check box “distance”	radio button Slider bars Discussion forum Checkbox

5	NA	<p>TA tracks the discussion forum. After 2 days prod students to debate about the reasoning posted in the forum</p> <p>1) Post the solution in the forum & include feedback on some of the common errors posted without taking names.</p> <p>2) Ask students to :</p> <p>a) Compare your answers with the one posted.</p> <p>b) Underline Make note of the errors you found in your solution, if any</p>	Looks at discussion forum posts & debate which of the reasoning are correct and why.	Discussion forum
6	NA	Instructor uploads the correct solution with brief discussion on the common misconceptions found.	<ul style="list-style-type: none"> • Compares their solution with that posted in the forum • Notes errors in their solution if any 	

10.2.2 Extending CuVIS framework to a collaborative TEL system

Another future research direction is to build a CuVIS TEL system based on the framework. In Chapter-6 of this thesis we have shown a potential instructional flow with CuVIS framework that was able to develop design expertise in instructors. We have also developed self-reflection scaffolds as part of the instructional flow that were identified as useful by the instructors. We present below a tentative design of the TEL system incorporating recommendations for developing design expertise from literature (Fig. 10.1). However, it does not support collaborative design activity among instructors. Researchers can take all the above resources provided by CuVIS framework and build a collaborative TEL system to foster self-regulated development of instructor's design expertise. The TEL system can incorporate features like automatic group formation based on certain demographic criteria, peer feedback mechanism, discussion forums where all entries can be shown simultaneously on-screen like in padlet and activity timer to keep the activity on track. It can then be tested with larger number of instructors to establish its effectiveness. Such a TEL system will be helpful to teacher-trainers as well to develop design expertise in instructors.

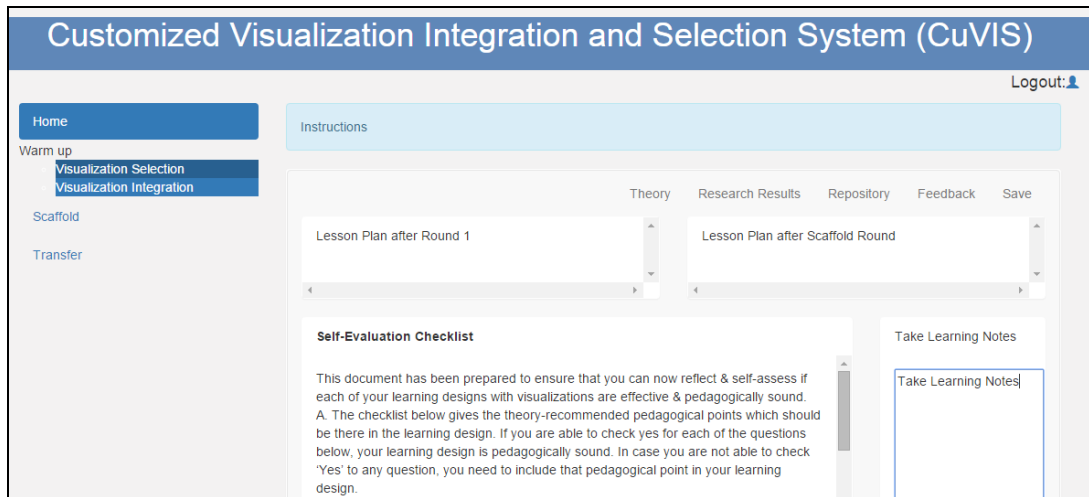


Figure 10.1: Snapshot of a potential CuVIS TEL system

10.2.3 Use CuVIS framework to create a framework for design expertise scaffolds for different instructor TPACK levels

In the thesis, we have created scaffolds based on ET principles with the aim of promoting student-centered design expertise in instructors. The instructor characteristics in our study were those who had either attended an online pedagogy workshop or had been mentored by ET experts with average teaching experience of eight years from varied domains. We have shown that these instructors were able to use the CuVIS framework scaffolds like Activity Constructor prompts, LD Blueprints mapped to the objective, domain and activity time duration. We have also identified features of these scaffolds that instructors found helpful in their design activity. Researchers can extend the CuVIS framework to develop a framework of design scaffolds for instructor design expertise. These guidelines can be mapped to different instructor TPACK levels like low and medium. Thus CuVIS framework can be extended to create an adaptive training system for instructors based on their TPACK levels.

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Publication List from Thesis

1. Banerjee G. & Murthy S. (2015). “CuVIS Tool to Develop Instructors’ Competency in Creating Meaningful Learning Designs”, Proceedings of 23rd International Conference on Computers in Education (ICCE).[Nominated for best paper award]
 2. Banerjee, G., Murthy, S., & Iyer, S. (2015). Effect of active learning using program visualization in technology-constrained college classrooms. *Research and Practice in Technology Enhanced Learning*, 10(1), 1-25. :Journal Paper
<http://www.telrp.com/content/10/1/15>
 3. Banerjee G., Patwardhan M. & Murthy S. (2014). “Learning Design Framework for Constructive Strategic Alignment with Visualizations”, Proceedings of 22nd International Conference on Computers in Education (ICCE), pp. 963-968.
 4. Banerjee, G., Kenkre, A., Mavinkurve, M., & Murthy, S. (2014). “Customized Selection and Integration of Visualization (CVIS) Tool for Instructors”, Proceedings of 14th IEEE International Conference on Advanced Learning Technologies (ICALT), pp. 399-400.
 5. Banerjee, G., Patwardhan, M., & Mavinkurve, M. (2013). Teaching with visualizations in classroom setting: Mapping Instructional Strategies to Instructional Objectives. Proceedings of IEEE Fifth International Conference on Technology for Education (T4E), pp. 176-183.
 6. Banerjee G., Murthy S. & Iyer S. (2013), “Program Visualization: Effect of viewing vs. responding on student learning”, 21st International Conference on Computers in Education (ICCE).
 7. Banerjee G., Murthy S. (2012), “Effect of Instructors’ Pedagogy and TPACK on integration of computer based visualizations”, Workshop Proceedings of 20th International Conference on Computers in Education (ICCE), Singapore, pp. 424-428.
- Kenkre, A., Banerjee, G., Mavinkurve, M., & Murthy, S. (2012). Identifying Learning Object pedagogical features to decide instructional setting. Proceedings of IEEE Fourth International Conference on Technology for Education (T4E), pp. 46-53.

Appendix A: The CuVIS Framework*

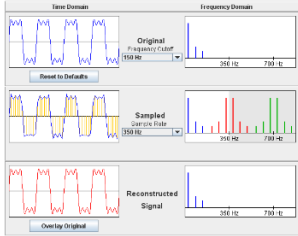
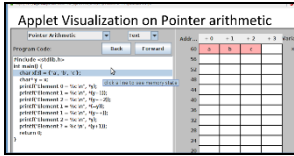
<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
1. Visualize to explain a concept with illustration	5-10	Peer Instruction (PI)	1. Decide the difficult part of the topic to target with visualization	<p>a] Think of aspects of the topic students generally find difficult to understand/ visualize & which is covered in your selected visualization</p> <p>b] Focus the activity with the visualization on this difficult to understand part of the topic you had identified.</p>	<p>Domain = EE <i>If topic = Coding Theory</i> <i>Students not able to decide if Position of source coding block & channel coding block in a digital communication block diagram can be interchanged.</i></p> <p>Domain =CS <i>If topic = travelling salesman problem,</i> <i>Students able to construct a tour but unsure whether the chosen tour is the minimum cost tour.</i></p>	CU_PI.ppt
			2. Decide how to connect topic to real-life	<p>You can connect the chosen topic to real-life in any 1 of the following ways (in descending order of desirability):</p> <p>OPTIONS :</p> <p>a] Situate the ‘PI’ activity question itself in a real-life context (preferred)</p> <p>b] Make students relate their personal experiences to come up with real-life application of the topic</p> <p>c] You present real-life examples of the topic with/without the visualization</p>	<p>Domain = EE <i>If topic = Sampling Theorem,</i> <i>1. How a data acquisition system (sampler) for a digital EEG /ECG iIs designed?</i> <i>2. Our voice in mobile phone is digital. How voice is converted into digital here?</i> <i>3. When you record a song in your mobile phone what is the initial block it goes into? Why?</i></p> <p>Domain = CS <i>1. Facebook and Twitter, which is directed and which is undirected?</i> <i>2. Why Facebook is both directed and undirected?</i> <i>3. State reason why Facebook is directed.</i> <i>4. State reason why Facebook is undirected.</i> <i>5. Why Twitter is directed?</i></p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
					6. How to use BFS on Facebook?	
			3. Decide what multiple condition sets to show students through visualization	<p>a] You need to play the visualization to show effect of varying the value (s) of multiple variables on the system.</p> <p>b] This will help the students to gain conceptual understanding of the system.</p> <p>c] Therefore, decide which input parameters (variable values) you will vary to show output effect.</p> <p>d] If you have video/animation, ensure it shows the different variations addressing guidelines 1-3 above.</p> <p>e] If you have a video/animation, note the timestamps in your lesson plan where you need to pause to show each condition.</p>	<p>Domain = EE, Topic = Digital Modulation <i>Show the simulation output for AM , PM, FM (digital amplitude modulation (ASK, phase modulation and frequency modulation) with:</i> <i>a] input all ones</i> <i>b] input all zeros</i></p> <p>Domain= CS <i>Show the animation output for the Pointer variable y with</i> <i>a] Prefix operator [Timestamp - 00:01:42]</i> <i>b] Post-fix operator [Timestamp - 00:03:42]</i></p>	
			4. Frame the PI activity question such that it addresses the difficult part identified	<p>a] Frame questions that are challenging but not leading.</p> <p>b] Should involve ‘what-if’ type of questions.</p> <p>c] Questions & the multiple answer options should be brief.</p> <p>d] Answer options should prompt</p>	<p>Domain =EE Q. Two traveling waves 1 and 2 seen in visualization, are described by the equations: $y_1(x,t) = 2 \sin(2x - t)$ $y_2(x,t) = 4\sin(x - 0.8 t)$ <i>All the numbers are in the appropriate SI</i></p>	

Objective	Activity Time Duration (mins.)	Strategy Suggested	Activity Constructor Prompts	Guidelines	Examples	LD Blueprint Template
				<p>students to look for covariation to identify causal variables + causal relationship</p> <p>e] The clear deliverable should be student predictions with reasoning</p> <p>f] You can consult questions from existing question banks like: http://www.cwsei.ubc.ca/resources/clients.htm#questions</p>	<p>(mks) units.</p> <p>Identify the wave(s) that has the higher speed.</p> <p>A) wave 1 B) wave 2 C) Both have the same speed.</p> <p>-----</p> <p>Domain = CSE</p> <p>Q. See the code on-screen :</p> <pre>void fun(int n) { Stack S; while (n > 0) { push(&S, n%2); n = n/2; } while (!isEmpty(&S)) printf("%d ", pop(&S)); }</pre> <p>Choose what will be the output of the function:</p> <p>(A) Prints binary representation of n in reverse order</p> <p>(B) Prints binary representation of n</p> <p>(C) Prints the value of Log(n)</p> <p>(D) Prints the value of Log(n) in reverse order</p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
			students through visualization			
			4. Decide parent activity question that addresses the difficult part identified	a] Frame a parent activity question whose solution can be shown through the visualization b] Solving the parent activity question should require students to do both : (i) Acquire the conceptual knowledge (ii) Confront the standard misconceptions.	Domain = EE Topic = Signal Transformation <i>Parent question to solve with visualization is: The input signal & output signal is shown on screen. Sketch the input signal at the various intermediate transformation steps.</i> Domain = CS Topic = Binary Search Tree <i>Parent Question: Binary Search Tree is shown as a doubly-linked list onscreen. Draw the linked list for the intermediate steps when Node 1 is deleted and Node 2 is added at position X.</i>	
			5. Decide sub-questions for your parent TPS activity question mapped to objective	a] Guidelines for <u>breaking the parent</u> ‘Think-Pair-Share’ question into phases: i) Break down the solution approach for this activity into a sequential set of steps like identifying the relationship between system variables followed by illustrating the relationships themselves for a given case. ii) Frame questions mapped to each of the modules/ knowledge components identified in previous step b] Guidelines for framing the ‘ <u>Think</u> ’ phase question:	Domain = EE Topic = Diode <i>Q. What is the problem to solve with visualization?</i> <i>Explain the working principle of diode operation</i> ● <i>Think phase: Think (individually)</i> a. <i>Identify the direction of electron movement with +ve voltage</i> b. <i>Identify the direction of holes on -ve voltage applied</i> c. <i>What would be the direction of diffusion current and drift current on external applied voltage</i>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				<p>i) Question should map to the initial modules you have identified i.e. identification of the relationship between system variables</p> <p>ii) Question should be broad enough for every student to attempt</p> <p>iii) The clear deliverable should be identification of the relationship between system variables</p>		
				<p>c] Guidelines for framing the <u>'Pair'</u> <u>phase</u> question:</p> <p>i) Question should be connected to 'Think' phase question but should be of higher difficulty</p> <p>ii) Question should lead students to build on the 'Think' phase deliverable i.e. draw/write the relationship among variables for this given case.</p> <p>iii) Clear deliverable for the group should be illustrating the state of the system for a given condition set</p>	<ul style="list-style-type: none"> ● <i>Pair Phase: Look into your neighbor's answers</i> <ul style="list-style-type: none"> a) <i>Discuss if you do not agree with your friend's answers</i> b) <i>You can also change your answer</i> c) <i>draw the transfer characteristics when different external voltage applied</i> 	

