Engineering design thinking skills in the context of analog circuit design

A First Annual Progress Report submitted in partial fulfillment of the requirements for the course of

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by

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Chapter 1

Overview of the past year

1.1 Introduction

Engineering design process is a complex amalgamation of disparate cognitive processes. It demands a variety of skills from the designer that goes much beyond knowledge. It takes the designers through known knowledge, problem identification, decomposition, unknown associations, exploration, pro and con analysis, iteration and so on which can bog down a student who has not been trained in design thinking skills. I have been intrigued by the design process and the thinking skills involved behind each process. Investigating further, I found myself drawn to the creative aspect of design process namely the divergent and convergent thinking skills. I therefore decided to explore divergent and convergent thinking skills in detail in the context of analog electronic design, for my doctoral thesis. Analog electronic design is in itself a complicated task and forces the designer to exercise all the design thinking skills that have been categorized so far and more specifically the divergent and convergent thinking skills. Therefore, it seems appropriate to study them together.

Technology enhanced learning (TEL) environments are guided learning environments that focus on teaching particular skills. The features in such TEL environments are backed by learning theory and cognitive science research. A literature survey has revealed a lack of such TEL environments for teaching divergent and convergent thinking skills. Building a TEL environment for teaching divergent and convergent thinking skills in the domain of analog electronics, would effectively fill this gap.

In this first annual progress seminar report, I first list out the significant activities and projects I was involved in over the past one year in the timeline of work done (Table 1.1). Next, I detail the literature review that I have done in the past year towards better understanding of my chosen thesis topic. I also elaborate on the different projects that I worked on during the past year as a learning process for research methodology or understanding a new domain. At the end of the report, I have attached the three conference papers that was the output of the different projects that I and my colleagues undertook as a team.

1.2 Timeline of work done

I have divided the past one year into four sections comprising of two intervals corresponding to the two semesters and two intervals corresponding to the time between semesters
and time after second semester and now.

<table>
<thead>
<tr>
<th>Time period</th>
<th>Work done</th>
</tr>
</thead>
<tbody>
<tr>
<td>July - October 2015</td>
<td>1. First version of concept, design and implementation of Geometry-via-gestures.</td>
</tr>
<tr>
<td></td>
<td>2. Conceptual design and knowledge structure development of vCLOT.</td>
</tr>
<tr>
<td></td>
<td>3. Study on design process followed by one expert towards solving an analog system design problem as a part of course seminar.</td>
</tr>
<tr>
<td></td>
<td>4. Course project for instruction design on the topic of local history lesson.</td>
</tr>
<tr>
<td></td>
<td>5. Course work.</td>
</tr>
<tr>
<td>November - December 2015</td>
<td>1. Attended T4E 2015 at NIT Warangal</td>
</tr>
<tr>
<td></td>
<td>2. Attended epiSTEME at HBCSE</td>
</tr>
<tr>
<td>January - April 2016</td>
<td>1. Improving design parameters of Geometry-via-gestures (G-v-G). Designing a study using G-v-G considering concepts learnt in RMET course.</td>
</tr>
<tr>
<td></td>
<td>2. Conceptualizing and designing an automatic tutoring system for teaching HDR skills.</td>
</tr>
<tr>
<td></td>
<td>3. Writing paper on vCLOT - knowledge structure project for ICALT 2016.</td>
</tr>
<tr>
<td></td>
<td>4. Attended Latice 2016 conference</td>
</tr>
<tr>
<td></td>
<td>5. Conducted pilot study using G-v-G with four students, did transcription and qualitative analysis.</td>
</tr>
<tr>
<td></td>
<td>6. Participated in SEQUEL workshop conducted at Thakur college and Father Agnel’s polytechnique college.</td>
</tr>
<tr>
<td></td>
<td>7. Course work.</td>
</tr>
</tbody>
</table>
2. Research study on 9 students from 9th Standard using redesigned version of G-v-G.  
4. Data analysis of SEQUEL workshop conducted at Father Agnel’s and Paper writing for ICCE 2016. |

Table 1.1: Timeline of work done between July 2015 and August 2016
Chapter 2

Literature Review

2.1 Engineering Design

Engineering design is according to Dym, “the systematic, intelligent generation and evaluation of specifications for artifacts whose form and function achieve stated objectives and satisfy specified constraint”. Engineering designers are expected to be adept at translating innovative ideas into products or artifacts that have exceptional and at the same time useful functionality while adhering to given constraints [1]. It is therefore an amalgamation of knowledge, process and enabling skills [2]. Engineering design is a highly non-linear process with designers going back and forth and switching between different aspects of design, all the while combining elements to form a whole or decomposing an element to sub-elements. The process of design can be viewed as one of continuous improvement [3].

One of the simplest description of engineering design process is by Brian [4] which involves the three stages of Express-Test-Cycle. Express stage corresponds to concept generation, Test stage corresponds to concept evaluation and Cycle symbolises the iterative nature of the process.

2.2 Thinking skills in Engineering design

Engineering design thinking is a complex cognitive process that includes a wide range of activities ranging from analytical reasoning to being creative and inquisitive. In between these disparate thought processes are the other stages of prototyping, modeling, information gathering, sense making, reasoning and so on. Often Systematic questioning that includes low level (existential) as well as deep reasoning (phenomenon) questions, help shape the design process. Some of the abilities that taken together constitute the Engineering design thinking are [2]:

1. Design thinking as divergent convergent questioning
2. Thinking about system dynamics
3. Reasoning about uncertainty
4. Making estimates
5. Conducting experiments and
6. Making design decisions.

Rim Razzouk et al [5] came up with a host of activities that are integral part of design process and hence indicate to required thinking abilities. Table 2.1 summarizes the activities.

