Development of Guidelines for Teaching and Learning with Virtual Laboratories in Engineering Education

Submitted in partial fulfillment of the requirements

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by

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Dedicated to

Sunil, Priya, Baba, Aai, Dada.

Declaration

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Approval Sheet

This thesis entitled "**Development of Guidelines for Teaching and Learning with Virtual Labs in Engineering Education**" by Anita Diwakar is approved for the degree of Doctor of Philosophy.

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Abstract

Engineering happens in laboratories hence the experiments students perform in the instructional laboratories should be carefully designed so that they become able experimenters, gain the desired knowledge and develop the necessary skills and attitudes. The experiment designs play an important role in the achievement of the laboratory learning outcomes. The tasks the students can perform in the virtual laboratories can lead to achievement of learning objectives at higher cognitive levels and certain skills and cognitive abilities such as manipulative, investigative, problem solving. This is possible due to the advanced features of the virtual laboratories. The engineering instructors should design student centered effective experiments based on scientifically proven instructional strategies and assign tasks exploiting these advanced features of the virtual laboratories. The instructors perceive that they will be able to design effective virtual laboratory experiments if comprehensive and specific guidelines are available. This problem led to the main objective of the research that is design and development of guidelines for virtual laboratory experiment design. The objective was achieved by following the three step process of **Need and Problem Analysis, Solution Design by S-D-I-V-E Methodology and Evaluation.**

The survey studies carried out with engineering instructors gave an insight into the aspects of the experiment design process for which the instructors need guidelines. These are: Selection of Broad Goal, Formulation of learning objectives, Designing experiments at different difficulty levels for the Expository Instructional Strategy, incorporating active learning methods within the Expository Instructional Strategy, designing experiments with Discovery, Well-Structured Problem Solving and Problem-Based Instructional Strategies, designing authentic assessment, using features of virtual laboratories to achieve the target learning objectives. The quality of each guideline was assessed based on eight criteria. The **S-D-I-V-E Methodology** was used for arriving at the solution.

The summative evaluation of the solution was carried out for the metrics of: Usability as perceived by engineering instructors, Usefulness as perceived by engineering instructors, Effectiveness with respect to the quality of experiment designs and Effectiveness with respect to impact on students' laboratory learning outcomes. The results of the studies indicate that the engineering instructors perceive that the virtual laboratory experiment design guidelines as usable and useful. There is an improvement in the quality of the experiment designs after using the guidelines. There is also an improvement in the laboratory learning outcomes of UG engineering students.

After introduction in the Chapter 1 the literature review is discussed in the second chapter. In Chapter 3 the methodology adopted for the work that is the (S-D-I-V-E) Scoping-Development-Internal Review-Validation-External Use is presented and the various questions this thesis addresses are stated. Chapter 4 deliberates the various studies as part of the need and problem analysis. In Chapter 5 the details of the design

and development of the solution design are provided. Chapter 6 presents the summative evaluation of the solution design carried out by means of five studies. Chapter 7 concludes the various sections and provides discussion regarding the generalizability of the work and various limitations. In Chapter 8 the contributions of the thesis are listed down and final reflection is discussed. The various Appendices added at the end of the thesis give details of the online SDVIcE tool, the instruments used for the studies, the rubric used to assess the quality of the experiment designs, bank of tasks and assessment questions for the BAE course, sample experiment designs and sample answer worksheets submitted by students.

Keywords: Virtual laboratory, Experiment design guidelines, Instructional Strategies, active learning, laboratory assessment.

The figures on the next two pages give an overview of the thesis.

Broad Problem

Literature review and self experience

1. Some laboratory learning objectives not achieved
2. Virtual laboratories have features that can improve laboratory learning outcomes
3. Instructors should design effective experiments to achieve the laboratory objectives
4. Existing models, frameworks and tools have limitations in our research context

Proposed Solution

Guidelines for designing effective virtual laboratory experiments

Need and Problem Analysis

Study 1

Artefact analysis
98 experiment designs used in traditional labs

Study 2

Survey with 430 engineering instructors to find out their perceptions regarding virtual labs

Study 3

Semi-structured interviews with engineering instructors to find out their perceptions about the problems in virtual laboratory experiment designs

Study 4

Survey with 95 engineering instructors to find out the phases in the experiment design for which they need guidelines

RQ1a: What are the problems in the experiment designs used in the traditional laboratories?

Results of the study

1. Broad Goal of the experiment - in 90% experiment designs - "To study"
2. Instructional strategy - 83% Cookbook nature
3. Learning Objectives - 76% lower cognitive levels
4. Laboratory task designs - 95% Tasks in objects domain
5. Laboratory Assessment - 90% questions based on theory
6. Difficulty level of the experiments - 90% experiments at lower difficulty levels
7. Incorporation of active learning methods and constructivist approach - None of the experiments incorporated this approach

Conclusions

1. Need of improvement in the quality of experiment designs
2. Virtual laboratories have features that can improve the laboratory learning outcomes if engineering instructors design effective experiments

The results and conclusions lead to the next study that explores the perceptions of engineering instructors regarding the usefulness and effectiveness of virtual labs

RQ1b: What are the perceptions of engineering instructors about the usefulness and effectiveness of virtual laboratories as compared to the traditional laboratories?

Results of the study

1. 100% instructors face problems while conducting experiments in physical labs
2. 60% instructors aware of virtual laboratories
3. 5% using virtual labs in their teaching
4. 93% perceive virtual labs to be more useful
5. 93% perceive virtual labs to be more effective
6. 100% would use virtual labs in future

Conclusions

1. Instructors perceive the virtual labs to be useful and effective
2. Very few actually using them

The results and conclusions lead to the next study in which we find out reason as to why very few engineering instructors are using virtual labs and the problems faced by them while using virtual labs

RQ1c: How can the problems faced by engineering instructors in using virtual laboratories in their teaching be solved?

Results of the study

Engineering instructors perceive that the problems they face while using virtual labs can be resolved if comprehensive guidelines are available for the following
1. Alignement of broad goals and learning objectives
2. Formulating learning objectives
3. Designing virtual laboratory tasks
4. Designing virtual laboratory assessment

Conclusions

Guidelines need to be developed for the following steps in the experiment design
1. Broad goals
2. Learning objectives
3. Tasks
4. Assessment

The results and conclusions of this study lead us to the next confirmatory study in which we confirm the results of this study and find out if the engineering instructors perceive the need of guidelines for some more steps in the experiment design

RQ1d: What are the various phases in the experiment design process using virtual laboratories for which engineering instructors need guidelines?