Objective	Activity Time Duration (mins.)	Strategy Suggested	Activity Constructor Prompts	Guidelines	Examples	LD Blueprint Template
				<p>Guidelines for framing the ‘Share’ phase question:</p> <p>i) Question should guide students to integrate the solutions of 'Think' & 'Pair' phases into a whole and/or, Ask the groups to share their solutions with the class.</p> <p>ii) Think which visualization feature you will use to show the solution to activity</p>	<ul style="list-style-type: none"> • <i>Share phase: Look at the visualization</i> <p>a) <i>Compare your answer with what is shown</i></p> <p>b) <i>Underline the errors you found in your solution</i></p>	
			5. Decide where to pause the visualization	<p>i) Pause visualization at a point which gives input value for ‘Think’ phase activity</p> <p>ii) To take screenshot, press 'Prtscr' button in your keyboard. The image will get saved in your PC. Upload this image file.</p>	<p>Domain = EE</p>  <p>Domain = CS</p> 	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
2. Visualize to explain the working of a process/algorithm or compare multiple processes	5-10	TPS	1. Decide the difficult part of the topic to target with visualization 2. Decide how to connect topic to real-life	Same as for other objectives	Same as for other objectives	PU_TPS.ppt PU_TPS.ppt
	15-20		3. Breakdown the process into 'individual components' or modules	a] Decompose the process into chunks, preferably going from easy to complex. b] Arrange the chunks into sequence.	<p>Domain = EE, Topic = Signal Transformation <i>If an output signal is to be drawn based on this transformation equation, $x(4 - t/2)$: then the drawing process can be broken down into :</i></p> <p><i>a] Sequencing of the identified transformation processes</i> <i>b] drawing the output</i></p> <p>Domain = CSE, Topic = Travelling Salesman Problem <i>To construct a minimum cost tour given graph G, solving process can be broken down into:</i></p> <p><i>a] Construct MST</i> <i>b] Do a pre-order walk of MST</i> <i>c] Construct tour</i></p>	

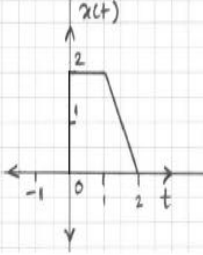
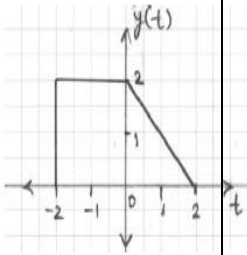
<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
			4. Frame the TPS activity question such that it is mapped to your objective	<ul style="list-style-type: none"> Guidelines for framing the parent ‘Think-Pair-Share’ question : <ol style="list-style-type: none"> Frame a parent question whose solution can be shown through the visualization. Frame questions that will cover all the modules/ knowledge components identified in previous step Guidelines for framing the ‘Think’ phase question: <ol style="list-style-type: none"> Question should map to the initial module(s)/steps Question should be broad enough for every student to attempt There should be a clear deliverable 	<p>Domain = EE Topic = Signal Transformation <i>If parent question to solve with visualization is:</i> <i>A continuous time signal $x(t)$ is shown on screen. It undergoes scaling, shifting and reversal. Sketch the output signal $x(4-t/2)$ after each transformation.</i></p> <p><i>Then,</i> <i>Think phase: Think (individually) :</i> <i>a) Identify in what sequence the given transformation operations: time scaling, sharing and reversal are happening</i> <i>c) Draw the output signal after the first transformation</i></p> <p><i>Domain = CS</i> <i>Topic = Travelling Salesman Problem</i> <i>If parent question to solve with visualization is:</i> <i>Construct a minimum cost tour given a graph.</i> <i>Then,</i> <i>Think phase: Think (individually)</i> <i>Construct the MST</i></p>	
				<ul style="list-style-type: none"> Guidelines for framing the ‘Pair’ phase question: <ol style="list-style-type: none"> Question should be connected to ‘Think’ phase question but should be 	<p><i>Domain = EE</i> <i>Pair Phase: Look into your neighbor's answers</i></p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				<p>of higher difficulty</p> <p>b) Question should lead students to build on the ‘Think’ phase deliverable</p> <p>c) Question should be specific enough to lead into the discussion you want to carry out later</p> <p>d) Clear deliverable for the group</p>	<p><i>a) Discuss if you do not agree with your friend’s answers</i></p> <p><i>b) You can also change your answer</i></p> <p><i>c) Together, try to draw the transformed signal</i></p> <p><i>d) Give reasons</i></p> <p><i>Domain = CS</i></p> <p><i>Pair Phase: Look into your neighbor's answers</i></p> <p><i>a) Discuss if you do not agree with your friend’s answers</i></p> <p><i>b) You can also change your answer</i></p> <p><i>c) Together, try to draw the final MST that you both agree on</i></p> <p><i>d) Give reasons</i></p>	
				<p>Guidelines for framing the ‘Share’ phase question:</p> <p>Question should relate to presentation of the answer integrating all the modules into the whole</p>	<p>Share phase (common to both domains):</p> <p>Look at the visualization</p> <p><i>a) Share your solution with the class</i></p> <p><i>b) Compare your answer with what is shown</i></p> <p><i>c) Underline the errors you found in your solution</i></p>	
			<p>5. Decide where to pause the visualization</p>	<p>a] Pause visualization at a point which gives input value for ‘Think’ phase activity</p> <p>b] To take screenshot, press 'Prtscr' button in your keyboard. The image will get saved in your PC. Upload this image file.</p>	<p>Same as for other objectives</p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
3. Write/ Draw alternate representations (like graph to equation) from the given visualization or vice-versa.	5-10	PI	1. Decide the difficult part of the topic to target with visualization 2. Decide how to connect topic to real-life	Same as for other objectives	Same as for other objectives	<u>MR_PI.ppt</u>
			3. Decide the multiple condition sets you will show students	a] Show both representations (graph/equation/model) together on-screen b] Decide which feature you want to change first in representation 1 and show its effect on the corresponding feature in representation 2 c] Choose 1 more feature in representation 1 whose effect you want to show on the corresponding feature in representation 2. d] If there are multiple variable features to change then show effect of change of each feature individually. e] Keep the effect of combination of the various variables together for the student activity later. f] If you have a video/animation, note the timestamps in your lesson plan where you need to pause to show each condition.	Domain = EE Q1] Multiple Condition Sets to show: For topic = Digital Modulation, <i>I will show Case 1: the AM and FM waveforms when signal is all zeros. I will relate between the different points in the digital and analog signals</i> <i>Case 2: I will show the AM and FM waveforms when signal is all ones. I will relate between the different points in the digital and analog signals</i> Domain = CS <i>Case 1: I will declare an integer array and keep its values constant.</i> <i>Case 2: I will use the array variable and along with it mathematical operators +, - to access the array values</i>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
			4. Decide parent activity question that addresses the difficult part you identified	<p>a] Frame a parent activity question on multiple representation whose solution can be shown through the visualization i.e. Choose those parameters in one representation (e.g. graph or equation or model) whose values you can change visually through checkboxes or slider bars or video capture etc.</p> <p>b] Solving the parent activity question should require students to do both :</p> <p>(i) Relate corresponding parts in the 2 representations (ii) Translate 1 representation into the other.</p>	<p>Domain = EE; Topic = Signal Transformation</p> <p><i>Parent question to solve with visualization is:</i></p> <p><i>A continuous time signal $x(t)$ is shown on screen. Sketch the signal $x(4-t/2)$ and write mathematical expression after each transformation.</i></p> <p>Domain = CS Topic = Binary Search Tree</p> <p><i>Parent Question: Binary Search Tree can have 2 representations: tree form with nodes & doubly-linked list form. Draw the linked list form after deleting a specified node.</i></p>	
			5.1. Decide the PI activity question(s) that will address the parent question	<p>a] Guidelines for breaking the parent question into modules:</p> <p>i) Break down the solution approach for this activity into a sequential set of steps like identifying the relation followed by translation.</p> <p>ii) Frame questions mapped to each of the modules/ knowledge components identified in previous step</p> <p>b] Guidelines for framing the <u>1st PI activity question</u>: i) Frame questions</p>	<p>Domain = EE Topic = Signal Transformation</p> <p><i>If solution steps are:</i></p> <p><i>i) Identify what transformation operations are happening</i> <i>ii) Identify in what sequence they are happening</i> <i>iii) Stepwise Draw & write mathematical expression for the combination of transformations Then,</i></p> <p><i>1st PI activity question: If input signal $x(t)$ is as shown on screen & the output signal is $x(4-t/2)$, then the transformation undergone by</i></p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				<p>that are challenging but not leading.</p> <p>ii) Questions & the multiple answer options should be brief.</p> <p>iii) Question should map to the initial modules you have identified iv) This question can involve identifying effect of changing a combination of features in representation 1.</p> <p>iv) Answer options should prompt students to look for relationship between features of 2 representations</p> <p>v) Thus, deliverable from this question should be identification of relation between 2 representations C] Decide which visualization feature(s) you will use to show feedback to this PI question.</p>	<p><i>the signal are: (i) time scaling -> time shifting -> time reversal (ii) time shifting -> time scaling -> time reversal (iii) time reversal -> time scaling -> time shifting</i></p> <p>Domain = CS , Topic = Binary search tree</p> <p><i>If solution steps are: i) Locate position variable of the specified node to delete in Binary Search tree</i></p> <p><i>ii) Identify position variable of those nodes that will be altered when the specified node is deleted</i></p> <p><i>iii) Draw the changed linked list representation then, 1st PI activity question should be framed on identification of position variable of those nodes which will get altered. In answer options, you should give at least 3 different possibilities where only 1 possibility will be correct.</i></p>	
			5.2. Decide the PI activity question(s) that will address the parent question	<p>a] Guidelines for framing the 2nd PI activity question:</p> <p>i) Frame questions that are challenging but not leading. + should involve ‘what-if’ type of questions.</p> <p>ii) Questions & the multiple answer options should be brief.</p> <p>iii) Question should map to the later modules you have identified i.e. identification of relation between 2</p>	<p>Domain = EE, Topic = Signal Transformation</p> <p>If solution steps are:</p> <p>i) Identify what transformation operations are happening</p> <p>ii) Identify in what sequence they are happening</p> <p>iii) Stepwise Draw & write mathematical expression for the combination of</p>	

Objective	Activity Time Duration (mins.)	Strategy Suggested	Activity Constructor Prompts	Guidelines	Examples	LD Blueprint Template
				<p>representations</p> <p>iv) This question can involve writing/drawing the alternate representation that the one given.</p> <p>v) Answer options should prompt students to translate between the 2 representations</p> <p>b)] Decide which visualization feature(s) you will use to show feedback to this PI question.</p>	<p>transformations Then,</p> <p>2nd PI activity question: If input signal $x(t)$ is as shown on screen & the output signal is $x(4 - t/2)$, then the graph of the transformed signal in the penultimate step will be:</p> <p>Answer options should be images of at least 3 possible graphs, of which 1 will be correct</p> <p>Identify which of the following is the correct mathematical representation of the signal transformation on signal $x(t)$ so as to get $y(t)$.</p> <div style="display: flex; justify-content: space-around;">   </div> <p>a. $y(t) = x(\frac{t}{2} + 1)$</p> <p>b. $y(t) = x(t + 2)$</p> <p>c. $y(t) = x(2t + 2)$</p> <p>d. $y(t) = x(-\frac{t}{2} + 1)$</p> <p>Domain = CS Topic= BSF</p> <p>If solution steps are: i) Locate position variable of the specified node to delete in Binary Search tree ii) Identify position variable of those nodes that will be altered</p>	<div style="border: 1px solid black; width: 40px; height: 40px; margin: auto;"></div>

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
					<i>when the specified node is deleted iii) Draw the changed linked list representation Then, 2nd PI activity question should be framed on the alterations in the linked list representation. Answer options should be images of at least 3 possible linked list representations, of which 1 will be correct</i>	
			6. Decide where to pause the visualization	Pause visualization at a point which gives input value for 'Think' phase activity	Same as for other objectives	
	15-20	TPS	1. Decide the difficult part of the topic to target with visualization 2. Decide how to connect topic to real-life	Same as for other objectives	Same as for other objectives	<u>MR_TPS_EE.ppt</u> <u>MR_TPS_CS.ppt</u>