Table 2.1: Activities in design thinking process

<table>
<thead>
<tr>
<th>Identify needs, set goals</th>
<th>Generating feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seek and use up to date resources</td>
<td>Redesign / modify</td>
</tr>
<tr>
<td>Combine information from different resources</td>
<td>Re-evaluate</td>
</tr>
<tr>
<td>Generate ideas from information</td>
<td>Make decisions</td>
</tr>
<tr>
<td>Assess resource credibility and quality</td>
<td>Recognize opportunities</td>
</tr>
<tr>
<td>Argue based on evidence</td>
<td>Show persistence</td>
</tr>
<tr>
<td>Experiment with system by breaking it down, prototyping and modeling, building theory</td>
<td>Manage time</td>
</tr>
<tr>
<td>Testing</td>
<td>Adapt parameters on demand</td>
</tr>
</tbody>
</table>

In her PhD thesis entitled ‘Development and assessment of engineering design competencies using a technology enhanced learning environment’, Mavinkurve [6] proposes a set of 5 competencies as the most important skills in Engineering design thinking. The competencies are

1. Structure open problem
2. Information gathering
3. Multiple representations
4. Divergent thinking
5. Convergent thinking

The author further elaborates each of the competencies to sub-competencies. A good design thinking process would involve effective use of these competencies. Many of the design activities listed in Table 2.1, are inherent in the five major design competencies detailed above.
2.3 Divergent and Convergent thinking

Design thinking is a highly complex cognitive process wherein the designer is required to perform multiple tasks in staggered as well as iterative process. While participating in a design activity, the designer is expected to ask a number of questions to understand a given problem, explore the problem space and the possible solution space in depth as well as breadth, restructure the problem or solution specifications when necessary, evaluate promising solution options in a detailed manner. A variety of thinking skills are required to perform these series of design activities. Two important skills that play a prominent role in these design activities are divergent thinking and convergent thinking. While divergent thinking has been characterized with the action of ideation and creation of multiple choices, convergent thinking is responsible for sifting and sorting through the choices and narrowing down the design pathway [1].

Divergent thinking supports pushing past the obvious so as to explore uncharted territory also called exploratory enquiry [3]. This entails different activities enumerated in Table 2.2 [7], [8].

Divergent thinking is stated to being more concept domain based rather than knowledge domain based [4]. Though divergent thinking is predominant in the early design stage when the concept generation process is in progress, it is seen at almost all stages of design, especially when the designer is at crossroads and needs multiple options in order to make right decisions. While early stage divergent thinking focuses on generating diverse ideas, later stage divergent thinking looks at ways to achieve specific characteristics of the selected concept [9].

Convergent thinking is on the other hand a directive process that uses logical reasoning to converge to correct answer that is also unambiguous [4], [8]. It is characterised by activities enumerated in Table 2.2 [7], [8].

Shanna Daly compiles a comprehensive list of some of the approaches used to finalize on a concept which includes intuition, feasibility judgement, multi-voting, numeric and non-numeric selection charts, pairwise comparisons, decision matrices and prototype testing [7]. Convergent thought process relies on existing understanding of a given topic and therefore can be said to operate in the knowledge domain [4].

Although most of the literature clearly demarcate the roles of divergent and convergent thinking and leave the responsibility of generating ideas squarely in the realm of divergent thinking, Cropley argues that both divergent and convergent thinking contribute to ideas. He goes on to distinguish them qualitatively indicating that ideas from divergent thinking have more variability whereas ideas from convergent thinking conform to orthodoxy. Cropley claims that divergent thinking is for generating novelty and convergent thinking is for exploring novelty and that both working in tandem are responsible for creative design solutions [8]. He further claims that convergent thinking is a prerequisite for divergent thinking practice.

2.3.1 Characterization of Divergent and Convergent thinking

Several measures have been defined to characterize divergent and convergent thinking. Table 2.3 lists the main characteristics of divergent thinking skill. An illustration of some of the characteristics of divergent thinking is shown in figure 2.1.

Further there are a few indirect characteristics of divergent thinking which are predominantly cognitive processes that aid in the thinking skill. Afixability (avoid getting
Table 2.2: Processes in Divergent and Convergent Thinking

<table>
<thead>
<tr>
<th>Activities in Divergent thinking</th>
<th>Activities in Convergent thinking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Shifting perspectives</td>
<td>1. Seeking single best solution</td>
</tr>
<tr>
<td>2. Seeing new possibilities</td>
<td>2. Testing and evaluation</td>
</tr>
<tr>
<td>4. Combining the disparate (conceptual bridging)</td>
<td>4. Synthesizing existing information.</td>
</tr>
<tr>
<td>5. Taking risks</td>
<td>5. being logical</td>
</tr>
<tr>
<td>6. Producing multiple answers.</td>
<td>6. Recognizing the familiar</td>
</tr>
<tr>
<td>7. Transforming the known</td>
<td>7. Combining what belongs together</td>
</tr>
<tr>
<td>8. Reframing and contextual shifting</td>
<td>8. Reapplying set techniques</td>
</tr>
<tr>
<td>10. Crossing boundaries</td>
<td>10. Achieving accuracy and correctness</td>
</tr>
<tr>
<td>11. Reinterpreting</td>
<td>11. Abiding by obviously relevant information</td>
</tr>
<tr>
<td></td>
<td>12. Making only nearest neighbour associations</td>
</tr>
</tbody>
</table>

fixated on an idea), abstractability (make connections and analogies), decomposability (handle complex problems), detailability (ability to think at a detailed level) and cognitive restructuring ability (when the existing cognitive knowledge structures applied to the design are either insufficient or inappropriate) [10], [11].

Convergent thinking characterizes the ability to dig deeper into the ideas. Some of the characteristics in convergent thinking are as seen in table 2.4 [7], [12].

Some of the causes for non-creativity in design are fear of the unknown, fear of failure, frustration avoidance, failing to see one’s strengths, over emphasis on traditional approaches, reluctance to experiment, reluctance to let go [10].

2.3.2 Steps involved in divergent and convergent thinking

There are a number of steps pertaining to divergent and convergent thinking in a design process. During the information acquisition phase, the activities include perceiving, learning and remembering all of which correspond to convergent thinking. In preparation phase, the activities of identifying problem and setting goals take place. This includes un-
Table 2.3: Characteristics of Divergent Thinking

<table>
<thead>
<tr>
<th>Characteristic of divergent thinking</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluency</td>
<td>Generate many solutions - ideation stage</td>
</tr>
<tr>
<td>Flexibility</td>
<td>Explore design space in multiple directions - indicates categories of ideas explored</td>
</tr>
<tr>
<td>Originality</td>
<td>Novelty present in the solution - expands solution space</td>
</tr>
<tr>
<td>Quality</td>
<td>Fitness of ideas to given design problem - usefulness</td>
</tr>
<tr>
<td>Elaboration</td>
<td>Adding details and expanding ideas</td>
</tr>
</tbody>
</table>