Results of the study

Engineering instructors perceive that the problems they face while using virtual labs can be resolved if comprehensive guidelines are available for the following
1. Alignement of broad goals and learning objectives
2. Formulating learning objectives
3. Designing virtual laboratory tasks
4. Designing virtual laboratory assessment

Conclusions

Engineering instructors perceive that they need comprehensive guidelines for the following
1. Decision on laboratory goals
2. Formulation of laboratory learning objectives at higher cognitive levels
3. Decision regarding the most suitable instructional strategy
4. Designing experiments at various difficulty levels
5. Incorporating active learning methods in the experiment designs
6. Designing tasks aligned to the learning objectives for Discovery, Structured Problem Solving and Problem-based instructional strategies.
7. Designing assessment aligned to the learning objectives
8. Using the affordances of virtual labs to achieve the various learning objectives.

The results and conclusions of this study helped us in identifying additional aspects in the experiment designs for which **engineering instructors need guidelines and also confirmed the aspects identified in the previous studies**

The results and conclusions of the four studies lead us to the next phase of our research that is the Design and Development of virtual laboratory experiment designs. The outcome of these four studies are the nine design questions. Each design question is based on one aspect of the experiment design.

Design and Development Phase

Methodology used for development of the nine sets of guidelines
S-D-I-V-E Scoping- Development - Internal Review - Validation - External Use

Criteria for quality of guidelines

Criterion 1 - Features
Criterion 2 – Structure
Criterion 3 – Overall scope and purpose
Criterion 4 – Stakeholder involvement
Criterion 5 – Rigor of development
Criterion 6 – Clarity of presentation
Criterion 7 – Applicability

Primary Design Question
DQ1: What guidelines will help engineering instructors in achieving their laboratory goals by making effective use of virtual laboratories for the course Basic and Advanced Electronics?

Design Sub Questions

DQ1a: How to select the broad goal depending on the type of topic content to be covered by the virtual laboratory experiment?

Guidelines Set I – Selecting the Broad Goal of the virtual laboratory experiment

Select you Broad Goal

1. Select the topic from your course for which you wish to design virtual laboratory experiment
2. Identify the knowledge components such as concepts, principles, and procedures of the topic.
3. Make a decision regarding which of the concepts, principles and procedures you wish to convert to a virtual laboratory experiment.
4. Identify the skills you wish to develop.
5. Identify the cognitive ability you wish to develop.
6. Select the ones you wish to target through the experiment.

DQ1b: How to formulate valid and clearly defined learning objectives at different cognitive levels as per Revised Blooms' Taxonomy for virtual laboratory experiment/s aligned to the broad goal of the experiment?

Guidelines Set II – Formulating the learning objectives of the virtual laboratory experiment

Formulate your learning objectives by following the steps:

1. Start the learning objective with the phrase "Student will be able to"
2. Make a decision regarding the cognitive level you wish to achieve through the experiment as per the Revised Bloom's taxonomy
3. The cognitive level of Remember is not normally chosen for a laboratory experiment. Try to formulate learning objectives at higher cognitive levels, as the virtual laboratory is more suitable for these objectives.
4. Choose action verbs appropriate to the chosen cognitive level by referring to the Tables LOa, LOb and LOc.
5. Check whether the learning objective is aligned to the broad goal of the experiment by referring to the Tables LOa, LOb, and LOc.
6. Check whether the learning objective can be achieved in the BAE virtual lab by referring to the Tables LOd.
7. There can be multiple learning objectives for one broad goal

DQ1c: How to design virtual laboratory experiment at different difficulty levels with Expository instructional strategy?

Guidelines Set III - Designing experiments at various difficulty levels for the Expository Instructional Strategy
Template for experiment design at different difficulty levels.

DQ1d: How to incorporate active learning methods in the virtual laboratory experiment design?

Guidelines Set IV - Incorporating active learning methods in the experiment design with Expository Instructional Strategy
Templates for designing experiment with expository instructional strategy and learning objectives at appy, analyze, evaluate and create level.

DQ1e: How to design an effective virtual laboratory experiment with Discovery or Guided Inquiry instructional strategy?

Guidelines Set V - Designing virtual lab experiment with Discovery instructional strategy
Template for experiment design with discovery instructional strategy.

DQ1f: How to design an effective virtual laboratory experiment with Well-Structured Problem Solving instructional strategy?

Guidelines Set VI - Designing virtual laboratory experiment with Well-Structured problem solving instructional strategy
Template for experiment design with well-structured problem solving strategy.

DQ1g: How to design an effective virtual laboratory experiment with Problem-Based instructional strategy?

Guidelines Set VII - Designing virtual laboratory experiment with problem-based instructional strategy
Template for experiment design with problem-based instructional strategy.

DQ1h: How to design authentic assessment for virtual laboratory experiment?

Guidelines Set VIII – Designing authentic assessment for virtual laboratory experiment
Framework for authentic virtual laboratory assessment and examples of assessment questions for each metric of assessment.

DQ1i: How to select virtual laboratory with features aligned to the learning objectives of the experiment?

Summative Evaluation Phase

Primary Research Question: RQ2: Are the guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics usable, useful to engineering instructors and effective in improving the quality of experiment designs and students' laboratory learning outcomes?

Study 5: Usability

RQ2a: What are the perceptions of engineering instructors regarding the usability of the virtual laboratory experiment design guidelines?

Results of the study

SUS Survey score of feedback from 58 engineering instructors obtained was 75.3.
This score is above the average score of 68.

Conclusions

The experiment design guidelines for virtual laboratories are usable.

Study 6: Usefulness

RQ2a: What are the perceptions of engineering instructors regarding the usefulness of the virtual laboratory experiment design guidelines?

Results of the study
Survey feedback from 58 engineering instructors

1. 85 percent of the engineering instructors find the experiment design guidelines useful for the selection, formulation and design of the various aspects of the experiment design.
2. 90 percent of the participants agreed that the guidelines for the aspects – decision regarding the steps in the design and broad goals, formulation of learning objectives and assessment questions are useful.
3. 80 percent of the participants agreed that the guidelines for the aspects – selection of Instructional Strategy, designing tasks as per the Instructional Strategy and aligned to the learning objectives, incorporating active learning strategies and selecting the virtual laboratory are useful.
4. For the two aspects of designing experiments at various difficulty levels and formulating questions at higher cognitive levels average agreement was 71 percent.

Conclusions

1. The engineering instructors perceive that the experiment design guidelines are useful in their design process.
2. They find a few sections very useful and some sections difficult to understand.
3. There is a consensus between the participants in the usability study and usefulness study regarding most of the aspects of the experiment design guidelines.

Study 7, Effectiveness

RQ2c: What is the effectiveness of the experiment design guidelines in improving the quality of experiment designs for using existing virtual labs?