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
		TPS	<p>3. Decide the multiple condition sets you will show students</p> <p>4. Decide the parent activity question that addresses the difficult part identified</p>	Objective specific => Same as that stated above for PI for multiple representation	Objective specific => Same as that stated above for PI for multiple representation	
			5. Frame the TPS activity question such that it is mapped to your objective	<p>a] Guidelines for breaking the parent ‘Think-Pair-Share’ question into modules:</p> <p>i) Break down the solution approach for this activity into a sequential set of steps like identifying the relation followed by translation. ii) Frame questions mapped to each of the modules/ knowledge components identified in previous step</p> <p>b] Guidelines for framing the ‘Think’ phase question:</p> <p>i) Question should map to the initial</p>	<p>Domain = EE</p> <p>Topic = Signal Transformation</p> <p>If parent question to solve with visualization is:</p> <p><i>A continuous time signal $x(t)$ is shown on screen. Sketch the signal $x(4-t/2)$ and write mathematical expression after each transformation.</i></p> <p>Then,</p> <p>Think phase: Think (individually) :</p> <p>(i) <i>Identify what transformation operations are happening</i></p> <p>(ii) <i>Identify in what sequence they are happening</i></p>	

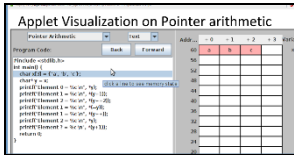
<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				<p>modules you have identified i.e. identification of relation between 2 representations</p> <p>ii) You can give the identification of which variables need to be changed in representation 1 to get the desired form of representation 2.</p> <p>iii) This question can involve identifying effect of changing a combination of features in representation 1.</p> <p>iv) Question should be broad enough for every student to attempt</p> <p>v) The clear deliverable should be the relation between 2 representations</p>	<p><i>(iii) Draw & write mathematical expression for the first transformation</i></p> <p>Domain = CS Parent Question: <i>Binary Search Tree can have 2 representations: tree form with nodes & doubly-linked list form. Draw the linked list forms after deleting the specified node in tree form.</i> Then, Think phase: Think (individually): <i>Identify what changes will occur in the linked list form when the specified node is deleted from the tree form.</i></p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				<p>c] Guidelines for framing the ‘Pair’ phase question:</p> <p>i) Question should be connected to ‘Think’ phase question but should be of higher difficulty</p> <p>ii) Question should lead students to build on the ‘Think’ phase deliverable i.e. draw/write the other representation stepwise after effecting the changes identified in 'Think' phase</p> <p>iii) Clear deliverable for the group should be translating between 2 representations.</p>	<p>Pair Phase: Look into your neighbor's answers</p> <p><i>a) Discuss if you do not agree with your friend's answers</i></p> <p><i>b) You can also change your answer</i></p> <p><i>c) Together, try to draw the transformed signal</i></p> <p><i>d) Give reasons</i></p> <p>Domain = CS</p> <p>Pair Phase: Look into your neighbor's answers</p> <p><i>a) Discuss if you do not agree with your friend's answers</i></p> <p><i>b) You can also change your answer</i></p> <p><i>c) Together, try to draw the transformed linked list representation</i></p> <p><i>d) Give reasons</i></p>	
				<p>Guidelines for framing the ‘Share’ phase question:</p> <p>i) Question should guide students to integrate the solutions of 'Think' & 'Pair' phases into a whole and/or, Ask the groups to share their solutions with the class.</p> <p>ii) Think which visualization feature you will use to show the solution to activity</p>	<p>Share phase (common to both domains): Look at the visualization</p> <p><i>a) Share your solution with the class</i></p> <p><i>b) Compare your answer with what is shown</i></p> <p><i>c) Underline the errors you found in your solution</i></p>	
			6. Decide where to pause	Same for TPS activity for other	Same as for other objectives	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
			the visualization	objectives		
4. Predict output of next step or a set of steps in a multi-step process or a phenomenon	5-10	PI	1. Decide the difficult part of the topic to target with visualization 2. Decide how to connect topic to real-life	Same as for other objectives	Same as for other objectives	Pedict_PI.ppt
			3. Decide what multiple condition sets to show students through visualization	a] You need to play the visualization to show effect of varying the value (s) of causal variables on the system. b] This will help the students to identify the strength and directionality of relationship between different causal variables c] Therefore, decide which input parameters (variable values) you will vary to show output effect on which variable values. d] If you have a video/animation, note the timestamps in your lesson plan where you need to pause to show each condition	Domain = EE <i>Show the simulation output for AM , PM, FM (digital amplitude modulation (ASK, phase modulation and frequency modulation) with:</i> a] <i>input all ones</i> b] <i>input all zeros</i> Domain= CS <i>Show the animation output for the Pointer variable y with</i> a] <i>Prefix operator [Timestamp - 00:01:42]</i> b] <i>Post-fix operator [Timestamp - 00:03:42]</i>	
			4. Frame the PI activity question	a] Frame questions that are challenging but not leading. b] Should involve ‘what-if’ type of	Domain =EE Q. <i>Two traveling waves 1 and 2 seen in visualization, are described by the equations:</i>	

Objective	Activity Time Duration (mins.)	Strategy Suggested	Activity Constructor Prompts	Guidelines	Examples	LD Blueprint Template
			such that it is mapped to your objective	<p>questions.</p> <p>c] Questions & the multiple answer options should be brief.</p> <p>d] Answer options should prompt students to look for covariation to identify causal variables + causal relationship</p> <p>e] The clear deliverable should be student predictions with reasoning</p> <p>f] You can consult questions from existing question banks like: http://www.cwsei.ubc.ca/resources/clients.htm#questions</p>	<p>$y_1(x,t) = 2 \sin(2x - t)$ $y_2(x,t) = 4\sin(x - 0.8 t)$</p> <p><i>All the numbers are in the appropriate SI (mks) units. Predict, with reasoning, which wave has the higher speed? A) wave 1 B) wave 2 C) Both have the same speed.</i></p> <p>Domain = CSE Q. See the code on-screen :</p> <pre>void fun(int n) { Stack S; while (n > 0) { push(&S, n%2); n = n/2; } while (!isEmpty(&S)) printf("%d ", pop(&S)); }</pre> <p><i>Predict, with reasoning, the output of the function: (A) Prints binary representation of n in reverse order (B) Prints binary representation of n (C) Prints the value of Logn (D) Prints the value of Logn in reverse order</i></p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
			5. Decide what questions to ask to guide reasoning	a] Ask questions to focus on different aspects of causal relationship. b] Add them to the prediction worksheet already created.	Domain: EE 1. <i>Why do more valves per cylinder increase horsepower?</i> 2. <i>In this case, what was the most direct cause of the bulb blowing up?</i> Domain: CS 1. <i>Will the printf statement show an increased value of variable y now?</i> 2. <i>What could be the cause behind increase in value of variable y here?</i>	
			6. Decide where to pause the visualization	Pause visualization at a point which gives input value for 'Think' phase activity	Same as for other objectives	
	15-20	Predict-Observe-Explain (POE)	1. Decide the difficult part of the topic to target with visualization 2. Decide how to connect topic to real-life	Same as for other objectives	Same as for other objectives	Predict_POE.ppt
			3. Decide what multiple condition sets to show students	Objective specific => Same as that stated above for PI for prediction	Objective specific => Same as that stated above for PI for prediction	

Objective	Activity Time Duration (mins.)	Strategy Suggested	Activity Constructor Prompts	Guidelines	Examples	LD Blueprint Template
			through visualization			
			4. Frame the POE activity question such that it is mapped to your objective	<p>a] Frame questions that are challenging but not leading</p> <p>b] Feedback for prediction must be shown through viz.</p> <p>c] Should involve ‘what-if’ type of questions.</p> <p>d] Question should prompt students to look for covariation among variables</p> <p>e] The clear deliverable should be student predictions + their reasoning of the causal relationship</p>	<p>Domain = EE Topic = Electromagnetic Wave Propagation <i>Show visualization of wave propagation with Ey component only. Ask students to predict what happens if I add Ez component</i></p> <p>Domain = CS Topic = Pointers <i>Predict output of the codeline: Q. Predict what will be the output if the highlighted code line, as shown on-screen, is executed.</i></p>	
			6. Decide what questions to ask to guide reasoning	Objective specific => Same as that stated above for PI for multiple representation	Objective specific => Same as that stated above for PI for multiple representation	
			7. Decide where to pause the visualization	Pause just after the input variable values have been changed		
5. Use a given visualization to compute	5-10/ 15-20	TPS	1. Decide the difficult part of the topic to target with	Same as for other objectives	Same as for other objectives	MP_TPS.ppt

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
the solution to the given problem involving multiple processes			visualization			
			2. Decide how to connect topic to real-life			
			3. Decide what multiple condition sets to show students through visualization	<p>a] You need to play the visualization to show effect of varying the value (s) of multiple variables on the system.</p> <p>b] This will help the students to gain conceptual understanding of the system.</p> <p>c] Therefore, decide which input parameters (variable values) you will vary to show output effect.</p> <p>d] If you have a video/animation, note the timestamps in your lesson plan where you need to pause to show each condition.</p>	<p>Domain = EE</p> <p>Show the simulation output for AM , PM, FM (digital amplitude modulation (ASK, phase modulation and frequency modulation) with:</p> <p>a] input all ones</p> <p>b] input all zeros</p> <p>Domain= CS</p> <p>Show the animation output for the Pointer variable y with</p> <p>a] Prefix operator [Timestamp - 00:01:42]</p> <p>b] Post-fix operator [Timestamp - 00:03:42]</p>	
			4. Breakdown the process into 'individual components' or modules	<p>a] Decompose the process into chunks, preferably going from easy to complex.</p> <p>b] Arrange the chunks into sequence.</p>	<p>Domain = EE, Topic = Signal Transformation</p> <p>If an output signal is to be drawn based on this transformation equation, $x(4 - t/2)$: then the drawing processs can be broken down into :</p> <p>a] identification of constituent transformation processes</p> <p>b] sequencing of the transformation processes</p> <p>c] drawing the output</p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
					Domain = CSE, Topic = Recursion <i>To write a program to generate Fibonacci series, solving process can be broken down into:</i> <i>a) Decide the variable to declare & their data type</i> <i>b) Decide the programming constructs to use like which loops?</i> <i>c) Write the pseudocode</i> <i>d) Develop the program</i>	
			5. Frame the TPS activity question such that it is mapped to your objective	Guidelines for framing the parent ‘Think-Pair-Share’ question : a) Frame a parent question whose solution can be shown through the visualization. b) Frame questions that will cover all the modules/ knowledge components identified in previous step Guidelines for framing the ‘Think’ phase question: a) Question should map to the initial module(s) that relate to conceptual understanding b) Question should be broad enough for every student to attempt	Domain = EE Topic = Signal Transformation If parent question to solve with visualization is: <i>A continuous time signal $x(t)$ is shown on screen. Draw each transformation of the input signal to arrive at the output signal $x(4-t/2)$.</i> Then, Think phase: Think (individually) : <i>a) Identify in what sequence the transformation operations: time scaling, sharing and reversal are happening</i> <i>c) Draw the output signal after the first transformation</i> Domain = CS, Topic = Recursion If parent question to solve with visualization	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				c) There should be a clear deliverable	is: <i>Write a program to generate Fibonacci series</i> Then, Think phase: Think (individually) <i>Write the pseudocode</i>	
				<p>Guidelines for framing the ‘Pair’ phase question:</p> <p>a) Question should be connected to ‘Think’ phase question but should be of higher difficulty</p> <p>b) Question should lead students to build on the ‘Think’ phase deliverable</p> <p>c) Question should be specific enough to lead into the discussion you want to carry out later</p> <p>d) Clear deliverable for the group</p>	<p>Domain = EE</p> <p>Pair Phase: Look into your neighbor's answers</p> <p><i>a) Discuss if you do not agree with your friend's answers</i></p> <p><i>b) You can also change your answer</i></p> <p><i>c) Together, write the program to generate Fibonacci series</i></p> <p><i>d) Give reasons</i></p> <p>Domain = CS</p> <p>Pair Phase: Look into your neighbor's answers</p> <p><i>a) Discuss if you do not agree with your friend's answers</i></p> <p><i>b) You can also change your answer</i></p> <p><i>c) Together, try to draw the final MST that you both agree on</i></p> <p><i>d) Give reasons</i></p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				Guidelines for framing the ‘Share’ phase question: Question should relate to presentation of the answer integrating all the modules into the whole	Share phase (common to both domains): Look at the visualization <i>a) Share your solution with the class</i> <i>b) Compare your answer with what is shown</i> <i>c) Underline the errors you found in your solution</i>	
			6. Decide where to pause the visualization	Pause visualization at a point which gives input value for ‘Think’ phase activity	Same as for other objectives	
6. Students devise an explanation for a given process or phenomena, through logical reasoning, from observations made from the visualization , before they have been taught the topic	5-10	PI	1. Decide the difficult part of the topic to target with visualization	Same as for other objectives	Same as for other objectives	Inquiry_PI.ppt
			2. Frame the parent activity question	Activity question should prompt students to come up with their own hypothesis of the phenomenon/process they are observing for the first time through visualization	Domain – EE Topic – Signal Transformation <i>Observe the visualization & deduce how the signal is getting transformed</i> Domain – CS, Topic = Bubble sort <i>Devise the algorithm followed in bubble sort</i>	
			3. Decide which different examples of the process/ phenomenon you would	Same as for other objectives	Same as for other objectives	