Figure 2.1: Characteristics of divergent thinking

understanding constraints, and defining functional requirements of the problem [13]. These activities also demand convergent thinking process. Next is the incubation phase where associations are made, networks are built. These activities are predominantly divergent in nature. Following this is the illumination phase wherein a promising new configuration is made. This activity also demands divergent thinking. Verification phase follows where the relevance and effectiveness of the new configuration in illumination stage is checked. It also includes the evaluation and decision making aspect wherein competing options are analysed. This requires a combination of convergent and divergent thinking. Next in line is the communication phase where the idea is presented, feedback is obtained, reflected and acted upon. Both convergent and divergent thinking have a role to play here. Finally
Table 2.4: Characteristics of Convergent Thinking

<table>
<thead>
<tr>
<th>Characteristic of convergent thinking</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analyzing</td>
<td>Break down ideas into components to understand them</td>
</tr>
<tr>
<td>Synthesizing</td>
<td>Combine different themes within an idea</td>
</tr>
<tr>
<td>Reorganizing and redefining</td>
<td>Change form of information by revisiting it</td>
</tr>
<tr>
<td>Evaluating</td>
<td>Appraising potential value of ideas</td>
</tr>
<tr>
<td>Seeing relationships</td>
<td>Drawing connections between different ideas</td>
</tr>
<tr>
<td>Designing to resolve ambiguity</td>
<td>bringing order to disorder</td>
</tr>
</tbody>
</table>

there is the validation phase where the effectiveness and relevance is judged. This requires convergent thinking process [8].

### 2.4 Teaching Divergent and Convergent thinking

#### 2.4.1 Various instructional strategies

There are many recommended suggestions for instructional approaches to foster creativity. They include

1. Open ended projects - Students reflect on their own creative processes as they work through the project.

2. Support risk taking in classroom - A controlled environment which frees the students from the anxiety of venturing into the realm of unknown has been shown to increase creativity [7].

3. Structured approach - Assigning specific tasks of say generating n solutions and in the process promote interactions among students.

4. Focus on cognitive skills such as thinking patterns using specific activities of information gathering, organizing, conceptual combination, idea generation, evaluation, implementation planning and solution monitoring.

5. Encourage students to let go of previous bias and approach problem in new ways.

6. Encourage students to do metaphorical thinking and drawing connections.
7. Adopt traditional brainstorming methods, mind mapping methods, attribute listing, idea checklists.

8. Organize information gathering experiences with say client interviews and also seed additional ideas in the process.

9. Reverse engineer to initiate solution approach.

10. Analyze data collected through self designed experiments so as to test the ideas.

11. Collaborate and share ideas with other teams such that there is a “How did they do it - how will we do it” approach leading to new solutions.

12. Use design heuristic to trigger idea generation process [14], [10], [9], [12].

2.4.2 Existing TEL environments to teach Divergent and Convergent thinking

Developing and applying the divergent and convergent thinking competencies has been by and large acknowledged to be essential to engineering design thinking process. However, a literature survey reveals a remarkable lack of TEL environments to teach divergent and convergent thinking specifically. There are existing TEL environments to teach a multitude of design thinking skills and few of them are summarised in Table 2.5. Part of the table has been adapted from the doctoral thesis of Madhuri Mavinkurve [6].

Although there seem to be no TEL environment that supports divergent and convergent thinking, literature indicates a range of applications that support different aspects of divergent and convergent thinking. Arvind Rangaswamy et al [15] classify software for new product design into four categories viz. idea generation, product design, project evaluation and portfolio analysis and project management. Out of these categories, idea generation and project evaluation tools seem to be closest to divergent and convergent design process. Some of the tools available for idea generation at the time of writing the article (1997) were Mindlink (uses wish triggers, idea triggers, option triggers, forced juxtapositioning of unrelated thoughts), IdeaFisher (helps make network of associated words to trigger imagination), Inspiration (visual thinking and mind mapping), Group Systems for brainstorming.

Tools for analysis included NewProd (assessing risks and rewards) and AHP (Analytical hierarchy process for choosing and prioritising). Though the above applications were directed towards new product design, the underlying ideas are valuable in terms of feature selection for a divergent - convergent TEL environment.

Blogs for verbalising [16], [17], brainstorming and mindmapping [18], [16], graphing, storyboarding and sketching or drawing [19] have been claimed to aid in divergent and convergent thinking process. Some of the tools available for brainstorming are Padlet, Freemind, Text2Mindmap, Edmodo, iBrainstorm. Infographics are another way to transfer ideas from mind to screen and yEd is one of the existing infographics tool.
Table 2.5: Existing TEL systems for teaching design thinking skills

<table>
<thead>
<tr>
<th>Design feature</th>
<th>WISE</th>
<th>Co-Lab</th>
<th>MIC-O-MAP</th>
<th>CTSiM</th>
<th>TELE-EDesC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skill Targeted</td>
<td>Scientific thinking</td>
<td>Experimental skill</td>
<td>Micro - Macro thinking</td>
<td>Computational thinking</td>
<td>Structuring open problem</td>
</tr>
<tr>
<td>Education Theory</td>
<td>Knowledge integration</td>
<td>Discovery learning</td>
<td>Guided Inquiry</td>
<td>Learning by modeling and design</td>
<td>Guided Inquiry</td>
</tr>
<tr>
<td>Interactivity</td>
<td>Simulations and graphing</td>
<td>Simulations</td>
<td>Simulations</td>
<td>Modeling and simulations</td>
<td>Limited to choosing right answer</td>
</tr>
<tr>
<td>Modeling Tools</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Reflection facility</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

2.4.3 Suitability of analog circuit design for Divergent and Convergent thinking

ABET criteria for engineering graduates recommends that they should be able to use their engineering skills to design effective solutions (ABET 2012). Electronics being an applied field, it is imperative for students to be able to conceptualize, design and build systems. Electronic system design process is hierarchical in nature and often overlaps with other domains. For instance, the top level or system level design decisions will have to consider functional behaviour of the whole system given a host of constraints regarding input, output, environment, available resources and so on. The lower levels on the other hand may have considerations primarily about interactions between blocks, functionality of each of the blocks and the interplay between them.

Most of the electronic systems have inputs or outputs in some other physical form which first needs to be transformed to electrical signals. For example, if one wants to design a PA system, one has to consider the nature of the input - output signals which is audio while the rest of the system deals with electrical quantities. A Temperature or humidity controller would have temperature and moisture content of atmosphere respectively as its input.

Designers therefore need to first identify the nature of signals involved and look for appropriate means to transform them to manipulable electrical quantities. This in itself forms one level of design wherein there are a multitude of alternatives to consider, evaluate and decide. Decisions made at this system level will have consequences at many
subsequent stages.