Results of the study
Field-testing with 10 engineering instructors

1. The quality of 4 experiment designs (10%) remained at low level
2. The quality of 12 experiment designs (30%) improved from low level to medium level
3. The quality of 12 experiment designs (30%) improved from low level to high level
4. The quality of 8 experiment designs (20%) improved from medium level to high level
5. There was no change in the quality of 4 (10%) experiment designs. They remained at high level.
6. There was no negative effect of using the guidelines

Conclusions

The experiment design guidelines are effective in improving the quality of the experiment designs.

Study 8,9,10: Effectiveness

RQ2d: What is the impact of experiments designed using the experiment design guidelines for virtual laboratories on the students' laboratory learning outcomes?

Results of the study
Quasi-experimental studies with 39, 142, 150 UG and 18 PG engineering students

1. Reaction - what participants thought and felt about the training
2. Learning - the resulting increase in knowledge and/or skills, and change in attitudes.

On both these dimensions the virtual laboratory experiment designed as per the guidelines receive a higher score than the experiment design with traditional methods.

Conclusions

If the guidelines are properly implemented and the experiments are designed using the virtual laboratory experiment design guidelines developed with scientific methodology the students' laboratory learning outcomes can be improved. Thus the experiments designed using the Experiment design guidelines have a positive influence on the students' laboratory learning outcomes.

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Abbreviations and Nomenclature

S-D-I-V-E	Scoping-Development-Internal Review-Validation-External Use
BAE	Basic and Advanced Electronics
LoTaAs	Learning Objectives Tasks and Assessment
SDVIcE	Scientific Design of Virtual laboratory Experiments
LQ	Literature Question
RQ	Research Question
DQ	Design Question
VL	Virtual laboratory
VLE	Virtual Learning Environment
IMS	Integrated Management System
LAMS	Learning Activity Management System
SLDF	Smart Learning Design Framework
ADDIE	Analysis, Design, Development, Implementation and Evaluation
SLID	Science Laboratory Instructional Design
NRC	National Research Council
NACOL	North American Council for Online Learning
GREET	**G**uideline for **R**eporting of **E**vidence based practice **E**ducational interventions and **T**eaching
NICE	National Institute for Health and Care Excellence
ESHRE	European Society of Human Reproduction and Embryology
SME	Subject Matter Expert
ETR	Educational Technology Researcher
ETE	Educational Technology Expert

SUS	System Usability Scale
VLEDG	Virtual laboratory Experiment Design Guidelines
ABET	Accreditation Board for Engineering and Technology, Inc.
UG	Undergraduate
TCA	Thematic Content Analysis
RBT	Revised Blooms Taxonomy
LG	Learning Goal

Chapter 1

Introduction

1.1 Background and Motivation

Laboratory work is an integral part of science and engineering education. The laboratory is the place where various theories are tested and relation between theoretical knowledge and physical materials is established. These labs have played a major role in the development of technologies, materials and information, which have made our lives easier.

The laboratories can be classified into three types namely Development, Research and Instructional. The development lab is a place where the engineers design, develop and test a new product. The research lab is used to obtain broader knowledge about the world. The third type of lab is the Instructional or Educational lab where the science and engineering students perform experiments to learn (Feisel, Ph, & Peterson, 2005). The three types of laboratories have many characteristics in common and some fundamental differences. These differences must be understood if there is to be agreement on the educational objectives that the instructional laboratory is expected to meet.

Practicing engineers go to the development laboratory for two reasons. First, they often need experimental data to guide them in designing and developing a product. The development laboratory is used to answer specific questions about nature that must be answered before a design and development process can be initiated. The second reason is to determine if a design performs as intended. Measurements of performance are compared to specifications, and these comparisons either demonstrate compliance or indicate where, if not how, changes need to be made.

While a development laboratory is intended to answer specific questions of immediate importance, research laboratories are used to seek broader knowledge that can be generalized and systematized. The output of a research laboratory is generally an addition to the overall knowledge that we have of the world, be it natural or human made.

When students, especially undergraduates, go to the laboratory, however, it is not generally to extract some data necessary for a design; neither it is to evaluate a new device nor to discover a new addition to our knowledge of the world. Each of these functions involves determining something that no one else knows or at least that is not generally available. Students, on the other hand, go to an instructional laboratory to learn something that practicing engineers are assumed to already know. That "something" needs to be better defined through carefully designed learning objectives if the considerable effort devoted to laboratories is to produce an associated benefit.

In engineering education, and engineering technology in particular, laboratory courses play a central role; Labs help students learn challenging concepts and develop practical skills. Labs are often one of the college learning experiences that students enjoy the most (Feisel et al., 2005). The laboratory is where elegant scientific theories meet messy everyday reality; so the laboratory experiences are at the core of undergraduate education in science and engineering. The laboratory experiences in science education will have to change as technology and economic trends transform educational institutions and curricula (Corter, Esche, Chassapis, Ma, & Nickerson, 2011).

The nature and practices of laboratories have been changed by two new technology-intensive automations: simulated labs (McAteer et al. 1996) and remote labs (Aburdene et al. 1991; Albu et al. 2004; Arpaia et al. 1998; Canfora et al. 2004) as alternatives for conventional hands-on labs. Advances in ICT during the last three decades have resulted in the emergence of two new modes of laboratory: Virtual (Simulated) labs which are approximated simulations of a process of a physical experimental rig and Online (Remote) labs which are platforms that allow remote access to the physical experimental rig through the Internet or intranet. The two new forms of laboratory can be perceived as educational enablers (Ertugrul 1998; Hartson et al. 1996; Raineri 2001; Striegel 2001) or as inhibitors (Dewhurst et al. 2000; Dibiase 2000).

These two new technology-mediated forms of laboratory experience are becoming more and more widespread in educational institutions. Remotely operated educational labs ("remote labs") offer students the ability to collect data from a real physical laboratory setup from remote locations (e.g., a dorm room, or even another city) via web-based computer technology. Computer-based simulations of educational experiments offer another means of gathering data to illustrate course concepts and principles, but using data generated by a simulation model. Both of these technological innovations have their unique benefits, including lower operational costs and convenience. However, they also have their unique limitations, including questions about educational effectiveness and student motivation (Corter et al., 2011).

The use of simulated or virtual labs and remote labs are often justified with economic reasons: using these new forms of labs frees up space in universities; also within a course the new lab formats reduce lab set-up and tear-down time (Magin & Reizes, 1990; Scanlon, Colwell, Cooper, & Paolo, 2004). The economic arguments may overshadow the more important question of just how effective the new lab formats are. In addition, the creation of labs implemented using these alternate technologies is often accomplished by engineers and programmers who seek to build something novel, interesting and useful. The educational effectiveness of the labs may be taken for granted, or assessed only through student course evaluations (Corter et al., 2011).

Despite the fact that hands-on laboratories are still central, combining the other modes with the hands-on lab in one model and applying them in a complementary way could result in better learning outcomes (Abdulwahed & Nagy, 2011).