Objective	Activity Time Duration (mins.)	Strategy Suggested	Activity Constructor Prompts	Guidelines	Examples	LD Blueprint Template
			want students to observe			
			4. Frame the 'peer instruction' question based on your chosen visualization	<p>a] Frame questions that are challenging but not leading.</p> <p>b] Answer options should give multiple hypothesis</p> <p>c] These hypothesis options should target student misconceptions you have identified in Prompt 1</p> <p>d] Questions & the multiple answer options should be brief.</p> <p>e] The clear deliverable should be a statement or hypothesis of the relationship</p> <p>f] You can consult questions from existing question banks like: http://www.cwsei.ubc.ca/resources/clients.htm#questions</p>		
			5. Where to pause the visualization for the activity?	<ul style="list-style-type: none"> Pause visualization at points that show examples of different states of the system <p>Upload at least 2 labeled screenshots of visualization at where to pause</p>		
			6. Decide how to connect topic to real-life	<ul style="list-style-type: none"> You can connect the chosen topic to real-life in any 1 of the following ways (in descending order of desirability): <p>OPTIONS :</p> <p>a] Make students relate their personal</p>	<p>Domain = EE; Topic = Sampling</p> <p>1. How a data acquisition system (sampler) for a digital EEG /ECG. Is designed 2. Our voice in mobile phone is digital. How voice is converted into digital here? 3. When you record a song in your mobile phone what is</p>	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				experiences to come up with real-life application of the topic b] You present real-life examples of the topic with/without the visualization	<i>the initial block it goes into? Why?</i> Domain = CS Topic = Radix Sort <i>Instructor may ask a question about the sorting approach applied in a Dictionary.</i>	
	15-20	TPS	1. Decide the difficult part of the topic to target with visualization	Same as for other objectives	Same as for other objectives	
			2. Frame the parent activity question	Activity question should prompt students to come up with their own hypothesis of the phenomenon/process they are observing for the first time through visualization	Domain – CS, Topic = Bubble sort <i>Devise the algorithm followed in bubble sort</i>	
			3. Decide which different examples of the process/ phenomenon you would want students to observe	Objective specific => Same as that stated above for PI for inquiry-based learning	Objective specific => Same as that stated above for PI for inquiry-based learning	

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
			4. Frame the 'think-pair-share' question based on your chosen visualization	<p>Guidelines for framing questions:</p> <p>'Think' phase:</p> <ul style="list-style-type: none"> - Question should be broad enough for every student to attempt - There should be a clear deliverable - Questions should prompt students to generalize observed patterns. - Formulate a statement or hypothesis of the relationship 	<p>Domain = EE</p> <p><i>Q. What is the problem to solve with visualization?</i></p> <p><i>A. Observe the visualization to plot ID vs. VGS for JFET.</i></p> <p>Think phase: Think (individually) : <i>Hypothesize the relationship between VDS ,VGS , ID</i> <i>Give reasons for your thinking</i></p> <p>Domain = CS</p> <p><i>A. Observe the visualization on bubble sort to write the pseudocode of the algorithm.</i></p> <p>Think phase: Think (individually):</p> <p><i>a) Identify the pattern in which the numbers are changing their position in each iteration.</i> <i>b) Draw the pattern. Give reasons for your thinking</i></p>	Inquiry_TPS.ppt
			<p>'Pair' phase:</p> <ul style="list-style-type: none"> - Question should be connected to 'Think' phase question but should be of higher difficulty - Students should come up with a generalization. - Question specific enough to lead into the discussion you want to carry out later 	<p>Pair Phase: Look into your neighbor's answers</p> <p><i>a) Discuss if you do not agree with your friend's answers</i> <i>b) You can also change your answer</i> <i>c) Together, come up with the plot of ID vs. VGS for JFET</i> <i>d) Give reasons</i></p> <p>Domain = CS</p>		

<i>Objective</i>	<i>Activity Time Duration (mins.)</i>	<i>Strategy Suggested</i>	<i>Activity Constructor Prompts</i>	<i>Guidelines</i>	<i>Examples</i>	<i>LD Blueprint Template</i>
				- Clear deliverable for the group	Pair Phase: Look into your neighbor's answers <i>a) Discuss your pattern with your friend's answers</i> <i>b) You can also change your answer</i> <i>c) Together, come up with the pseudocode for bubble sort</i> <i>d) Give reasons</i>	
				Guidelines for framing the 'Share' phase question: Question should relate to presentation of the solution by student groups	Share phase: Look at the visualization <i>a) Compare your answer with what is shown</i> <i>b) Underline the errors you found in your solution</i>	
			5. Where to pause the visualization for the activity?	Objective specific => Same as that stated above for PI for inquiry-based learning	Objective specific => Same as that stated above for PI for inquiry-based learning	
			6. Decide how to connect topic to real-life	Objective specific => Same as that stated above for PI for inquiry-based learning	Objective specific => Same as that stated above for PI for inquiry-based learning	

Appendix B: Visualization Selection Checklist

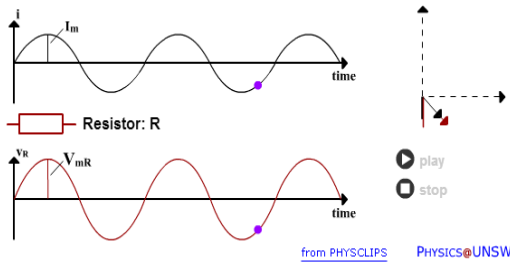
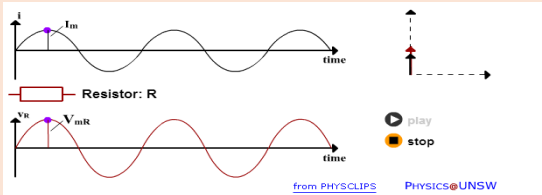
<i>Objective</i>	<i>Choose a visualization that has the following features:</i>
1. Visualize to explain a concept with illustration	<ul style="list-style-type: none"> a] Covers the difficult to understand/visualize part of the chosen topic b] Shows change in the system with motion/time (in video /animation) Or, Allows (in simulation) user to change values of system variables & see the effect on the system c] Allows you to pause whenever you want d] Contains text labels/color codes/text explanation with visuals to activate prior knowledge e] Shows stepwise demonstration of phenomenon
2. Visualize to explain the working of a process/ algorithm or compare multiple processes	<ul style="list-style-type: none"> a] Covers the difficult to understand/visualize part of the chosen topic b] Shows change in the system with motion/time (in video /animation) Or, Allows (in simulation) user to change values of multiple system variables & see the effect on the system c] Shows stepwise demonstration of process d] Allows you to pause whenever you want e] Contains text labels/color codes/text explanation with visuals to activate prior knowledge
3. Write/Draw alternate representations (like graph to equation) from the given visualization or vice-versa.	<ul style="list-style-type: none"> a] Shows both representations together on-screen b] Allows user to make or show (in a video/animation) changes in 1 representation c] Dynamically shows/reflects changes made in 1 representation on the other d] If multiple changes made, shows the effect of these changes in stepwise mode e] Has pause button
4. Use a given visualization to compute the solution to the given problem involving multiple processes	<ul style="list-style-type: none"> a] Covers the difficult to understand/visualize part of the chosen topic b] Shows change in the system with motion/time (in video /animation) Or, Allows (in simulation) user to change values of multiple system variables & see the effect on the system c] Allows you to pause whenever you want d] Contains text labels/color codes/text explanation with visuals to activate prior knowledge e] Shows stepwise demonstration of phenomenon/process

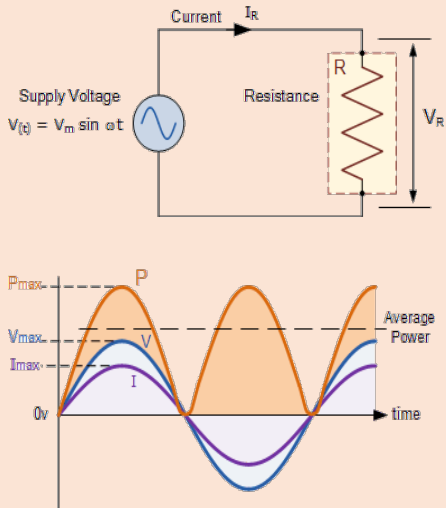
<i>Objective</i>	<i>Choose a visualization that has the following features:</i>
5. Predict output of a phenomenon/next step or a set of steps in a multi-step process	<ul style="list-style-type: none"> a] Shows (in video/animation) or allows(in simulation) you to change variable values & see the effect on the system/phenomenon in stepwise mode b] Demonstrates both directionality and strength of the causal relationship c] Allows you to pause whenever you want d] Contains text labels/color codes/text explanation with visuals to activate prior knowledge
6. Devise an explanation for a given process or phenomena, through logical reasoning, from observations made from the visualization, before the topic has been taught	<ul style="list-style-type: none"> a] Covers the difficult to understand/visualize part of the chosen topic b] Shows change in the system with motion/time (in video /animation) Or, Allows (in simulation) user to change values of system variables & see the effect on the system c] Allows you to pause whenever you want d] Contains text labels/color codes/text explanation with visuals to activate prior knowledge e] Shows stepwise demonstration of phenomenon/process

Appendix C: Sample LD Blueprint (for Multiple Representation using Peer Instruction)

Learning Design for '<Topic Name>' :				
Domain = <.....>; Course Name = <.....>				
Topic Name = <.....>				
Objective = <.....>				
Visualization URL = <.....>				
Setting = <.....>; Time Duration = <.....>; Strategy Suggested = <.....>				
Step No.	Time (mins.)	What Instructor Does	What Student Does	Visualization affordance used, if any
1	2	Play the visualization for the multiple conditions: <Enter the multiple condition sets to show relationship between 2 representations>	Listens & Observes	Play button
2		Pause the visualization at this point. < Insert screenshot of the point where visualization is to be paused to ask the activity question>	Listens & Watches	Pause button Slider bar Dynamic linkage Simultaneous representation
3	2-3	Show the activity question : <Insert PI question with options>	<u>Individual Activity</u> 'Thinks' about the answer for 2 – 3 mins.	Pause button Slider bar
4		a) Ask students to think & commit to an answer. b) Call out each option & ask students to raise their hand if it matches with their answer	Raises hand when instructor calls out their answer	
		Ask students to think individually & write down their answer with reasoning	Writes down the answer with reasoning	
5	5-7	a) Ask students to form groups of 2-3 with partners who have different answers. b) Ask each group to discuss their reasoning & arrive at a common answer	<u>Group Activity</u> <ul style="list-style-type: none"> ● Teams up & discusses their answers with reasoning with group members ● Group members can change their answers ● Each group arrives at a common answer 	
6		Ask each student to again indicate their chosen answer option by show of hands as before.	<u>Individual Activity</u> Votes again by show of hands	
7		a) Run the visualization with the given input value. b) Explain the answer with reasoning.	Notes the difference, if any, with their solution Receives instructor feedback on their errors	Play - Pause button Slider bar
8		End the session by connecting the topic to Real-life, if activity question itself was not place in real-life context : <Insert Real-life connection>	Students relate the topic to real-life	