Next the designers have to breakdown the design problem to sub-blocks such as noise reduction and signal conditioning block, amplifying block, threshold sensing block, gain control block, signal modulation block and so on. There could be a permutation and combination of many blocks each having their own limitations and constraints. Likewise each of the sub-levels come with a host of design decision questions which designer will have to decide based on say available options, and design constraints. Constraints could be as varied as the power level of operation, frequency of operation to capacitance in the system, loading, impedance matching, frequency response, stability, noise tolerance as well as placement of components used, packaging, heat dissipation mechanisms and so on. Therefore a combination of design thinking skills are required at different granularities of the design of the system.

There are multiple approaches to electronic design. While one approach is to have a completely analog system, the other approach is to use data acquisition systems and convert signals early on in the system to digital form which can then be manipulated either digitally (VLSI design) or programmatically (microcontroller based systems). Each approach has its own set of merits, limitations and design considerations. However, analog system design is inherently more challenging because of the continuous nature of signal, lower tolerance to noise and use of discrete components all of which have to interact in desired manner to generate required output amidst their own operating ranges and limitations. This variety lends a richness to analog system design which may be true to a smaller extent in the digital design. This richness in turn demands application of design thinking skills especially divergent - convergent thinking skills by the designer so as to get the most optimum system.

2.4.4 Existing TEL environments for analog circuit design

TEL environments developed in-house viz. MIC-O-MAP for conceptual understanding of analog devices and TELE-EDesC [6] to develop design thinking - specifically structuring open problem seem to be the only existing TEL environments catering to analog electronic systems. There are a plethora of design support systems that cater to electronic design in general. This includes analog and digital design. Dean Grant Curtis Scothern in his thesis “A knowledge based support tool for the early stages of electronic engineering design” [20], classifies design support systems as conventional toolkits that help designers in schematic entry, simulations, PCB design and specific expert knowledge based system.

The conventional toolkits are by and large user directed passive systems that mainly support later stages of design [20]. In this respect, design environments for VLSI based systems cover the widest range of support in terms of behavioural, functional, to chip floor plan. The main categories in conventional toolkits are tools for simulation and analysis, and tools for PCB design. Table 2.6 summarises a few available toolkits and their functionality.

Even though there are no readily available TEL environment for analog circuit design, there is a lot of value in using the simulation and analysis toolkits for learning electronic design. Michael Singh [21] extolls the virtues of using circuit simulators for exploring alternative circuit ideas and simulate many variations of implementations. Simulators lend themselves readily to analysis of a given circuit with different specifications and constraints. For instance, SEQUEL circuit simulator supports a whole host of analysis techniques such as ac analysis, dc analysis, transient analysis and also enables students to
view signals at different points in the circuit in a graphical format. Such features make it invaluable for students who are exploring the pro and con of using different circuit blocks - a vital process step in divergent and convergent thinking.

2.4.5 Gap analysis

Considering its importance to engineering design, divergent and convergent thinking must be explicitly taught to the students. There is therefore a need for a TEL environment that helps students to practise divergent and convergent thinking. In terms of analog circuit design, this would mean that such a TEL environment would have features like

1. ability to view multiple options or possibilities for a given design problem

2. support building multiple prototypes (e.g. multiple schematics), execute/simulate them and see the outputs concurrently

3. support for comparison in terms of

   (a) Circuit performance
   (b) Power requirement
   (c) Noise tolerance
   (d) Number of components
   (e) Bandwidth
   (f) Stability
   (g) Supply requirement

to name a few.

4. support scaffolding in terms of expert feedback on selected choices

L.J Ball et al recommended a design framework based on their observation of three electronic engineers solving three different design problems [13]. Recommendations suggest the design environment to aid with problem definition and representation, encourage search for alternate solutions, assist in choosing from competing design solutions, promote flexible and easy navigation in problem and solution space, facilitate multiplicity of design representation such as text, graph, equation, circuit schematic etc, allow for deviations from structured design approach and preserve history of design actions.
<table>
<thead>
<tr>
<th>Toolkit</th>
<th>Purpose</th>
<th>Design type</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pspice</td>
<td>Analog circuit simulation and analysis</td>
<td>Analog</td>
<td>GUI</td>
</tr>
<tr>
<td>ngspice</td>
<td>Analog circuit simulation and analysis</td>
<td>Analog</td>
<td>Text based</td>
</tr>
<tr>
<td>SEQUEL</td>
<td>Analog circuit simulation and analysis</td>
<td>Analog</td>
<td>GUI</td>
</tr>
<tr>
<td>LabVIEW</td>
<td>Analog and digital systems</td>
<td>Hardware and Software combination</td>
<td>Visual programming</td>
</tr>
<tr>
<td>Xilinx</td>
<td>Simulation, synthesis, implementation and hardware realization</td>
<td>Digital</td>
<td>GUI</td>
</tr>
<tr>
<td>Protel, CircuitMaker</td>
<td>PCB layout</td>
<td>Analog, Digital</td>
<td>GUI</td>
</tr>
<tr>
<td>PEDA, VEXED, LEAP</td>
<td>Early expert system based guided design</td>
<td>Digital</td>
<td>GUI</td>
</tr>
</tbody>
</table>
Chapter 3
Future work for thesis

In the next one year, I plan to further investigate the role that Divergent and Convergent thinking plays in analog circuit design. For this I plan to conduct a study in the Engineering Physics undergraduate basic electronics lab course (EP215). The lab course is designed with the objective of equipping students with the ability to solve a given open problem using experimental techniques by applying basic electronics principles.

Daly et al [7] categorize reconciling contradictions as one of the ways to prompt innovative thinking among students. Some of the experiments in the lab course bring out contradictions in terms of either outputs seen for given standard circuits being radically different from the expected or change in functionality of a standard circuit due to measurement techniques. The students are expected to trace the underlying factors that contribute to such contradictions in apparently standard circuits.

One example is the bridge rectifier circuit connected such that it receives input from function generator and the output is measured across a load resistor. Students are encouraged to simultaneously view the input and the output of the circuit using the two channels of a digital storage oscilloscope. Owing to the common ground that the oscilloscope channels have, the circuit stops behaving as a rectifier due to two of the four diodes being rendered inactive. Students are expected to observe this phenomenon and deduce the effect of measurement on the output. The bridge rectifier circuit is a classical circuit with well known output. When the output is not as expected, the students are initially flummoxed and then they begin the reasoning process which helps them understand why conventional approaches to understanding the circuit may be limiting due to different problem definition [7].