The Engineering laboratory instruction has reached a crisis level due to inadequate instructional resources and the desirable learning outcomes are not being achieved. There is a lack of challenge and initiative provided to the students in performing experiments. The experiment designs should provide realistic and challenging goals so that the students can become able experimenters. There is a need of improving the quality of experiment designs. The traditional laboratories have limitations due to which the instructors may have difficulties in implementing the modified learning designs. The Virtual labs create an immersive, highly interactive virtual environment tailored to the needs of learners. Virtual experiments provide educationally valuable features not available in physical experiments. These features allow implementation of the modified experiment designs and achievement of the desirable learning objectives.

Instructors play a critical role in designing effective laboratory experiences. Improving instructors' capacity to design effective laboratory experiments is critical to advancing the educational goals of these experiences. This can be achieved by developing more comprehensive systems of support for Instructors. The Instructors can achieve their laboratory goals if they design

- Student centered effective experiments
- Based on scientifically proven instructional strategies

- Exploiting the features of virtual labs

Any learning design whether classroom or laboratory specifies the teaching and learning process, along with the conditions under which it occurs and the activities performed by the teachers and learners in order to achieve the required learning objectives. (R. Felder and R.Brent, 2004) point out that most of the engineering instructors wish to achieve higher level learning objectives but their learning designs are targeted at lower level objectives. The instructors find the learning design for effective virtual laboratory experiments difficult due to a number of factors such as lack of suitable training and non-availability of appropriate guidelines. There are a few frameworks, guidelines and tools to facilitate this process but they have certain limitations such as:

- Frameworks and models are for learning designs for either classroom learning material or traditional science laboratories.
- They specify the components of the laboratory experiment instructional design but not for the virtual labs and also not specifically for the engineering context.
- The guidelines are broad and not specific so instructors may not find these very useful in implementation of their day-to-day laboratory teaching.
- The available tool is complex to use and is for K-12 education and not mainly for engineering education.
- The basic assumption made for the usage of the available tool is that the instructors are trained in the various instructional strategies.
- The instructors need to spend lot of time in order to understand the various components in the tool.

These limitations imply the need of guidelines that are usable and useful to the engineering instructors. Using the guidelines the instructors can design effective experiments to be given to the students with minimum time and resource demands. They should highlight how the affordances of the virtual laboratories may be utilized so as to achieve learning objectives otherwise difficult to achieve in traditional laboratories. Hence the aim of this research is to design and develop comprehensive guidelines for engineering instructors so as to facilitate the process of effective learning designs for virtual laboratory experiments.

1.2 Research Objective

The main objective of this research is: **Development of guidelines to help engineering instructors in designing effective experiments and achieve their laboratory goals by using virtual laboratories.**

The guidelines have been developed for engineering instructors so as to facilitate the design of effective experiments for using virtual laboratories and converted to the online version in the form of the SDVIcE tool (Scientific Design of Virtual Laboratory Experiments) to increase accessibility.

The main reason for choosing the research objective as the development of guidelines and the tool was the outcome of need analysis carried out through three studies with the engineering instructors. The literature also suggested that the development of support systems to help instructors in their learning designs will lead to better laboratory learning outcomes and enable development of engineering students as able experimenters. Thus the broad research question of the thesis was derived as follows.

Broad Research Question

RQ: What guidelines will help engineering instructors in achieving their laboratory goals by making effective use of virtual laboratories for the course Basic and Advanced Electronics?

In order to answer the broad research question a series of research and design activities were carried out and answers to various research, design and literature questions were found out. Various studies were carried out in order to answer the research questions. The following questions were identified and the solutions arrived at by different mixed methods.

Specific Research Questions

RQ1: What are the perceptions of engineering instructors regarding the guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics?

RQ2: Are the guidelines developed using S-D-I-V-E methodology for making effective use of virtual laboratories usable and useful to engineering instructors and effective in improving the quality of experiment designs and students' laboratory learning outcomes?

Specific Design Questions

DQ1: What guidelines will help engineering instructors in achieving their laboratory goals by making effective use of virtual laboratories for the course Basic and Advanced Electronics?

Specific Literature Questions

LQ1: What is the problem context?

LQ2: What is the existing work related to the problem context and what is the gap?

LQ3: What should be the nature of guidelines for the problem context?

1.3 Research Methodology

The main objective of this research is to design and develop comprehensive guidelines for engineering instructors to enable them to use virtual labs effectively by designing quality experiments. The design, development and evaluation of these guidelines followed a three-step process. The steps of the process are as shown in the Figure 1.1.

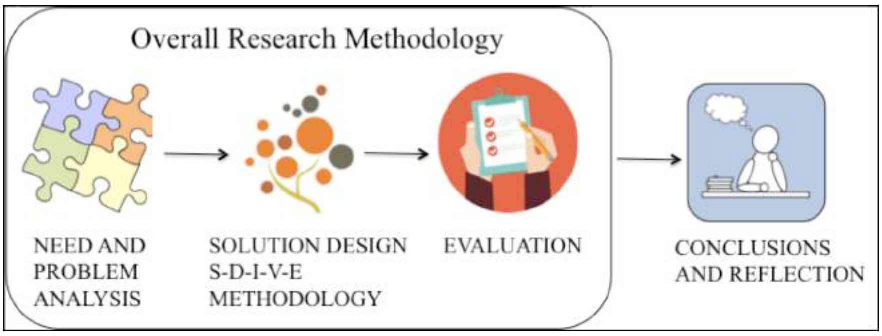


Figure 1.1 Overall Research Methodology

Phase I - Need and Problem Analysis

This was the first phase in the research process, which helped in identifying the various aspects in the virtual laboratory experiment design for which the engineering instructors perceive the necessity of guidelines. The decision regarding the nine aspects was taken based on the results of the four studies carried out in this phase. The first study was artefact analysis of 98 experiment designs used in traditional labs, the second was survey with 430 engineering instructors, the third was semi-structured interviews of 13 engineering instructors and the fourth also a survey with 95 engineering instructors.

Phase II – Solution Design by S-D-I-V-E Methodology

In the second phase of the research the experiment design guidelines for the nine aspects of the design process were designed and developed. The methodology adopted to arrive at the guidelines was (S-D-I-V-E) Scoping-Development-Internal Review-Validation-External Use These nine aspects are - decision regarding the broad goals of the experiment, formulate learning objectives at higher cognitive levels, incorporating the various instructional strategies in their experiment designs, incorporate the active learning methods, design tasks aligned to the selected instructional strategies, design authentic assessment in the virtual laboratory and use of virtual laboratory features necessary to achieve the desired learning outcomes.