Appendix D: Sample LD created by an instructor using CuVIS

Learning Design for 'Resistive Circuit' :				
Domain = Electrical Engineering; Topic Name = Resistive Circuit				
Objective = Define the relationship between voltage and current in resistive circuit				
Visualization URL = http://www.animations.physics.unsw.edu.au//iw/AC.html#resistors				
Setting = Lecture; Time Duration = 15-20 mins.; Strategy Suggested = Think-Pair-Share				
Step No.	Time (mins.)	What Instructor Does	What Student Does	Visualization on affordance used, if any
1	2	<p>Play the visualization for the multiple conditions:</p> <p>A. I will explain and show how an alternating quantity can be viewed as in phase with each other.</p> <p>B. The vector changes and correspondingly the quantity changes so the revolution of alternating current and voltage in phase</p>  <p style="text-align: right; font-size: small;">from PHYSCLIPS PHYSICS@UNSW</p>	Listens & Observes	Play button
2		<p>Pause the visualization at this point.</p> <p>I will stop the play when the vector reaches to 90 degrees</p>  <p style="text-align: right; font-size: small;">from PHYSCLIPS PHYSICS@UNSW</p>	Listens & Watches	Stop button
3	3-6	<p>Pose the activity question :</p> <p>Draw the phasor diagram for a 90 degrees shift</p>		Stop button
4		<p>Show Think phase:</p> <ol style="list-style-type: none"> Identify the value of current and voltage at 90 degrees of rotation Identify the vertical component of the phasors Compare the behavior of current and voltage in Resistive circuit 	<p><u>Individual Activity</u></p> <ul style="list-style-type: none"> 'Thinks' about the answer for 2 – 3 mins. 	Stop button

		d) Define Power in resistive circuit		
		Ask students to think individually & write down their answer with reasoning	Writes down the answer with reasoning	
5	5- 10	<ul style="list-style-type: none"> Ask students to form groups of 2-3. Ask students to discuss their answers of ‘Think’ phase question Pair Phase: Show question <ul style="list-style-type: none"> Discuss your answer + reasoning if you do not agree with your friend’s answers <ul style="list-style-type: none"> You can also change your answer Together agree on a final answer <p>Draw the phasor diagram at the rotation of vectors by another 90 degrees shift</p>	<p><u>Group Activity</u></p> <ul style="list-style-type: none"> Teams up & discusses their ‘Think’ phase answers with group members Discusses & writes down solution to ‘Pair’ phase question as a group 	
6	12 -15	<ul style="list-style-type: none"> Ask random student groups to share their solutions with the class. Highlight important points of each answer. 	<p><u>Group Activity</u></p> <p>Presents their group solution to the class.</p>	
7		<ul style="list-style-type: none"> After 5-10 mins., show the ‘Share’ phase question a) Compare your answer with what is shown b) <u>Underline the errors</u> you found in your solution 	<p><u>Group Activity</u></p> <p>Compares their solution with on-screen solution</p>	
		<ul style="list-style-type: none"> Run the visualization with the given input value. 	<ul style="list-style-type: none"> Notes the difference, if any, with their solution Receives instructor feedback on their errors 	Play- Stop button
8		<p>End the session by connecting the topic to Real-life, if activity question itself was not placed in real-life context: A purely resistive circuit</p> 		

Appendix E: Post-test questions for Experiment 2

CS 101: In-class Tutorial Sheet on Pointers

Roll No: _____

Date: 12.3.2013

Instructions:

Today you learned about Pointers using demo. This tutorial sheet will help you to practice your learning. It will also help me to evaluate the effectiveness of today's class. **Your responses to these questions will not affect your marks or your grade in any way, so please attempt all questions sincerely.**

Topic: Pointers

Q1) Predict the output of the following program. Show the memory at the step indicated in comments.

```
int main () {
    int firstvalue = 5, secondvalue = 15;
    int *p1, *p2;
    p1 = &firstvalue; p2 = &secondvalue;
    *p1 = 10;
    *p2 = *p1; // Show the memory arrangement after this step is executed.
    p1 = p2;
    *p1 = 20;
    cout << firstvalue << secondvalue << endl;
return 0;}
```

Ans:

Q2) Your friend wrote the program below to print 573 and -123, and then print 573 and -123 again. Does the program give the desired output? If not, locate the error in the code.

```
int main() {
    int M, N, A [3]; M = 573; N = -123;
    int *ptr1, *ptr2;
    Cout << M << "and" << N << endl;
    ptr1 = &M; ptr2 = ptr1 + 1;
    cout << *ptr1 << " " << *ptr2 << endl;
return 0 ;}
```

Ans:

Q3) Predict the output of the following program

```
int main () {
    int A [4], *p;

    for (int i = 0; i < 4; i++) A[i] = i;
    p = &A [0];
    cout << *p << " " << *(p +=2) << *(p+1) + *(p-1) << endl;
return 0}
```

Appendix F: CLOES - A Framework to Generate Customized Learning Object Evaluation Instruments

Brief Context

This was the first research problem I had taken up to explore as my thesis problem. It deals with generating instruments for evaluation of learning objects which includes visualizations. I came up with the CLOES framework after around two years of research work. Later I decided to transition from evaluation of quality of visualization resources to framing guidelines for instructors to effectively teach using visualizations. This later work became my main thesis work which I have presented from Chapter 1 to Chapter 10. In this Appendix, I present a summarized draft of the learning object evaluation research I had done in my initial years.

Abstract

Evaluation of Learning Objects (LOs) is necessary for establishing their effectiveness. This has resulted in the creation of a large number of LO evaluation instruments by different evaluators, addressing somewhat different, but overlapping quality criteria. But the vast array of instruments offers little help to a new evaluator, since a single instrument may not address their goals and requirements. LO evaluation frameworks help to some extent, as they outline a systematic procedure to evaluate different aspects of LOs. However, existing frameworks are not customizable for new evaluators, who may have their own requirements for evaluation criteria. In this paper we present an LO evaluation framework, 'Customized LO Evaluation System' (CLOES), that would help evaluators generate instruments tailored to their requirements, without having to create an instrument from scratch. CLOES is founded on learning theories and research in educational technology. The framework has been validated by establishing the reliability and validity of the instruments generated from it, and its recall value as a question retrieval system is shown to be acceptable. CLOES has been implemented as a software tool to aid potential LO evaluators in generating customized evaluation instruments, and also teachers in selecting LOs of high pedagogical quality.

Keywords

Learning object, Customized framework, Evaluation instrument, Reliability, Validity

Introduction

LOs have the potential to be valuable learning and teaching resources, providing customized, high-quality learning experience to students. LOs provide a way of overcoming the challenges faced by developing countries like increasing number of students, shortage of books and libraries in rural areas, dearth of trained faculty and absence of adequate infrastructure (Krithivasan et.al, 2005).

Among the various existing LO definitions, L'Allier's definition was chosen for CLOES. The justification for this choice is given in Table 1. The analysis in Table 1 is based on Polsani's (2006) discussion on learning object definitions.

Table 1: Analysis of LO definitions

LO Definitions in use	Applicability to current study
"[...] a Learning Object is defined as any entity, digital or non-digital, that may be used for Learning, education or training" (IEEE Learning Technology Standards Committee 2001).	The focus of this paper is to evaluate digital educational materials. Hence, this definition was not adopted since it includes non-digital resources also.
Learning Object is ... 'any digital resource that can be reused to support Learning.' (Wiley 2002)	This definition, though restricting to digital resources, is still too broad and includes resources like webpages and static images that are not part of the present work.
"Learning Objects are much smaller units of Learning, typically ranging from 2 minutes to 15 minutes."	This definition includes the time factor. However, research studies contend that learning time

LO Definitions in use	Applicability to current study
(Wisconsin Online Resource Center, Beck 2001)	depends on the individuality of the learner and cannot be specified (Polsani, 2006).
“[A Learning Object] is defined as the smallest independent structural experience that contains an objective, a Learning activity and an assessment.” (L’Allier, 1997)	This definition covers digital resources that are small units of learning material and puts pedagogy of LOs in focus (Metros, 2005). Thus, it was in tune with our objectives and deemed suitable for the current work.

For LOs to be effective learning tools, quality evaluation should be integral to the LO system (Reeves, 1994).

LO Evaluation Approaches and Frameworks

LO evaluation can broadly be categorized into summative (product) and formative (process) evaluation (Han, 2004). Summative evaluation is further classified into explicit and implicit. Explicit evaluation involves collecting direct feedback about the LO from different users (for example, through questionnaires), whereas implicit evaluation involves collecting indirect feedback from LO usage data such as number of visits and number of downloads. Explicit ratings can be combined with implicit ratings to rank the LOs in a repository, such as in a recommender system (Sanz-Rodriguez et al., 2010) or Bayesian Belief Network (BBN) model (Kumar et al., 2005). In the current paper, we have focused on explicit LO evaluation, which is a necessary condition since it reflects LO users’ opinion and leads to increased user confidence in these LOs (Freebody, 2007). Additionally, explicit evaluation provides a feedback loop to the production process (Cochrane, 2005; Krauss & Ally, 2005). Thus every LO evaluator requires an explicit evaluation instrument, specific for different stakeholders – peer-reviewers, teacher-users and students.

There are numerous LO evaluation approaches and corresponding instruments documented in literature. A survey by Tzikopoulos et al. (2007) found around 23 such approaches adopted by LO repositories. The list of instruments has increased in recent times (Jones & McNaught, 2005; Freebody, 2007; Kay & Knaack, 2009; Hadjerrouit, 2010). As for evaluation instruments, Vourikari et al. (2008) presented a comparison of thirteen instruments and came up with eight dimensions for classifying the instruments currently in use. These instruments address the different stakeholders and incorporate diverse evaluation criteria.

However, there are a number of problems reported with existing evaluation instruments. There is little uniformity in summative evaluation measures across LO repositories with many of the existing ones servicing only a single repository (Haughey & Muirhead, 2005; Vuorikari, 2008). There is also a lack of theoretical validation from learning theories to the constructs/criteria being measured in many of these instruments (Kay & Knaack, 2009; Haughey & Muirhead, 2005). Few instruments have any form of robustness (validity / reliability) results reported. The lack of such reports undermines the confidence in the conclusions derived from these instruments (Kay & Knaack, 2009). Even reliable instruments like PMLQ (Nokelainen, 2006) and LORI (Leacock & Nesbit, 2007) have reported problems: they are either long (56 items in PMLQ) or uni-dimensional (PMLQ addresses only pedagogy) or require prior training of reviewers (LORI).

The missing theoretical validation for the quality constructs and criteria mentioned above, has been addressed by LO evaluation frameworks (Haughey & Muirhead (2005), Nokelainen (2006), Leacock & Nesbit (2007), Hadjerrouit (2010)). The constructs of LO quality that emerge from these frameworks are Pedagogy, Technology and Content (Hadjerrouit, 2010). These constructs have been expanded into a set of evaluation criteria, validated from learning theories and empirical research. However, the existing frameworks either focus on a single construct (Nokelainen, 2006) or simply provide a list of criteria without classifying them into constructs (Leacock & Nesbit, 2007). Researchers have adopted a subset of these criteria to predict LO acceptance model (Lau & Woods, 2008) or student/teacher satisfaction with LOs (Windle et.al, 2011; Boskic, 2003). There is no single framework that encompasses the entire set of validated criteria. Some of these frameworks have gone a step further and operationalized the criteria set into evaluation questions in form of rubrics (like LORI) or questionnaires (like PMLQ).

Overview of the Customized LO Evaluation System (CLOES)

Analysis of LO evaluation frameworks reveals the challenges for evaluators intending to create an instrument customized to their evaluation goals. Different LO evaluation frameworks contain overlapping, but not the same set of criteria. On the other hand, different terminologies are used to refer to the same criteria. This lack of uniformity in both existing evaluation frameworks and instruments present a confusing scenario to potential LO evaluators. Moreover, a criterion like formative assessment, which is a component of many LOs, is not explicitly addressed by many existing frameworks. Finally, no framework has attempted to customize the criteria set based on the goals and requirements of LO evaluators.

This paper addresses these gaps by developing a framework that enables LO evaluators to generate a customized, evaluation instrument for particular stakeholder types without having to invest the effort of creating a new instrument. CLOES generated instruments come with reported robustness status of constituent questions. The evaluation criteria included in CLOES are recommended from learning theories and research studies. They form a super-set of criteria assembled from key existing evaluation frameworks and instruments and brought under a common nomenclature. Thus CLOES ensures a comprehensive evaluation of LOs by harnessing the benefits of existing research work done in this area and potentially eliminating the need to create yet another LO evaluation instrument.

The CLOES framework is relevant to evaluators requiring an instrument to evaluate LOs, like LO creators, the quality control team of new LO repositories or e-learning companies creating LOs. CLOES provides them with customized instruments to record feedback about their LOs from different stakeholders. In addition, CLOES facilitates the instructors' search for LOs of high pedagogical quality by providing a checklist of pedagogical selection criteria recommended from learning theories and tailored to their requirements.

Research Question and Solution Approach

Comprehensive evaluation of an LO typically involves a variety of criteria such as interface usability, content accuracy, presentation design and others. Evaluators might require yet other criteria based on their goals. In addition, separate evaluation instruments may be needed to record feedback of different stakeholders of an LO, namely, peer-reviewers, teacher-users and student-users. In the context of this diversity, our research goal is to build a framework that i) guides evaluators in choosing appropriate constructs and their specific criteria to ensure a comprehensive quality evaluation, based on their goals and ii) leads to creation of customized LO evaluation instrument addressing different stakeholders.

In order to address the above goal, the specific research questions to be answered are:

Q1. Given a set of goals and requirements of LO evaluator, what aspects of the LO (constructs/criteria/sub-criteria) need to be evaluated for a comprehensive quality evaluation?