Daly also claimed that one of the instructional approaches to fostering creativity is by providing support in classroom for risk taking. Some of the experimental sections in the lab course encourage students to push the limits of circuits or instruments provided such as power source, function generator and so on, so as to explore the behaviour of the system at extreme situations. For example, as an extension to one of the experiments on voltage and current source, the students are asked what happens if the power supply is shorted. Students initially don’t perform the experiment and say that the supply will probably get destroyed due to shorting. However, they are permitted to perform the experiment (taking risks in a controlled environment) and they discover that the power supply has an internal protection mechanism which promptly displays that the supply is now in constant current mode and not in the regular constant voltage mode. The students then reflect on why this happens and come up with appropriate reasoning.

The lab course instructor is therefore introducing multiple scenarios to encourage cre-
ative thinking among students. It would be an interesting study to evaluate effectiveness of such an initiative on students’ learning.

Expert - novice approach to engineering design is an oft studied aspect so as to unearth the productive actions of experts and patterns of behaviour while designing [17] that would help students in their design process [22], [13], [23]. It would be worthwhile to investigate expert productive actions with respect a divergent - convergent thinking process during analog electronic design. I plan to study first design a suitable design question based on analog circuit design and study design strategy used to solve the design question by a few experts as well as a few novices.
Chapter 4

Other projects

4.1 Geometry via gestures

4.1.1 Overview

Understanding and interpreting structure and properties of 3-dimensional (3D) objects is important in several areas of science and engineering. Students begin learning about 3D Geometry at high school and find it difficult to visualize 3D structures and derive important properties from them. When de-constructing a 3D structure into its constituent 2D parts, or constructing 3D structure from 2D primitives, the student has to mentally visualize the intermediate structures. For instance, when a student has to think of a right circular cylinder (3D) as being made of a rectangle (2D primitive) or imagine that a cylinder (3D) can be constructed from rectangles (2D primitive) or visualize formation of cylinder from rectangles to look like opening of a book. Traditionally to teach topics that have three dimensions, 3D artifacts or models and computer applications have been used. However, physical models of 3D structures, do not lend themselves to manipulations such as breaking open, changing shape, 2D - 3D translation to name a few. Although computer applications provide interactivity with 3D objects with I/O interfaces such as keyboard and mouse, these interactions are restricted by the affordances which keyboard and mouse provide.

3D geometry thinking is closely connected to students’ ability to calculate properties of solids such as volume and surface area [24]. It is desirable that students be able to link the structure of the 3D object with the formulae of its properties and properties of underlying 2D primitives that combine to form the 3D object. Visualization and construction are two main thinking process in geometry [25]. Geometrical knowledge can be constructed in a meaningful way in contexts that serve as “fields of experience”. Fields of experience encompasses the internal and external context of the learner as well as the teacher context. In case of traditional setup, the “field of experience”[25] is severely limited by blackboard and viewing of models. Also by physically providing models and technology tools with limited affordances there is no/minimal control over the learners internal context. Activities in class room are more oriented towards the abstract proofs and theorems rather than concrete mental construction.

G-v-G along with certain activities that enable learners to visualize and manipulate 3D structures using gestures. The application guides learners through a series of activities involving 2D and 3D structures. Learners use gestures to do the activities. The application senses gestures and modifies the object on the screen accordingly. For example, a swipe
gesture will enable the user to construct a right circular cylinder from a rectangle. The user will be able to view on the screen the initial state, trajectory made by the rectangle and modified state due to effect of user gesture on the rectangle.

We developed two versions of “Geometry-via-Gestures” (G-v-G) - the first version was designed and subsequently evaluated for usability using a pilot study with 4 students. Based on the feedback from the students, G-v-G was redesigned by transferring to a new platform, including pre task practise and individual activity scaffolding. A research study was conducted using this redesigned system with 9 students of 9th grade. The research questions of the first pilot study were -

1. How do learners use G-v-G to learn 3D geometry?
2. What features are required to strengthen the pedagogical design of G-V-G?

The research questions of the second study were -

1. What can students learn about the properties of 3D structure after interacting with Geometry-via-Gestures?
2. What is students' perception of learning about 3D geometry after using Geometry via Gestures?

In both the studies, the researcher acted as a facilitator, who observed the student and asked guiding questions or prompts, the responses to which were later analyzed using thematic analysis [26]. Learning is also evaluated using a post-test that mainly looked into transfer of knowledge obtained during the use of G-v-G, to new problems. Analysis of data from verbal interaction during the intervention, post-test responses and learning perception indicate that G-v-G application in conjunction with reflection prompts from a facilitator, promises to be a valuable supplement to students’ Geometry lessons.

### 4.1.2 Design and Pilot study

**Design**

The system 'geometry via gestures', has been developed around a leap motion controller connected to a computer. Leap motion controller is a gesture sensing device. It is connected to the computer via the USB port. It does not require additional power supply or hardware such as GPU on computer. The controller is made of an array of infra-red sensors and IR emitting LED’s and is capable of detecting a multitude of gestures using hands, fingers and even a limited set of tools.

For the leap motion device to interact with the computer, a leap SDK (Software development kit) is available. The SDK includes necessary libraries for the interaction between the leap motion device and the application on the computer. The application in turn requires:

- a 'Controller' object, which establishes a connection between the device and the application,
- a 'Listener' subclass, which enables the application to cater to the events from the controller,
- two basic methods viz. OnConnect() method and onFrame() method.
The `onFrame()` method parses the frame to obtain detailed information present in the frame such as the number of hands, fingers, recognized gestures, co-ordinate position and so on. JavaFX is the Java platform that supports development of applications that have rich graphical content, interactivity, along with web connectivity. Existing Java libraries can be directly used in applications developed using JavaFX.

Activities

A set of three activities were designed in the GeometryviaGesture application.

- **Task 1** A right circular cylinder was shown on the screen. Student had to try various gestures and observe the corresponding movement of the 3D object. The goal of this activity was to perk up the students interest and at the same time acquaint them to the gesture based interaction process.

- **Task 2** A circle or circular disk was shown on the screen. Student had to first deduce the right gesture (vertical swipe) to manipulate the onscreen object. Using the swipe gesture, the student had to stack multiple circles on top of each other to form a cylinder. The goal of this activity was to enable the students to construct a 3D object from a known 2D primitive and conceptually derive the volume of the constructed 3D object.