Phase III – Evaluation

The evaluation of the developed experiment design guidelines was the third phase in the research. The evaluation was carried with the help of four studies. The first study gathered the perceptions of the engineering instructors about the usability of the experiment design guidelines. In the second study the perceptions of the engineering instructors regarding the usefulness of the experiment design guidelines were measured. The third study, which was field-testing with ten engineering instructors, measured the effectiveness of the guidelines by assessing the quality of the experiment designs by means of a rubric. All the instructors designed four experiments each before and after using the guidelines. The last three studies were to measure the effectiveness by means of the impact of the experiment design guidelines on the laboratory learning outcomes of the UG engineering students. This was done by means of three quasi-experimental studies with samples of 39, 142 and 150 respectively. The first two studies were for the course Basic and Advanced Electronics and the third for the course Mobile Communications. The ETR (Educational Technology Researcher) carried out the first study and SMEs (Subject Matter Expert) carried out the later two studies.

Conclusions and Reflections

The development and evaluation of the guidelines led to the conclusions of the three phases and later the paper based experiment design guidelines were converted to online format in the form of the SDVIcE tool. The reflection on the entire research process was carried out to identify the limitations and how this work can be carried forward in the future.

1.4 Solution

1.4.1 Experiment Design Guidelines Based on LoTaAs Framework

The final solution of the research consists of the Experiment Design Guidelines for the nine aspects of the design process. These guidelines are based on the LoTaAs framework. This framework was synthesized from the science laboratory instructional design (SLID) model proposed by (Nuri Balta, 2015).

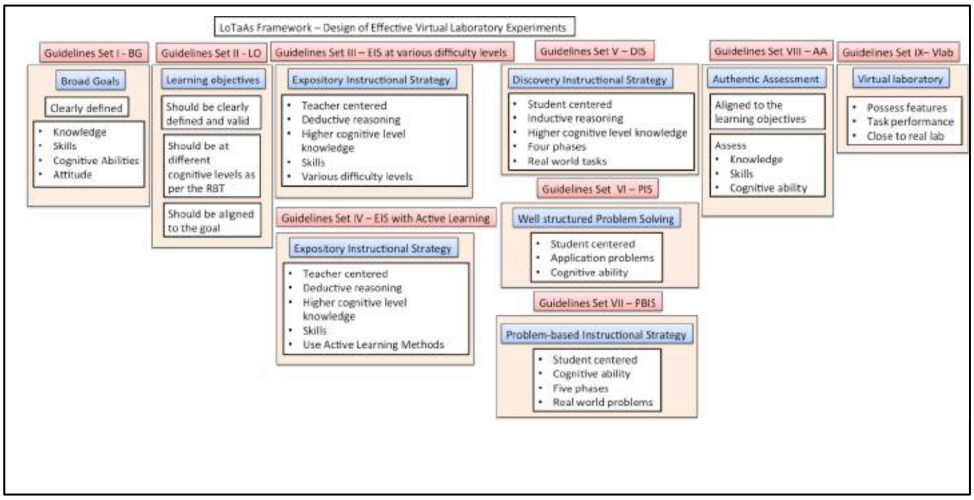


Figure 1.2 LoTaAs Framework

1.4.2 Online SDVIcE Tool

In order to make these guidelines accessible and attractive they were converted to an online format as the SDVIcE tool. The tool provides a step-by-step process by which the engineering instructors can design experiments for using virtual laboratories. The tool has an inbuilt bank for all the aspects of experiment design as well as templates for the four instructional strategies of Expository, Guided Inquiry (Discovery), Structured Problem Solving and Problem-based.

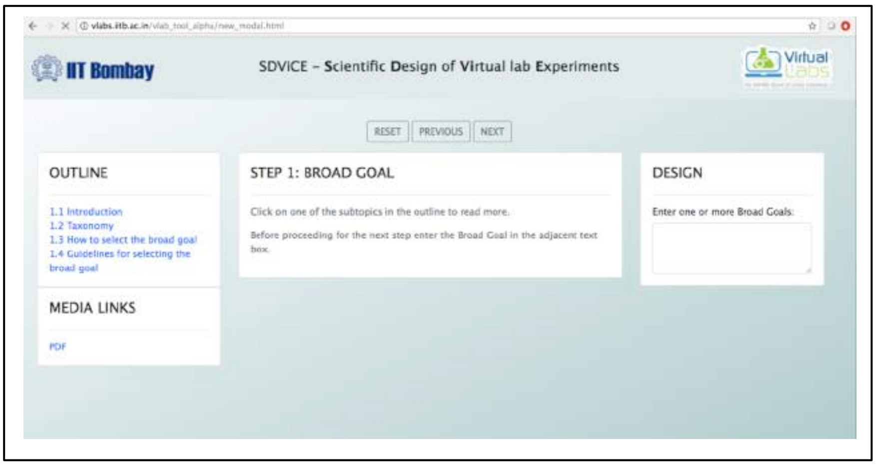


Figure 1.3 Screen shot of Online SDVIcE tool

1.5 Scope of Thesis

The virtual laboratories and their effective use in engineering education is a very broad area. So the work was scoped based on the constraints across which work could be done. This section gives a clear understanding of the scope of this research related to the virtual labs used for various studies, curriculum considered for designing the guidelines and data bank of tasks and demographics across which the curriculum is common.

Scope of Virtual Laboratories

The virtual labs considered for this research are the Basic Electronics, Advanced Electronics and Digital Electronics labs. The virtual labs used are the labs based on the curriculum of these courses developed under the NME ICT project of MHRD India and other external sources. These are simulation labs and have various features useful for conduction of a variety of tasks suitable for target learning objectives. There are 200 labs with 1500 experiments spread across multiple disciplines with 24/7 availability to the students over the Internet. The following are the labs used for the various studies.

1. Basic and Advanced Electronics Virtual lab – BE vlab. This lab is available at the URL - http://vlabs.iitkgp.ernet.in/be/
2. DoCircuits Virtual Laboratory – DoC vlab. This lab is available at the URL – www.docircuits.com
3. Circuit lab available at URL -https://www.circuitlab.com/editor/
4. Electronics Simulator available at URL - http://www.partsim.com/simulator
5. Mobile Communication Virtual laboratory available at the URL - http://vlabs.iitkgp.ernet.in/fcmc/index.html#

Scope of Curriculum

The curriculum considered while designing the guidelines is the curriculum of engineering UG under Mumbai University in India. The content of the curriculum for which the experiments were performed consisted of topics in Basic and Advanced Electronics (BAE) and Digital Electronics (DE). The topics for which the data bank of the tasks and assessment questions are designed and developed are as follows

1. P-N Junction Diode
2. Zener Diode
3. Bipolar Junction Transistor
4. Field Effect Transistor
5. Logic Gates
6. Implementation of Arithmetic circuits using logic gates

The topics for which the various examples from the course BAE are designed are as follows

1. V-I Characteristics of P-N Junction diode
2. Diode Clipper
3. Diode Clamper
4. BJT Characteristics
5. BJT Biasing
6. BJT Single Stage Amplifier
7. Voltage Regulator using Zener Diode
8. Oscillator using BJT and FET
9. Logic Gates
10. Implementation of Arithmetic circuits using logic gates

Scope of Tasks

The tasks designed for the development of guidelines are limited to the content given in the previous section and which can be performed by students while working with the selected Virtual labs.