Q2. How can the constructs/criteria/sub-criteria be operationalized into questions for a robust evaluation instrument?

Solution Approach

CLOES takes as its input the goals and requirements of an LO evaluator and the stakeholder type, maps them to the relevant evaluation criteria and outputs a customized evaluation instrument (Figure 1).

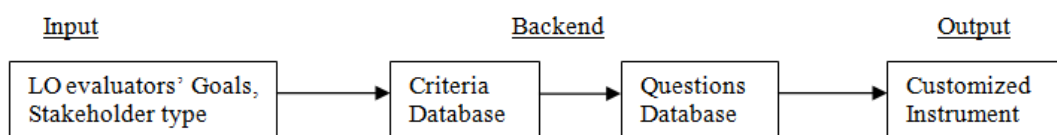


Figure 1: Overview of CLOES Framework

Methodology adopted for formulating the framework

An LO evaluation framework can be defined as outlining a systematic procedure to evaluate different aspects of LOs. The framework is based on a standard set of constructs and criteria grounded in learning theory and educational technology research. CLOES framework is based on Williams' (2000) participant-oriented model of LO evaluation focusing on the product evaluation stage. The participant oriented approach in Williams' model emphasizes the evaluation users, and their evaluation needs. Williams' model provides a step-wise methodology,

where the users are consulted to determine the criteria for evaluation and the questions to be asked. This ensures that CLOES is able to handle the different goals and requirements of stakeholders satisfactorily and the evaluation results thereof are meaningful to all stakeholders.

The stepwise methodology followed in CLOES to create the framework is represented in Figure 2. The output of each step in the methodology is discussed in the following subsections.

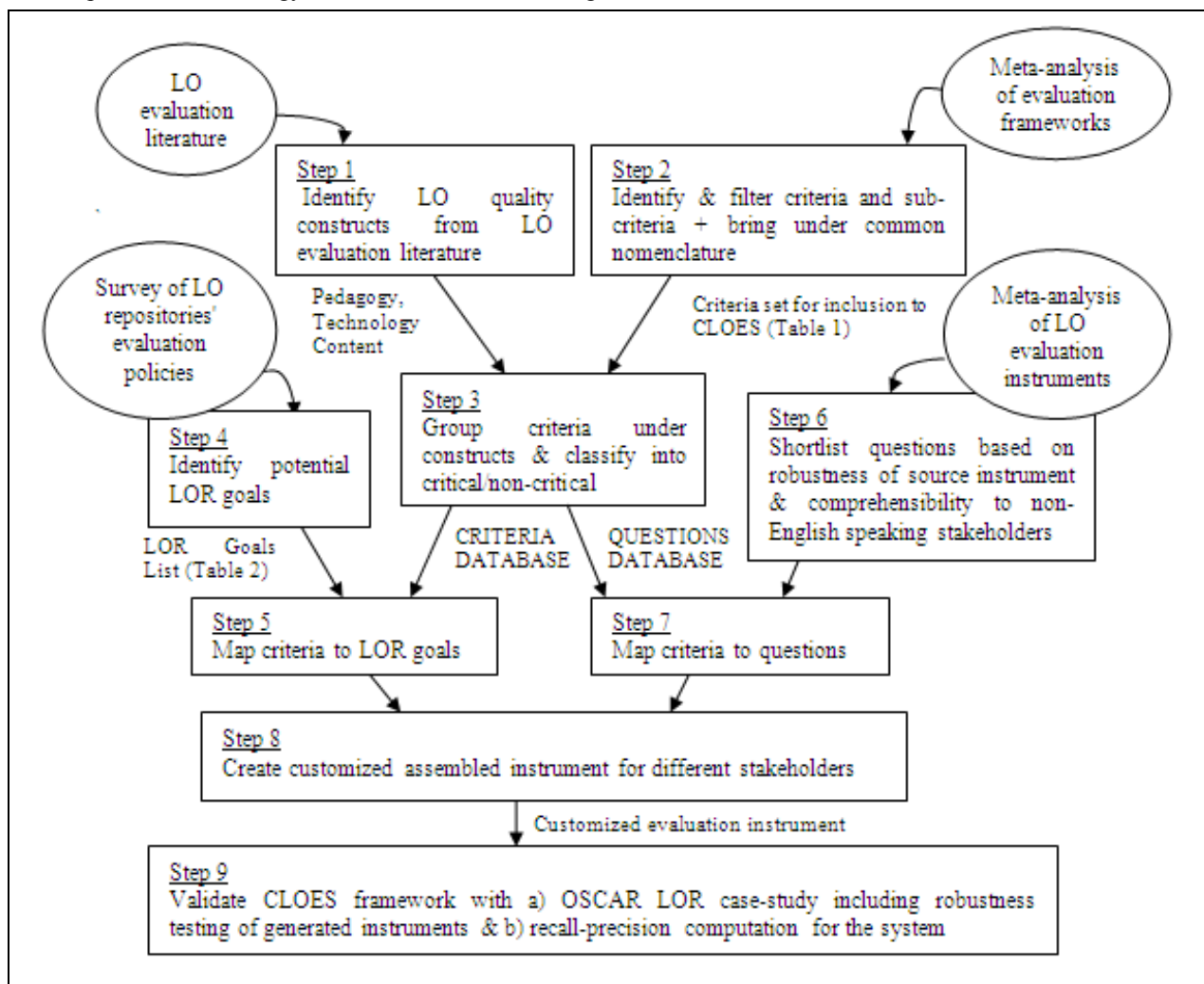


Figure 2: CLOES Framework formulation Methodology Flow Chart

Identifying Constructs for LO Evaluation (Step1)

The main constructs which form the basis for LO evaluation criteria were identified from literature of evaluation frameworks, acceptance models and evaluation instruments (refer to 'LO evaluation approaches and frameworks' section). The three fundamental constructs of LO evaluation were identified as Pedagogy, Technology and Content. CLOES focuses on the Pedagogy construct in contrast to Technology and Content.

Identifying Criteria for LO Evaluation (Step 2)

A meta-analysis was done of thirteen e-learning evaluation frameworks (Abiagam & Usoro, 2009; Teng, 2004; Jung, 2011; Ozkan et al., 2009; Sun et al., 2008; Phipps & Merisotis, 2000), in order to identify specific evaluation criteria. The broader field of e-learning evaluation frameworks was studied to ensure that all criteria and sub-criteria relevant to LO evaluation were included in CLOES. Each of the frameworks was found to refer to a subset of criteria but none of them covered all. Our starting point involved doing a union of criteria from different frameworks. The filter for inclusion of a criterion into CLOES was that it should be validated from learning theory or educational technology research and be recommended by multiple evaluation frameworks and be relevant to LOs. Certain e-learning evaluation criteria, such as faculty support, course development,

institutional support and reliability of online examinations that were not applicable to LOs were excluded from CLOES. The criteria were finalized only after the identified set started repeating across multiple research studies with no new criteria being addressed.

Within the resulting criteria superset, similar criteria from different frameworks were brought under a common nomenclature. For example, the criterion defined to measure accommodation of different learner types is termed Adaptation in LORI but Flexibility in PMLQ. In CLOES, it was adopted as Adaptation.

Creation of Criteria Database (Step 3)

Based on steps 1 and 2, the criteria were grouped under relevant constructs and classified into critical and non-critical categories. A criterion is termed critical, if it has been recommended by multiple evaluation frameworks and has been operationalized by multiple evaluation instruments, reflecting its relevance. In the CLOES tool, the critical criteria are by default selected but LO evaluator can de-select if required. The ‘Criteria Database’ is shown in Table 2.

Table 2: Shortlisted criteria and sub criteria in CLOES

Construct	Criteria & Sub-criteria (if any)	Criteria definition
Pedagogy	Learning value (Learning, Reflective thinking, Transfer potential, Cognitive loading, Self-contained, Valuation of prior knowledge, Pre-requisites, Assessment, Feedback)	Potential effectiveness as a teaching-learning tool
	Motivation*	LO promotes student engagement
	Presentation Design* (Organization, Multiple representation, Navigation)	Graphic design aspects of LO that promote learning
	Goal orientation*	Learning activity + assessment maps to learning objectives
	Adaptation*	Adaptive to different learner types
	Value Added	Value addition to learning in contrast to traditional educational resources like textbooks
	Compatibility with other resources	Integration with traditional educational resources
	Collaborative learning	Using LO in group work
	Socio-cultural sensitivity	Sensitive to social and cultural background of learners
Technology	Interface usability*	Ease of use of the interface
	Reusability*	Usable across different instructional contexts like educational level, curriculum, instructional setting
	Accessibility	Accessible to differently abled learners
	Standard Compliance	Adherence to e-learning technical standards like SCORM
	Metadata	Tags to promote easy search and retrieval
	Intellectual property rights	Copyright issues of learning material
Content	Accuracy*	Factual accuracy of content
	Content coverage & scope *	Depth of content coverage
	Content Presentation (Content sequencing*, Writing style bias, Hyperlinks, Up-to-date)	Style of content presentation

*= critical

Identifying LOR Goals and Mapping Them to Criteria (Steps 4, 5)

To identify the common goals and requirements of LORs, technical documents about evaluation policies and evaluation instruments of various repositories like Le@rning Federation (Freebody et.al., 2007), LORDEC(LO USE, 2007), MERLOT were consulted. Semi-structured interviews were conducted with OSCAR LOR (OSCAR, 2013) creators. A list of potential LOR goals was shortlisted and mapped to the identified criteria on basis of criteria definition provided in the existing frameworks given in Table 2. Mapping to criteria for the Pedagogy construct is shown in Table 3.

Table 3: Mapping potential LOR goals to Pedagogy criteria

Potential LOR goals	Criteria
Effectiveness as a learning/teaching tool	Learning
Promoting learner engagement	Motivation
Promotion of learning by visual/auditory design	Presentation Design
Mapping learning activity/assessment questions to learning objectives	Learning goal alignment
Adaptive to different types of learners	Adaptation
Relative advantage over traditional educational resources	Value added
LO fits in other resources like textbooks	Compatibility with other resources
Promotion of group learning	Collaborative learning
Accommodation of socio-cultural differences of learners	Socio-cultural sensitivity

Creation of Questions Database and Mapping to Criteria (Steps 6 & 7)

Comparative study of LO evaluation instruments yielded a large number of questions mapped to the same criterion. Hence a short-listing mechanism was implemented for inclusion of questions into CLOES:

1. Questions were taken from robust instruments. Only when a robust source was not found for questions, was a non-robust instrument source considered.
2. When multiple questions addressing the same criteria competed for inclusion, the question from a robust source instrument was favoured. If both source instruments were robust, the more clearly worded question (as judged in the pilot testing by students and peer-reviewers) was included.

Creation of Questionnaire (Step 8)

CLOES thus sources questions from multiple instruments for each stakeholder type to assemble customized questionnaire. The detailed working of the assembly process is presented in the next section ‘Working of CLOES framework’.

Validation of CLOES Framework (Step 9)

CLOES framework was validated in two phases. In phase 1, a case-study was done with OSCAR LOR testing robustness of the generated instruments (OSCAR). In phase 2, comparative study of existing LOR questionnaires with the CLOES generated ones was done to estimate performance efficiency of CLOES. These studies are described in detail in the section ‘Establishing validity of framework’.

Working of CLOES framework

The main objective of CLOES is to enable LO evaluators to create a customized instrument, harnessing the benefits of educational technology research. The secondary objective is to provide LO evaluators with the option of adopting robust instruments that address majority of their goals. The working of CLOES framework can be broadly divided into 3 stages: Input to Framework, Back-end work by Framework and Output from Framework (Figure 3). CLOES takes the following data as input: a) stakeholder type to be addressed and b) aspects of the LO that the evaluator wants evaluated. CLOES maps the evaluation goals to criteria and subsequently to operational questions. Finally the framework generates a customised evaluation instrument as output. CLOES has been operationalized as a software tool (CLOES).