- **Task 3** A rectangle with two circles on either sides, was shown on the screen. Student had to first deduce the right gesture (horizontal swipe) to manipulate the onscreen object. Using the swipe gesture, the student had to rotate the rectangle. A trace of the rectangles could be seen as the rectangle rotated along the circle. This generated a cylinder. The goal of this activity was to introduce a different perspective to the construction of 3D object. This was meant to convey to the student the idea that 3D objects could be constructed from a variety of 2D primitives.

As the student is interacting with the application, the facilitator poses questions which have been scripted. Questions posed by the facilitator is expected to make students reflect on what action they did, why they did that particular action/gesture, what happened to the object on screen, what insight did the student gain from this activity and finally can the student conceptually describe the volume property of the 3D object in terms of the 2D objects. The student answers are evaluated based on a rubric. The facilitator also has a observation protocol sheet which they would have to fill as the learner responds and interacts.

Posttest:

A rectangular sheet of cardboard is given to students and they are questioned on the number of ways in which a right circular cylinder can be formed, using the sheet. A triangular cutout in a cardboard is provided to students and they are asked to generate 3dimensional objects using the triangular cutout. The expected outcome is a triangular prism structure obtained such triangular cutouts are stacked. Also expected is the conceptual understanding of volume of such a structure.

Postinterview:

Interview learners on the role of gesture in the 3D structure formation, and also the usefulness of the tool and any features they would have preferred.
4.1.3 Redesign and Study

After the pilot study, a number of design as well as research considerations that were not made, came to light and the system was redesigned to accommodate the limitations of the pilot design and study. The redesigned system had similar use cases but included scaffolding, better GUI, more sensitive response to gestures, different platform (Javascript), hand position indicator on screen and an inbuilt demo for acclimatization to new medium of interaction.

The second study was conducted with 9 students, all from class 9. The activities were only marginally different from the pilot study. As the student is interacting with the application, the facilitator poses questions which have been scripted. Questions posed by the facilitator is expected to make students reflect on what action they did, why they did that particular action/gesture, what happened to the object on screen, what insight did the student gain from this activity and finally can the student conceptually describe the volume property of the 3D object in terms of the 2D objects. A written post test comprising of knowledge transfer based questions and perception of tool was given at the end of the intervention. Data from the interview and posttest was used to answer the research question.

4.1.4 Contributions

The outcomes of the pilot study is being written jointly by Lakshmi, Prajish and myself, along with Prof.Sahana and Prof.Sanjay, as a workshop paper for ICCE 2016. My contributions for the pilot study was

- Application development - 30%
- Conceptualizing - 40%
- Study implementation, data collection - 33%
- Analysis - 75%
- Writing - 33%

The outcomes of the second study has been written jointly by Lakshmi, Prajish and myself, along with Prof.Sahana, as a full paper for T4E 2016. The paper entitled “Geometry via Gestures: Learning 3D geometry using gestures”, is attached to the end of this report. My contributions for the redesign and study was

- Application development - 25%
- Conceptualizing - 50%
- Study implementation, data collection - 33%
- Analysis - 95%
- Writing - 75%
4.2 vCLOT

4.2.1 Overview

vCLOT or virtual clot, is a game based learning environment where students can learn about the blood clotting process by playing a game. The learning environment is built using an open source virtual world platform - open wonderland. vCLOT extends the benefits of animations by

1. providing an immersive and situated learning environment,
2. providing more control to the learner in the learning environment.

The design of vCLOT combines the immersive nature of virtual worlds with an engaging game based learning environment. A well-defined knowledge structure at the backend links concepts, procedures and their relationships. Knowledge structures provide a means of capturing learner’s knowledge by linking the activities of the learner to the concepts and procedures. In this way, knowledge structures help the researcher track learner’s knowledge gain over multiple game attempts.

4.2.2 vCLOT - the game

The goal of vCLOT is enable learners to identify the different artifacts required for blood clot formation and use them in a series of steps to complete the blood clot formation process. In order to play the game, the learner first signs in to the virtual world and creates his or her avatar. The learner is briefed about the blood clot formation process and what he or she is expected to do in order to win the game. This briefing is done with the help of a narration. The narration uses the audio/video player tool (that the Open Wonderland environment supports) and a flowchart to depict the procedural nature of the blood clot formation process.

The learner then starts to play the game. The game is in the form of a quest. A quest is defined as a task involving multiple activities, that a player-controlled character must complete in order to gain a reward. In vCLOT, the objective of the quest is to heal an injury by blood clot formation. There are a number of interactive artifacts floating and moving around the learner’s avatar. Some of the artifacts in this quest are 'Prothrombin', 'Thromboplastin', 'Calcium ions', 'Fibrinogen', 'Fibrin threads', 'Platelets', 'White blood cells', and 'Red blood cells'. These artifacts correspond to the concepts that are involved in the blood clot formation process.

In the blood clot formation process involves four distinct procedure steps. In each of the steps the learner is expected to identify the relevant artifacts, grab them and finally use the grabbed artifacts to synthesize a new artifact. The game progresses to the next procedure once the synthesis of the new artifact is complete, eventually leading to blood clot formation. "Grab" and "Synthesize" are user actions in the virtual world, done using the mouse. Successful blood clot formation heralds the completion of the quest. The whole game is a timed activity and the learner has to ensure that he or she advances through the different procedures as quickly as possible, so as to heal the injury. On successful completion of the game, based on the time taken, the number of right or wrong artifacts grabbed or procedure followed, the learner gets a corresponding trophy.

The above learning design is based on the principles of effective game design [27] and affordances of the virtual environment. In vCLOT, the learner has to grab and synthesize
the correct artifacts in order to proceed further in the game. Proceeding further in
the game ensures that the steps required for the formation of the blood clot are also
learnt. Hence, the learning required to succeed in the game is the same learning required
by the instructional objectives. The virtual world provides an immersive experience to
the learner. While playing the game, the learner is making some executive decisions on
inactive chemicals and triggers the corresponding activity. The learner is not only learning
the process, but also plays an active part in its execution.

4.2.3 Design

vCLOT has been designed in Open Wonderland which is an open source Java based
toolkit to develop virtual 3D environments. Open Wonderland supports development
of immersive learning environments where learners can become a part of their learning
environment by assuming a role of an avatar and interact with artifacts available in the
environment. The design of vCLOT can be broadly divided into three components:

1. the frontend is the virtual world,
2. the backend is a knowledge structure and
3. the interface layer that facilitates communication and data processing between the
   frontend and the backend.