Scope of Participants in the Study

There are three categories of participants in the various studies who belong to the virtual lab community as part of the Virtual lab project.

Engineering instructors: The various users in the five year study are the engineering instructors from the institutes which are Nodal centers of the Virtual labs project. A few participants are from engineering colleges affiliated to Mumbai University but not nodal centers.

As part of this research workshops were conducted for engineering instructors at various stages of the educational design process. The first set of workshops was conducted in order to gauge the readiness of the engineering instructors and their perceptions regarding the usefulness and effectiveness of the virtual laboratories. The second set was conducted to get feedback on the usability and usefulness of the experiment design guidelines and design of effective virtual laboratory experiments using the guidelines. The following table gives the details of the participants at each stage of the research.

UG Engineering students: The virtual laboratory experiment designs were administered to the UG engineering students undertaking the Basic and Advanced Electronics course. The impact of the experiment designs on the students' learning outcomes was measured.

Table 1.1: Engineering Instructor Participants in the research work

<table>
<tr><td colspan="3">Stage 1 – Need and Problem Analysis -- Perceptions of engineering instructors and problems faced by them</td></tr>
<tr><td>Region</td><td>Institutes</td><td>Number of Participants (Engineering instructors)</td></tr>
<tr><td>Mumbai</td><td>8</td><td>297</td></tr>
<tr><td>Nagpur</td><td>12</td><td>110</td></tr>
<tr><td>Aurangabad</td><td>6</td><td>45</td></tr>
<tr><td>Total</td><td>25</td><td>452</td></tr>
<tr><td colspan="3">Stage 2 – Design and Development of Experiment Design Guidelines (S-D-I-V-E)</td></tr>
<tr><td>Region</td><td>Institutes</td><td>Number of Participants (SME+ETR)</td></tr>
<tr><td>Mumbai</td><td>3</td><td>6+1</td></tr>
<tr><td>Pune</td><td>1</td><td>2</td></tr>
<tr><td>Total</td><td>4</td><td>8+1</td></tr>
<tr><td colspan="3">Stage 3 – Evaluation of Experiment Design Guidelines (Usability, Usefulness and Effectiveness)</td></tr>
<tr><td>Region</td><td>Institutes</td><td>Number of Participants (Engineering instructors)</td></tr>
<tr><td>Pune</td><td>1</td><td>28</td></tr>
<tr><td>Baroda</td><td>7</td><td>15</td></tr>
<tr><td>Nagpur</td><td>3</td><td>20</td></tr>
<tr><td>Mumbai</td><td>6</td><td>86</td></tr>
</table>

Total	17	149
Stage 3 – Evaluation of Experiment Design Guidelines (Impact on students' learning)		
Region	**Institutes/Experiments**	**Number of Participants (UG Engineering students)**
Mumbai	2 (3)	(39+142+150) UG and 18 PG

Domain Experts: The experts are engineering instructors, research scholars and industry experts from electrical and electronics engineering domains. The following table gives the details of the domain experts at various stages of the evaluation and validation of the instruments used at each of these stages.

Table 1.2: Domain Experts in the research work

Stage of Research Design and Development of EDG	Number of SME and ETR
Cooperative evaluation of guidelines for Broad goals and learning objectives	2 + 1
Cooperative evaluation of guidelines for selection of Instructional Strategy	2 + 1
Cooperative evaluation of guidelines for task designs aligned to the Instructional Strategy	2 + 1
Cooperative evaluation of guidelines for assessment questions	3 + 1
Stage of Research Validation of instruments	Number of SME and ETR

Survey instrument 1 - Perceptions	1+1
Survey instrument 2 - Problems	1+1
Survey instrument 3 – Experiment Design Aspects	1+1
Rubric for quality of virtual lab experiment	2+1
Pre-test question paper	4+1
Post-test question paper	4+1
Learning outcome test papers	4+1

Scope of Assessment Methods

The assessment methods used is online evaluation of the tasks performed by students while working with virtual labs.

1.6 Research Studies Done in this Thesis

The nine studies were carried out as part of this research of which four were part of Need and Problem analysis and later five of Summative Evaluation of the experiment design guidelines. The Need and Problem Analysis phase answered the broad research question "What are the perceptions of engineering instructors regarding the guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics? Of the four studies, three are survey studies with engineering instructors and the fourth study is an artifact analysis. These studies established the need of the work and helped in the formation of the research objectives and arriving at the design questions.

Studies in Phase I – Need and Problem Analysis

Study 1: Analysis of the Existing Traditional Laboratory Experiment Designs for the Course Basic and Advanced Electronics Under Mumbai University (Experiment Designs Used in Traditional Laboratories)

This study was an Artefact analysis carried out to find out the problems in the experiment designs being used in the traditional laboratories and to identify the aspects of the experiment design, which need to be addressed in order to improve the quality of the designs. The target question for this study was RQ1a: What are the problems in the experiment designs used in the traditional laboratories?

Study 2: Engineering Instructors' Perceptions About Virtual Laboratories

This survey study answered the specific research question

RQ1b: What are the perceptions of engineering instructors about the usefulness and effectiveness of virtual laboratories as compared to the traditional laboratories?

The results of the study indicate that the engineering instructors have a positive perception regarding virtual laboratories but very few are using them in their regular teaching.

Study 3: Problems Faced by Instructors in Using Virtual Laboratories

The next study a semi-structured interview format answered the specific research questions:

RQ1c: How can the problems faced by engineering instructors in using virtual laboratories in their teaching be solved?

The results of this study point out to the need of suitable and accessible guidelines for using virtual laboratories and the various aspects for which guidelines are needed.

Study 4: Aspects in the Virtual Laboratory Experiment Designs for which Engineering Instructors Need Guidelines

This survey study answered the specific research question: RQ1d: What are the various aspects in the experiment design process using virtual laboratories for which engineering instructors need guidelines?

This was a follow-up confirmatory study to endorse the various aspects for which guidelines would be designed and developed.

In the third phase five studies were carried out which were part of the summative evaluation of the final experiment design guidelines. The research question answered in this phase was: "Are the refined guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics usable, useful to engineering instructors and effective in improving the quality of experiment designs and students laboratory learning outcomes?" This was answered with the help of two survey studies, one artefact analysis and three quasi-experimental studies.