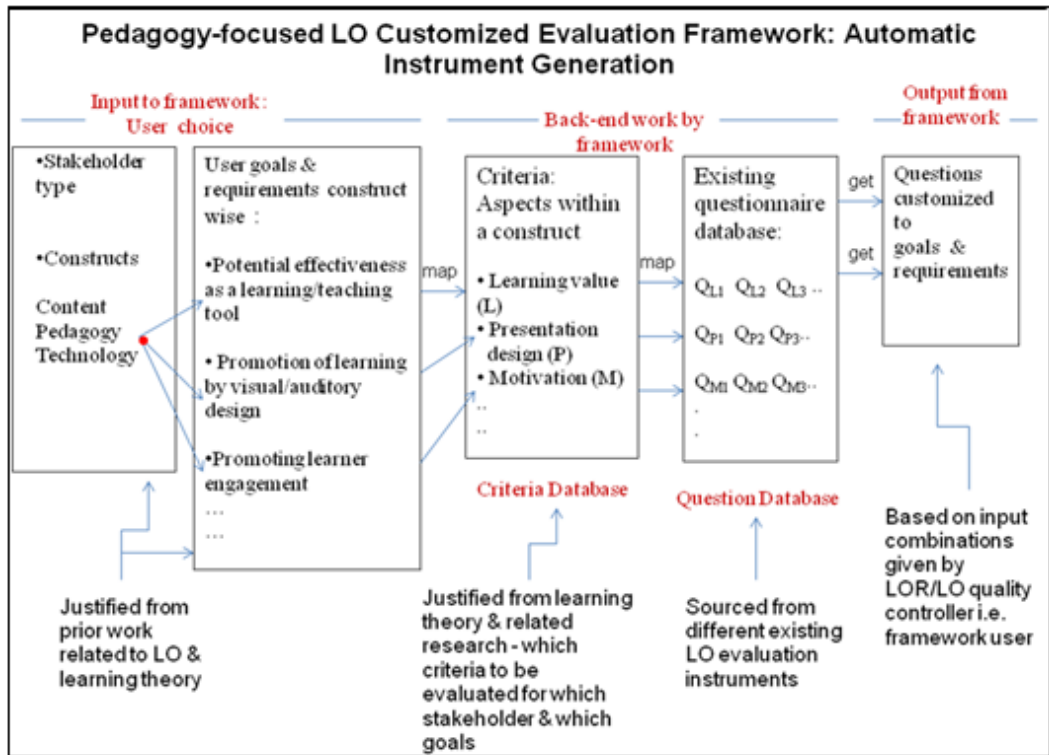


Figure 3: Customized LO evaluation instrument (CLOES) Framework

Stage 1: Input to Framework

The framework requires the following input from the LO evaluator:

- Stakeholder type: Peer-reviewers/students
- Evaluation goals: Potential evaluation goals are given as options to framework users to choose from (Table 3). These goals are classified into pedagogy, technology and content constructs. The constructs presented are specific to stakeholder type. (Figure 4).

Stage 2: Back-end functioning

The goals are mapped to evaluation criteria from the 'Criteria Database' (Steps 3 & 6). Then the framework retrieves the corresponding questions from the 'Questions Database' (Step 7).

Stage 3: Output from Framework

- Prototype: LO evaluators are first presented with a prototype containing questions addressing all the criteria. They have the option of deselecting the undesired questions. This prototype instrument is color-coded to indicate the robustness status of the constituent questions (Figure 5).
- Final Instrument: Once LO evaluators finalize the choices in the prototype instrument, they are given the option of downloading the final version of the CLOES generated questionnaire as a pdf file.

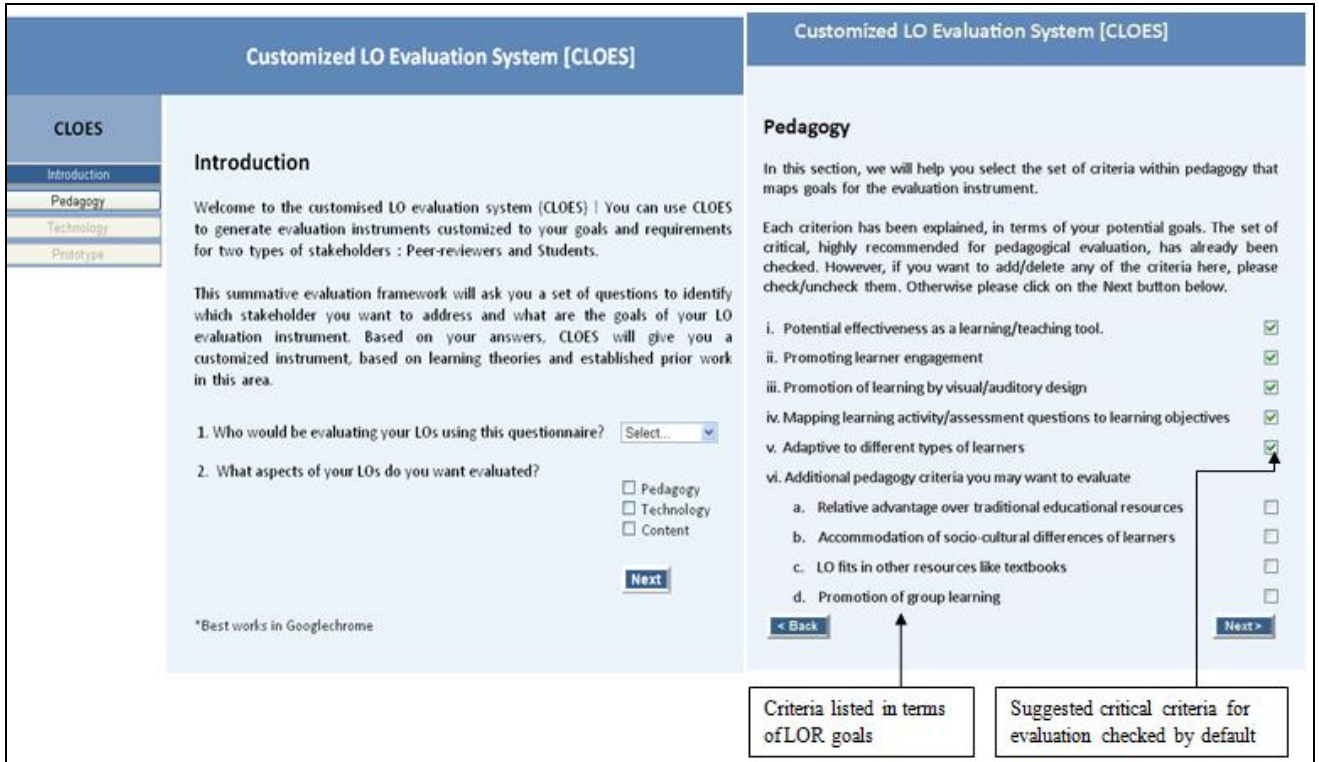


Figure 4: Snapshot of Introduction & Pedagogy screen

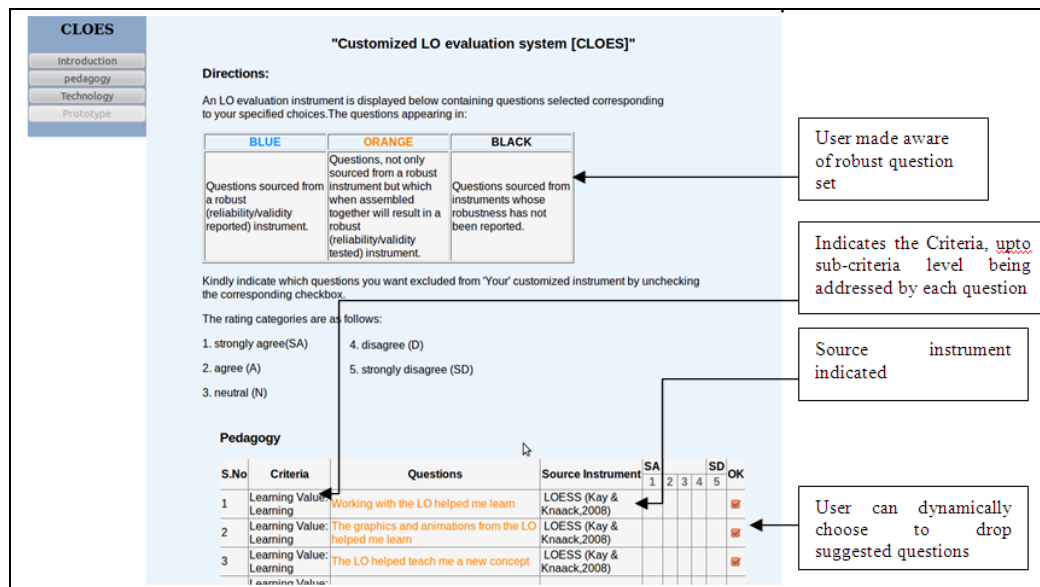


Figure 5: Snapshot of a section of CLOES prototype

Establishing validity of CLOES framework

The validity of the CLOES framework is established in two phases. In Phase 1, a case study was done with OSCAR LOR, generating evaluation instruments for different stakeholders through CLOES and testing their validity and reliability. In Phase 2, CLOES was applied to LORs both within and outside our study frame. The precision and recall as a performance measure of CLOES as a customized question retrieval framework was calculated.

Phase 1: Case Study with OSCAR LOR:

The OSCAR LOR, created as part of the Government of India’s National Mission on Education through ICT (NMEICT), is an open-source LOR hosting LOs in science and engineering, at tertiary level. OSCAR LOR creators used the CLOES framework to generate evaluate instruments by choosing their stakeholders, relevant constructs and goals. Table 4 shows how CLOES addressed the OSCAR goals.

Table 4: Addressing OSCAR goals in CLOES

OSCAR requirement for evaluation instrument	How CLOES addresses them
Need feedback from stakeholders - Peer reviewers, Teacher-users and students	Addresses stakeholders - Peer reviewers and students
Evaluate main sections of OSCAR LOs – Objectives, Learning activity & Assessment	Addresses these within the list of evaluation goals, like ‘Potential effectiveness as learning resource’
Evaluate value add-on that LOs are perceived to bring to the learning process	Includes ‘Value added’ in the evaluation goal list
Evaluate presentation and interface design of LO	Includes ‘Presentation Design’ and ‘Design of user interface’ in evaluation goal list
Evaluate content authenticity	Includes ‘Content correctness’ in evaluation goal list
Ensure proper chunking of content	Includes ‘Content coverage and scope’ in evaluation goal list
Should contain a couple of open-ended questions	Provides option of including open-ended questions in the final questionnaire

Testing Reliability/Validity of CLOES Generated Instruments for OSCAR

Discussion with OSCAR LOR creators revealed two additional requirements: (a) the instrument should be domain neutral and (b) it should address tertiary education. In order to test the robustness of CLOES generated instruments under these conditions, a variety of statistical tests for different types of reliability and validity was conducted. Statistical analysis was performed using the Statistical Packages for Social Science ver.16. Table 5 gives an overview of these tests.

Table 5- Statistical Tests for robustness of CLOES generated questionnaire

Student Questionnaire generated by CLOES for OSCAR		
Purpose	Statistical Test	Result Summary
Internal Reliability of items within each criteria	Cronbach’s alpha	Above 0.6 for almost all criteria, Good internal reliability
Internal Reliability of the questionnaire items	Cronbach’s alpha	Above 0.75, Strong internal reliability
Convergent Validity	Pearson’s correlation coefficient for correlations within the Pedagogy criteria	Statistically significant (p<0.01) correlation (0.3 - 0.6)
Construct Validity	Principal component analysis of the instrument items	Orthogonal varimax rotation corresponded well with the grouping of the items into criteria. Overall, good construct validity.
Face Validity	Agreement frequency for the question “the instrument effectively captures my feedback”	63.3% (N=320) Respondents agreed that questionnaire items measured what they aimed to measure.
Peer-review rubric generated by CLOES for OSCAR		
Purpose	Statistical Test	Result Summary
Inter-rater reliability for rubric	Intra-class correlation coefficient (ICC)	4 items : Strong agreement (ICC:07-0.8); 5 items: Moderate agreement (ICC: 0.33-0.84)
	Percent agreement at modal value	Range of 50% - 66.67% for moderate ICC. Good agreement.
Face Validity	Agreement frequency for the question	97.8% (N=46)

	“the instrument effectively captures my feedback”	
Construct Validity	Expert Interview - “Do you think the questions effectively measure each of the constructs?”	Positive response from 100% (N=46). Good construct validity

OSCAR Student Stakeholder:

The customized questionnaire was administered face-to-face to students from two engineering colleges in Mumbai. LOs from Electrical Engineering [EE] (N= 71; female = 22; male = 49) and Mechanical Engineering [ME] (N=97; female = 3; male =94) were evaluated to establish domain neutrality. The LOs were chosen from the OSCAR repository and covered the topics of ‘Thevenin Norton Theorem’ (EE) and ‘Open systems’ (ME). Students were administered the questionnaire after interacting with the LOs. The CLOES generated customized OSCAR instrument (OSCAR-CLOE) for students contained questions sourced from: a) LOESS [Validity reported: Face, Content, Convergent, Predictive + internal reliability], previously implemented only in K-12 setting (Kay and Knaack, 2009), b) LITE [Validity reported: Face] implemented at tertiary level and c) questions on assessment created by CLOES. For purpose of statistical analysis, the Pedagogy construct was segregated into separate criteria sections of Learning Value, Presentation Design, Value added, Motivation and Feedback (includes Assessment). The single question on Interface design was placed under Technology construct (Kurilovas & Dagiene, 2009).

Internal Reliability of Items: Cronbach’s alpha for internal consistency of the items within each Pedagogy construct in OSCAR-CLOE is given in Table 6. All the criteria, except Presentation Design, exhibit moderately strong internal consistency (0.66-0.74) in both domains. Presentation Design exhibited strong consistency in ME but weaker consistency in EE.