There are a plethora of tools that such an environment can include. Whiteboards,
video/audio players, document viewers are a few such tools that are relevant in a virtual
world meant for education. In addition to these existing tools, developers can import their
own 3D or 2D models and define their behaviour. A game-based learning environment
can therefore be made quite rich in terms of visual quality and possible interactivity.
However, the interactivity has to be enabled with solid backend architecture support that
facilitates exchange of information and execution of meaningful actions. This calls for
some important design considerations that will facilitate seamless merging of operations
between the front-end and the backend.

vCLOT comprises the following components:

1. Virtual World Component  This component is the user interface and includes all
   visible artifacts in the virtual world, their properties and possible interactions. For
   example, Prothrombin is an artifact which can be synthesized at one level or grabbed
   in a different level. On the other hand, “Calcium ions” are artifacts that can only
   be grabbed in the virtual world.

2. Interface Layer Component  The interface layer has various listeners for keyboard
   and mouse events that are triggered by the learner in the virtual world. For exam-
   ple, the learner can synthesize Prothrombin by selecting the Thromboplastin and
   Calcium ions artifacts and clicking on "synthesize" using the mouse. This mouse
   event is captured by the interface layer and a new artifact Prothrombin is created
   in the virtual world.

3. Knowledge Structure Component  The quests, concepts and procedures of blood
   clot formation are defined and stored in the form of knowledge structures. These
   knowledge structures are created and managed as XML files at the server. When
a learner logs into vCLOT, these XML files are read and converted to Java objects via the use of JAXB Java library. Based on the learner’s interactions in the virtual world, vCLOT modifies corresponding objects accordingly. The modified objects are then transformed back to XML files and written back to the system.

The Knowledge Structure Component has the following three XMLs -

1. Concept XML - The function of blood clot involves multiple concepts. A concept is an idea about a class of objects, processes etc. Each artifact in the virtual world corresponds to a concept in the Concept XML. The collection of all relevant concepts along with their associations and relations with each other, are stored in the concept XML.

2. Procedure XML - Blood clotting process is accomplished by a sequence of activities wherein a given activity triggers a subsequent activity. Each individual reaction in the blood clotting process is defined as procedure and the sequence of reactions that combine to form blood clot, are defined in the procedure XML.

3. Quest XML - Quest XML holds the information about the nature of interaction supported by the concepts. Concepts in the form of artifacts, which can be grabbed, are labeled as clickable and concepts that are synthesized from other concepts are labeled synthesizable.

4. Student XML - Information about student activities can be stored in Student XML. Information could include the number of and types of artifacts collected and synthesized by student, number of attempts made in order to complete the quest, time taken to complete the quest and so on.

4.2.4 Contributions

vCLOT was designed as a part of the course on Knowledge structures. It was a team effort with three team members (Anurag, Prajish and Soumya). The objective of this design was to understand the power of knowledge structures and use them in building a learning environment. We wrote a paper based on this project, which was accepted at ICALT 2016 and was presented at the conference by Prajish Prasad. The paper is attached to the end of this report. My contributions for the project and paper was

- Application development - 55%
- Conceptualizing - 65%
- Writing - 65%

4.3 Teacher’s professional development program - Case study in using SEQUEL

4.3.1 Overview

Short term training programs are relevant in Indian context as an effective teacher professional development program as it addresses the ever present problem of paucity of
time among engineering faculty members and the need to keep abreast with latest technological offerings. Most of the training programs studied so far, deal with techniques to incorporate Technology, Content and Pedagogy in classroom teaching. However, they do not adequately represent the techniques required when technology and content are inter-related as seen in circuit simulations for instance.

In a teachers’ professional development program organized at Father Agnel’s poly-technique college and conducted by Prof. M.B.Patil, we explored effect of training with immersivity in Technology, Content and Pedagogy as an effective format for TDP when the technology aspect is closely connected to the content. The training workshop was designed using immersivity in technology, pedagogy and content as well i.e. in all three dimensions suggested by TPACK framework. Constructive alignment between content, technology and pedagogy was ensured following A2I model recommendations. We specifically looked into the integration of SEQUEL - a circuit simulation and analysis tool, in the context of teaching analog electronic circuit design.

4.3.2 SEQUEL tool

SEQUEL is a general-purpose circuit simulation application for electronic and power electronic circuits. It is free for download and is therefore easily accessible. SEQUEL allows learners to construct as well as simulate circuits rapidly and easily and has a very short learning curve. SEQUEL component library includes general purpose components such as resistors, dependent and independent sources, inductors and capacitors, diodes, transistors, and transformers. An additional feature is the model option wherein user can create model of a specific component (typically diodes and transistors). The model thus created can be saved and used in the user’s circuit. An intuitive Graphical User Interface (GUI) facilitates easy schematic entry. The simulation results can be viewed as plots or tables.

SEQUEL provides users with multiple options with respect to the type of simulations that can be performed. Some of them are DC simulation, AC (frequency-domain) simulation, and transient (time-domain) simulation. Digital circuits are handled using the event-driven approach. steady-state waveform (SSW) simulation is another important simulation variation in which the steady-state solution is directly computed instead of waiting for long transients to stabilize before computing the steady-state solution. A repository of a number of circuits are available with the simulator. Learners can refer to these circuits and use the circuit files directly or with suitable modifications.

4.3.3 Workshop format

The short term training program included multiple training sessions spread over 2 8-hour days. There were 11 stable participants and a few additional transient participants during each of the sessions.

The first session dealt with simulation design training wherein the faculty members were trained to develop SEQUEL based simulations for their classrooms. We selected simple RC circuit for the training process. To ensure immersivity, the faculty members were initially trained as students. Subsequently, they designed simulations for their classroom application. We evaluated their simulations to find effect of adding technology immersivity in TPD sessions.
The focus of the second session was conceptual development through content training. In this session we trained participants for content knowledge by using active learning strategies. We designed sessions in which participants were first trained for content as students. During the sessions they were also shown ways in which SEQUEL tool could be integrated in lessons to improve conceptual understanding. Instructor applied active learning strategies such as Peer Instruction (PI), and Flipped classroom to demonstrate use of technology integration in classroom for developing conceptual understanding of students. We evaluated effect of immersivity through the tests conducted during the sessions. In this session, effect of immersivity in content was observed from the change in learning gains of the faculty members.