Study 5: This survey study answered the specific research question: "What are the perceptions of engineering instructors regarding the usability of the experiment design guidelines?" For the survey with feedback from 58 instructors the SUS score is 75.3.

The results of the SUS survey indicates that the engineering instructors perceive that the experiment design guidelines are usable.

Study 6: This survey study answered the specific research question: "What are the perceptions of engineering instructors regarding the usefulness of the experiment design guidelines?" The results of the survey indicate that the engineering instructors perceive that the experiment design guidelines are useful in their experiment design process.

Study 7: This was artefact analysis to answer the specific research question: "What is the effectiveness of the experiment design guidelines in improving the quality of the experiment designs for using virtual labs?" The results indicate that the guidelines are effective in improving the quality of the virtual lab experiment designs.

Study 8,9 and 10: These three studies were experimental studies carried out with UG engineering students to measure the impact of the experiment designs using the guidelines on the students' laboratory learning outcomes. The Researcher carried out the first study and the Subject Matter Experts carried out the follow-up studies. The results of these studies prove that the experiment designs using the guidelines have a positive influence on the students' laboratory learning outcomes.

1.7 Contributions of Thesis

- Identification of different aspects of virtual laboratory experiment design which instructors find difficult to implement and hence need comprehensive guidelines.
- Design and development of guidelines for the nine aspects such that they are usable for virtual laboratory context in Basic Electronics.
- Identification of criteria for assessment of quality of guidelines.
- Synthesis of the S-D-I-V-E methodology for guidelines development.

- Rubric for evaluation of quality of virtual lab experiment.
- LoTaAs Framework for experiment design for virtual laboratories in engineering education.
- Virtual laboratory assessment framework.
- SDVIcE tool

1.8 Structure of Thesis

There are total eight chapters in the thesis.

After introduction in the Chapter 1 the literature review is discussed in the second chapter. It starts with the problem in the research context, covers the existing solutions and then the gaps in the existing solutions. This leads to the main research objectives of the work. Chapter 3 presents the methodology adopted for the work that is the (S-D-I-V-E) Scoping-Development-Internal Review-Validation-External Use and the various questions this thesis addresses. Chapter 4 deliberates the various studies as part of the Phase I that is the Need and Problem Analysis. In Chapter 5 the details of the Design and Development of the proposed solution are discussed. Chapter 6 presents the Summative Evaluation of the proposed solution carried out by means of five studies.

Chapter 7 concludes the various sections and provides discussion regarding the generalizability of the work and various limitations. Chapter 8 lists down the contributions of the thesis and final reflection. The various Appendices added at the end of the thesis give details of the online SDVIcE tool, sample experiment designs before and after using the guidelines, the instruments used for the studies, the rubric used to assess the quality of the experiment designs.

Chapter 2

Literature Review

I have been working in the engineering education since last two and a half decades. The laboratory work has always intrigued and motivated me. I believe that true engineering happens in these laboratories. But while conducting laboratory work I faced many difficulties and also realized that other colleagues face similar problems. During this period I came to know about the virtual laboratories and their benefits in engineering education. Thus virtual laboratories became the natural selection as a topic of my research. As an engineering instructor I realized the potential of the virtual labs after using them in my teaching. I observed that most of my colleagues were apprehensive in using these labs, as there were no proper guidelines on how these labs can be used in regular teaching. This led to the research aim of developing guidelines for the engineering instructors so that they can integrate the virtual labs in their teaching. The literature and personal experience together implied that the laboratory learning outcomes of students could be improved if they use the virtual labs for learning certain concepts and developing certain skills. This directed the research towards carrying out literature review to get in-depth insights in the domain of virtual laboratories.

Thus a systematic review and analysis of literature from journals, conference papers, books and websites related to the problem space and identifying existing solutions was carried out. Initially the literature explored was related to virtual laboratories, their features and existing models for laboratory experiments. The focus was on finding out the position of virtual laboratories in the broad realm of learning environments and the features that play important role in the laboratory learning as reported by the literature. The next step was to find out if there are any models that may be used as the theoretical basis in the context of virtual laboratories. This exploration led to the following literature questions that are answered through the review process.

LQ1: What is the problem context?

- LQ1a: What is the theoretical basis of the problem?
- LQ1b: What is a Virtual laboratory? - Definition in the research context
- LQ1c: What are the pedagogically useful features of Virtual laboratories?

The answers to these questions guided to the next step that was finding out whether there are any solutions already reported in the context of the research. While exploring the literature on existing solutions it was observed that they fall into three broad categories that are – frameworks, guidelines and tools. Thus it was decided to further explore these three categories related to the context of virtual laboratories and laboratory work in general. The literature was also analysed to find if the existing solutions could be used in the context of the research with no modifications or there are certain gaps that need to be addressed in order to arrive at the proposed solution. Thus the answers to the following questions were found out.

LQ2: What is the existing work related to the problem context and what is the gap?

- LQ2a: What are the existing frameworks for laboratory learning designs?
- LQ2b: What are the existing guidelines for laboratory experiment designs?
- LQ2c: What are the existing tools for laboratory experiment designs?
- LQ2d: What gaps in the existing solutions are addressed in this research?

The analysis of literature in the solution space led to the conclusion that the solution to be proposed should be in the form of quality guidelines. Thus this led to further exploration of the two constructs of “guidelines” and “quality”. Thus the next step was to find answers as to what qualifies to be a guideline and what makes a quality guideline that is what criteria should be met in order for the guideline to qualify the construct of “quality”. This led to answering the following questions.

LQ3: What should be the nature of guidelines for the problem context?

- LQ3a: What is a guideline?
- LQ3b: What criteria constitute quality guidelines?