Internal reliability of Questionnaire: Cronbach’s alpha for the internal consistency of the overall questionnaire (14 items) measures the latent construct of LO quality. The value of Cronbach’s alpha obtained for EE (0.763) and ME (0.764) shows that the questionnaire exhibited strong internal consistency in both domains.

Table 6: Cronbach’s alpha for each Pedagogy criteria domainwise

Criteria	No. of items	Alpha(ME)	Alpha(EE)
1. Learning value	4	0.702	0.668
2. Value Added	3	0.740	0.661
3. Presentation Design	2	0.419	0.660
4. Motivation	2	0.644	0.716
5. Feedback	2	0.670	0.515
6. Interface design	1	-	-
7. Latent construct- LO quality	14	0.759	0.765

Convergent Validity: Convergent validity indicates that items measuring different aspects of the same construct should be strongly correlated (Lewis-Beck, 1994). The correlation matrix in Table 7 gives the Pearson’s correlation coefficient between the different Pedagogy criteria. The value of the correlation coefficient in each cell shows the average correlation over all the items measuring a particular criterion. The matrix shows statistically significant and moderate positive correlation between all criteria except between ‘Value added’ and the single item of Interface Design (Technology). Thus the result confirms that each criteria in the questionnaire measures different aspects of the pedagogical quality of LOs.

Table 7: Correlations between different criteria of LO quality

Pedagogy criteria	I	L	V	P	E
Interface Design (I)	1	0.358**	0.071	0.631**	0.245**
Learning (L)	0.358**	1	0.471**	0.382**	0.455**

Pedagogy criteria	I	L	V	P	E
Value added (V)	0.071	0.471**	1	0.175*	0.413**
Presentation Design (P)	0.631**	0.382**	0.175*	1	0.204**
Engagement (E)	0.245**	0.455**	0.413**	0.204**	1

**Correlation significant at 0.01 level (2-tailed) and * Correlation significant at 0.05 level (2-tailed)

Construct Validity: Construct validity explores whether the structure of relationships between different questionnaire items is consistent with the theoretically derived hypothesis of their relationships (Lewis-Beck, 1994). Exploratory factorial analysis was chosen to test construct validity, because from the analysis of theory and prior research, the different criteria under Pedagogy and Technology have been outlined but their interrelation has not been strongly established for LO quality. With all communalities being above 0.56, Principal Component Analysis (PCA) was deemed suitable to establish construct validity. The ‘Interface design’ criterion was clubbed with ‘Presentation Design’ under the broader ‘LO Design’ criterion since both relate to LO design. With OSCAR-CLOE being hypothesized as a 5-factor design: Learning value, Motivation, Feedback (including Assessment), LO design and Value added, the PCA was set to 5 factors. Sampling adequacy was established through Kaiser-Meyer-Olkin Measure (0.783) and Bartlett’s test of sphericity ($p < 0.001$). Both orthogonal (varimax) and oblique (direct oblimin) rotation methods produced identical results. Thus, orthogonal varimax rotation method was chosen since it simplified the data interpretation. The resulting rotation corresponded well with the grouping of items into criteria done by CLOES with two exceptions (Table 8):

- a. Factor 3, the feedback sub-criteria loaded onto a separate factor and also showed high loadings in one each of the ‘Learning value’ and ‘Presentation Design’ items. This can be well explained since they are both related to LO feedback.
- b. Factor 5, the ‘Motivation criteria, showed a high loading in one of the ‘Presentation Design’ item dealing with easy instructions.

Table 8 – Varimax rotated factor loadings for OSCAR –LOE

OSCAR-CLOE items	Criteria	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
L1-Interact	Learning value	0.757				
L2 – Learning from Feedback		0.692		0.497 ^a		
L3- Graphics		0.680				
L4- New Concept		0.617				
V2 – textbook	Value Added		0.784			
V3 – Extra Problems			0.834			
V4- No addl. Time			0.671			
P1 –easy instructions	LO Design				0.835	0.450 ^b
P3 – well-organized				0.543	0.524	
I1 – Interface design					0.825	
F2 – Answering helped	Feedback			0.731		
F3 – Timely feedback				0.802		
E1- Motivating	Motivation					0.735
E2- Use again						0.776

The table above shows that the set of questionnaire items, meant to measure a certain criterion, are actually loading together onto the same factor as desired for construct validity.

Face Validity: It signifies if the questionnaire items are measuring what they are intended to measure. This is usually decided by asking the survey respondents (Kerlinger, 1973). In this case, 63.3% of the student respondents agreed that the evaluation instrument satisfactorily covers their feedback about the LO. The partial non-response rate was 2.38% indicating acceptable wording of the items in the questionnaire.

Summary: Thus robustness of student instrument generated by CLOES was proved through internal consistency as well as construct, convergent and face validity with low partial non-response rate.

Peer-reviewer Stakeholder:

The peer reviewers were sampled from faculty instructors of engineering colleges. Among the 46 peer-reviewers surveyed, all were domain experts with eight also being educational technology experts. They used the CLOES generated questionnaire to review a total of fourteen different LOs from varying domains. The domains were varied to test domain neutrality of the instrument. Interviews were conducted with peer-reviewers to establish face and construct validity. The instrument generated by CLOES for peer-reviewers is an analytical rubric combining both qualitative and quantitative descriptors. It consisted of 10 items and sourced questions from: a) QAMLM (CEMCA, 2009) and b) Questions framed by us.

Face Validity: Peer-reviewers were asked if they had feedback to give which was *not* captured by the questionnaire. 89% (41/46) affirmed in the negative thus establishing face validity of the instrument. (Cronbach’s alpha could not be computed since the same LO was not reviewed by all reviewers.)

Construct Validity: Peer-reviewers were asked verify if the questions under each construct truly addressed that construct. All gave positive response, thus indicating construct validity.

Inter-rater Reliability: A subset of 10 peer-reviewers individually (without prior training) reviewed the same set of three EE LOs using the CLOES instrument. 2-way random ANOVA model with absolute agreement was chosen for computing intra-class correlation coefficient (ICC) (Table 9). Out of ten items, four items (C2, C3, P1, P6) with ICC of 0.7-0.8 showed strong agreement (Stattools), five items (C1, P2, P3,T1, T2) with ICC in range 0.3-0.6 showed moderate agreement. Only one item (P7) showed poor agreement. The percent agreement at the modal value was calculated for items with low and moderate ICC value by taking the mean of the percent agreements at the modal value of observations per LO. The percent agreement for these items were in the range of 50-67%, implying low to moderate ICC values were due to less variance between cases (between LOs) even though there was good rater agreement. For P7 (feedback), the low variance between LOs can be attributed to the fact that all the LOs were created by the same person. Similarly, for T1 and T2, low variance between LOs may have resulted from the common design template used for OSCAR LOs. Thus it can be concluded that CLOES-generated rubric for peer-reviewers was able to generate satisfactory inter-rater agreement.

Table 9: Inter-rater reliability for OSCAR peer-review instrument

Question items	Average ICC (10 raters)
C1 – Content accuracy	0.648
C2 – Content coverage	0.802
C3 – Content explanation	0.842
P1 – Content and Assessment maps to objective	0.840
P2 – Content sequence	0.441
P3 – Choice of medium	0.593
P6 – Interactive	0.775
P7 – Feedback	0.12
T1 – User-friendly	0.474
T2 – Fonts and color	0.330

Summary - The reliability and validity tests show that the CLOES generated instruments are robust for each of the stakeholders - students and peer-reviewers.

Phase 2: Establishing performance efficiency of CLOES

To establish performance efficiency of CLOES, it was applied to four LORs, two for each type of stakeholder instrument. Within the two, one LOR was part of the framework analysis study on which CLOES is based and one was external to the analysis. The respective goals, as disclosed in the LOR documents and existing instruments, were entered as input data. The questions in CLOES generated questionnaires were compared with those implemented by the LOR. The number of similar questions addressing the same sub-criteria was counted

as well as the number of questions not common to both. The recall and precision values were computed as per the equations: Recall = $[tp / (tp + fn)]$, Precision = $[tp / (tp + fp)]$.

Table 10: Contingency Table of CLOES

	Relevant questions	Non-relevant questions
Questions retrieved by CLOES	True positives [tp]	False positives [fp]
Questions not retrieved by CLOES	False negatives [fn]	

Recall indicates to what extent CLOES was able to generate the relevant questions for the LOR while precision signifies to what extent CLOES returned more relevant questions than irrelevant for the same LOR. In context of CLOES, recall is more important than precision since it gives the percentage of questions of the actually implemented questionnaire that CLOES was successful in retrieving. A high recall would thus imply that CLOES is able to replicate a large proportion of an instrument that was created through the resource-intensive and time-demanding process of manual instrument generation. From the values in Table 11, it can be inferred that CLOES showed acceptable level of recall thus establishing the validity of CLOES framework as a customized question retrieval system.

Table 11: Recall and Precision of CLOES

Stakeholder	LOR	Goals & requirements	Recall (%)	Precision (%)	Within study frame? (Y/N)
Student	LORDEC	Engagement, Learning Value, Usability (Presentation Design)	78.57	52.38	Y
	Le@rning Federation (Freebody et. al., 2007)	Instructional design (Presentation Design), student engagement, learning value (promotes active learning + creative and critical thinking), adaptation, usability, accessibility, collaborative learning	85.72	52.17	N
Peer-reviewer	LEARNet (Jones & McNaught, 2005)	Design & Functionality (Interface design); Learning Potential, Content Quality, Metadata (Quality of LRC records)	66.67	59.26	Y
	Wisconsin Online resource center	Learning objectives, relevance, content mastery, critical thinking, concept understanding, reusability, interactive, content, completeness, easy to use, feedback, assessment : provides feedback; maps to learning objectives; assessment type appropriate	73.33	61	N

Answering the research questions

The CLOES framework enables LO evaluators to generate an evaluation instrument customized to their requirements to capture particular stakeholder feedback without having to invest the time and resources required for creating a new instrument as per the standard methodology of instrument creation (Cohen, 2010). CLOES generated instruments come with reported robustness status of constituent questions and are based on learning theories and educational technology research studies. They contain criteria super-set assembled from existing evaluation frameworks and instruments and brought under a common nomenclature. To construct the framework, we had posed the following questions, to which we provide the answers below:

Q1. Given a set of goals and requirements of LO evaluator, what aspects of the LO (constructs/criteria/sub-criteria) need to be evaluated for a comprehensive quality evaluation?

The 'Criteria Database' in CLOES provides the list of constructs, criteria/sub-criteria (Table 2) that need to be evaluated to ensure comprehensive evaluation of LOs. These criteria and constructs have been included in CLOES through a systematic process (Figure 2) involving a comparative analysis of thirteen e-learning evaluation frameworks and selection filters. These criteria are grouped construct-wise and classified into critical and non-critical within the database. They are then customized to potential LOR goals on the basis of the criteria definition provided in the source frameworks.

Q2. How can the constructs/criteria/sub-criteria be operationalized into questions for a robust evaluation instrument?

The 'Questions Database' contains operationalizing questions for each criterion stored in the 'Criteria' database. This database was constructed by analyzing 12 LO evaluation instruments. The questions were mapped to criteria on basis of the mapping given in existing evaluation instruments.

In the 'Questions Database', majority of the questions are sourced from robust instruments. The robustness probability of CLOES generated assembled instruments was further tested with a case study of OSCAR LOR during phase1 of framework validation. A series of statistical tests were done to establish reliability and validity of CLOES generated instruments for both stakeholder types of OSCAR (Table 4).

Conclusion

CLOES framework presents the LO evaluator with set of constructs and criteria, recommended by learning theories, that would lead to comprehensive evaluation of LOs and generates a customized instrument with robustness status of the constituent questions reported. Given that existing research on LO evaluation has already come up with criteria and questions, albeit in strewn pieces, CLOES exploits this progress by enhancing the process of creating assembled instruments. In addition, CLOES provides a criteria set for selecting LOs of high pedagogical usability to teacher-users. The validity of the CLOES framework has been tested with multiple LORs and robustness of CLOES generated instruments has been studied in context of OSCAR LOR.

The CLOES framework is focused on pedagogy with the two other constructs of technology and content not studied in that great detail. Thus, a limitation of the framework is it may not provide the most relevant questionnaire if technology or content is the focus area of evaluation. Currently, CLOES has been tested only with LOs from science and engineering. While education level neutrality of many of the questions included in CLOES was tested and established, some aspects of learning specific to K-12 level, like child development factors (Huaghey & Muirhead, 2005) have not been considered in CLOES. Among the stakeholders, teacher-users' feedback has not been addressed yet. Overall, CLOES is a tested framework for LO evaluators to generate robust evaluation instruments customized to their goals, without having to construct and test evaluation instruments anew.

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