The objective of the third session was to train faculty members in Pedagogy. Immersivity in pedagogy was ensured by incorporating different instructional strategies throughout the training sessions. Prior to the instruction on pedagogy, the participating teachers prepared a lesson plan detailing SEQUEL based strategies for their selected content. At the end of the pedagogy training session, the teachers re-designed the lesson plan for their classroom integrating SEQUEL and active learning strategies in the plan aligned to learning objectives. We evaluated these lesson plans to explore immersivity in the three dimensions of TPD.

4.3.4 Data collection and analysis

The data collected and analyzed over the different sessions are as tabulated in Table 4.1.

4.3.5 Contributions

The workshop, data obtained from the it and subsequent analysis was written jointly with Madhuri Mavinkurve and Prof. M.B. Patil, as a paper entitled “Exploring effects of immersivity across three dimensions in Training Design: Technology Integration Training Workshop for Engineering Teachers in India”, for ICCE 2016 to be held at IIT Bombay in November. The paper has been accepted in the short paper category. The paper is attached at the end of this report. My contributions for the workshop and paper was

- Workshop participation - 50%
- Data analysis - 40%
- Writing - 40%

4.4 GI - An automatic tutoring system

GI - a TEL environment to teach Hypothetico-deductive reasoning (HDR) skills among students in the field of Genetics, was developed as a part of automatic tutoring system course project. The design of the TEL environment was closely aligned to CTSim - a TEL environment developed to teach computational thinking. Lawson’s table was the primary format used to teach HDR skill. Lawson’s table endeavours to teach HDR skills by detailing a series of reasoning steps that students need to follow to do Hypothetico-deductive reasoning for a given problem. The TEL environment helps students to model a
given problem by defining the 'Agents', their properties and behaviour, sensed and acted upon parameters and environment elements. GI supports self-learning mode and was designed to be an automatic tutoring system.

After initial introductory pages covering concepts of HDR skill and Genetics, the student is provided with a focus question that details the problem for which student has to model a system and use the Lawson’s table approach towards solving the problem. The student has to first come up with a hypothesis and then an experimental design to prove the veracity of the hypothesis. Next the student model the experiment where the student specifies what are the dependent variables, what are the independent variables, what are the agents in the experiment and what are their behaviours that influence the outcome stated in the focus question. Next the student builds the model with suitable values for each of the properties of the agent. Subsequently the student runs the model and then compares the output obtained with that of an expert. The TEL environment also features a tutor agent who provides scaffolding to the students in the course of their interaction in the TEL environment.

The TEL environment was developed in collaboration with 4 other research scholars (Prajish, Kavya, Anurag and Lakshmi). HTML and Javascript was used to develop the GI TEL environment and my contribution in development was building the experimental design page in addition to conceptualizing the entire TEL environment via brainstorming sessions with other team members. My contribution was

- Conceptualization and discussion- 25%
- Application development - 10%

4.5 Stemland

STEMLand is an initiative by Dr.Sanjeev Ranganathan and his team to bring a new approach to basic STEM education. Their pedagogy aims to encourage students to practise higher order thinking skills such as critical thinking, reasoning, visualization and abstraction, when learning a new concept. Their approach towards achieving this goal is by adopting constructivist learning methods such as discovery learning, and learning by doing. STEMLand provides children with freedom to make their own learning goals, choose their own learning path and in the process construct their own knowledge. A team of mentors facilitate the children in their quest for knowledge.

Children thus indulge in self-directed learning for which they use a plethora of tools such as software programming tools, visual programming tools (scratch), geogebra, arduino kits, Alice programming, 3D modeling using blender and 3D printer, a range of simple measuring instruments as well as improvised tools, LEGO MINDSTORMS EV3 for building robots and puzzles and games to name a few. In the course of their learning, they interact with peers, seniors as well as mentors.

The STEMLand program works in collaboration with 2 schools in Auroville. Students spend part of their school time at STEMLand where they work, tinker and play and in the process learn new concepts and demonstrate their mastery over the concepts with artifacts they generated in the process of learning. The artifacts include software programs, 3D models, robots, electronic circuits, experimental setup’s, games and puzzles.

Our interaction with STEMLand began at epiSTEME 2015 where Dr.Sanjeev presented a paper on learning math in STEMLand. We collaborated with him in the quest
to formalize research methods to evaluate effectiveness of this approach to learning. We (Prof.Sahana, Kavya, Lakshmi and Soumya) interacted with Dr.Sanjeev and his team including Bala, Vaidegi and Sundar. Over a teleconference and mails, we began working on three themes under the broader ambit of STEMLand. One of the themes was about evaluating Peer learning and how it affects the learning experience of children and see if it motivates them to move from learning for exams to learning for the joy of it. The second theme was about examining factors that influence female students’ declining interest in Mathematics and come up with suitable interventions using tools such as geogebra and jodo gyan to shift the attitude to a more positive one. The third theme was to develop leadership skills among children. We began by urging the team at STEMLand to use the idea proposal template (IPT) to outline the ideas which they would like to work on. We guided them in this by first giving them a sample IPT and subsequently providing a detailed feedback on the three IPT’s that they submitted. Subsequently, we prepared a detailed outline for a prospective T4E paper to motivate them to pursue the research. The project is presently at the stage where the STEMLand team is working on our suggestions.

My contribution was

- Participation in discussion- 25%
- Evaluation and feedback - 50%
Table 4.1: Data collection and analysis

<table>
<thead>
<tr>
<th>Session/Activity</th>
<th>Data source</th>
<th>Observation</th>
<th>Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology training session</td>
<td>Circuit simulation and analysis files</td>
<td>Scores based on rubrics</td>
<td>All participants were successful in selection and assignment of components. Many faced difficulty in deciding specific parameter and final analysis settings.</td>
</tr>
<tr>
<td>Conceptual understanding session</td>
<td>Pre and post poll answers</td>
<td>Change in conceptual understanding using SAT diagram</td>
<td>For 2 questions, all converged to right answer while for other 3 questions most of the participants converged to correct answer</td>
</tr>
<tr>
<td>Flipped classroom session</td>
<td>Pre and post test scores</td>
<td>Learning gain</td>
<td>The difference between pre and post test scores is significant (gain=2.5, t=9.25, p&lt;0.01)</td>
</tr>
<tr>
<td>Pedagogy training session</td>
<td>Pre and post lesson plans</td>
<td>Transition from being teacher centric to student centric</td>
<td>10 out of 11 participants changed from teacher centric to student centric lesson plan.</td>
</tr>
</tbody>
</table>
Bibliography