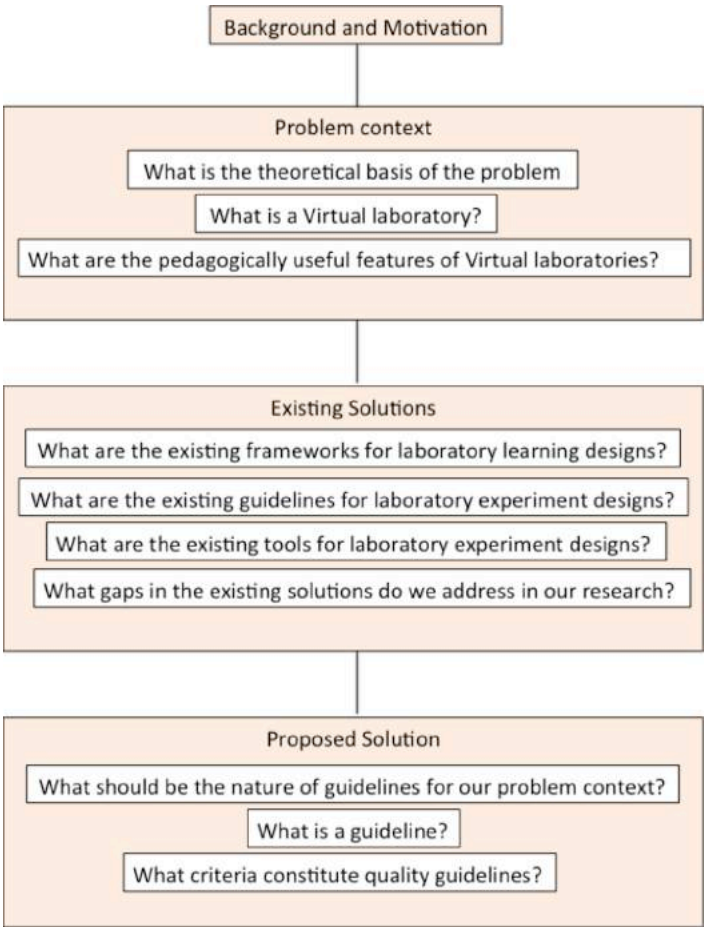


Figure 2.1 Overview of literature review

2.1 Problem Context

2.1.1 Theoretical Basis of the Problem

Laboratory work is an integral part of science and engineering education. In engineering education, and engineering technology in particular, laboratory courses play a central role in helping students learn challenging concepts and develop practical skills. Labs are often one of the college learning experiences that students enjoy the most (Feisel et al., 2005). The nature and practices of laboratories have been changed by two new technology-intensive automations: simulated labs (McAteer et al. 1996) and remote labs (Aburdene et al. 1991; Albu et al. 2004; Arpaia et al. 1998; Canfora et al. 2004) as alternatives for conventional hands-on labs. The Engineering laboratory instruction has reached a crisis level due to inadequate instructional resources. There is a lack of challenge and initiative provided to the students in performing experiments.

(Susan R. Singer et al., 2006, Bryce & Robertson, 2008; N. Cagiltay et al., 2011) Instructors play a critical role in leading effective laboratory experiences. Improving instructors' capacity to lead laboratory experiences effectively is critical to advancing the educational goals of these experiences. This can be achieved by developing more comprehensive systems of support for Instructors. (Mishra & Koehler, 2006; Angeli & Valanides, 2009; Tsai & Chai, 2014) the Instructors can achieve their laboratory goals if they design

- Student centered effective experiments
- Based on scientifically proven instructional strategies
- Exploiting the features of virtual labs

There are a few frameworks, guidelines and tools to facilitate this process but they have certain limitations. The details of these are discussed in section 2.2. To address the limitations of existing solutions in the research context the aim is to design and develop comprehensive guidelines for engineering instructors to facilitate effective learning designs for virtual laboratory experiments.

2.1.2 Virtual Laboratory as a Learning Environment - Definition in the Research Context

Learning environment refers to the diverse physical locations, contexts, and cultures in which students learn. A learning environment typically contains the learner and a space where the learner acts with tools and devices to collect and interpret information through a process of interaction with others (Wilson, 1996). The concept of a learning environment is that of a flexible learning space and quite different to the instructional sequence, which has previously, characterized instructional design strategies.

A virtual learning environment (VLE) is a virtual environment (VE) that supports learning activities. It inherits general VE features like social space, social presence, awareness tools etc. and that can be exploited by pedagogic strategies and according instructional design models (Balamuralithara & Woods, 2009). While there is a tendency to focus on either physical institutional learning environments (such as classrooms, lecture theatres and labs), or on the technologies used to create online personal learning environments (PLEs), learning environments are broader than just these physical components.

These also include:

- the characteristics of the learners;
- the goals for teaching and learning;
- the activities that best support learning;
- the assessment strategies that best measure and drive learning
- the culture that infuses the learning environment.

Classification of Learning Environments

The learning environments are classified as : Face to face, Online and Hybrid. The virtual laboratories are a special form of online learning environments with various types of media. The five principal media forms in any multimedia-learning environment are: Narrative, Communicative, Adaptive, Productive, and Interactive (Laurillard, 2002). Narrative media tell or show the learner something (e.g. text, image). Interactive media respond in a limited way to what the learner does (e.g.

search engines, multiple choice tests, simple models). Communicative media facilitate exchanges between people (e.g. email, discussion forum). Adaptive media are changed by what the learner does (e.g. some simulations, virtual worlds). Productive media allow the learner to produce something (e.g. word processor, spreadsheet). The virtual laboratories mainly consist of the three types: Narrative, Interactive and Adaptive .

Simulations of scientific phenomena are used to model something that is not easily observed in real life. They are used in teaching situations where computer simulation offers advantages such as students can (a) interact with the system by changing parameters and observing the results of their manipulation, (b) make a great number of simulations in a short time and (c) investigate phenomena that would not be possible to experience in a classroom or laboratory. (Urban-Woldron, 2009) describe simulations as computer programs that have an implicit model of the behavior of a physical system and that allow students to explore and to visualize graphic representations. De Jong defines a simulation broadly as ‘‘a program that contains a model of a system (natural or artificial; e.g., equipment) or a process’’ (de Jong & van Joolingen, 1998). Other interpretations define simulation as a representation or model of an event, object, or phenomenon (Thompson, Simonson, & Hargrave, 1996) or, specifically in science education, the use of the computer to simulate dynamic systems of objects in a real or imagined world (J. P. Akpan & Andre, 1999).

Virtual labs combine technology resources, reusable software environments, and automation, along with tried and true training concepts, to enable hands-on training that can be delivered to anyone, anywhere, anytime (Alan Greenberg, 2004). They are richly featured platforms for centrally managing software training via scheduled and on-demand delivery mechanisms, with automated processes for rapid deployment. They are meant to provide a compelling and personalized experience for learners, one that goes beyond just looking at content or interacting with simulations.

Virtual (or synthetic) environments (VEs) are three-dimensional, computer-generated environments that can be interactively experienced and manipulated by the user in real-time. AVE is either a projection of some real environment, a fairly realistic environment. VE's provide an interface between humans and computers by artificially mimicking the ways humans interact with their physical environments. (Ahmed K Noor.et al., 2001).

The term virtual laboratory has been defined in different ways in the literature.

According to cpsc.ucalgary.ca: The Virtual Laboratory is an interactive environment for creating and conducting simulated experiments: a playground for experimentation. It consists of domain-dependent simulation programs, experimental units called objects that encompass data files, tools that operate on these objects. A Virtual Laboratory is a heterogeneous distributed problem-solving environment that enables a group of researchers located around the world to work together on a common set of projects.

(K.C.Chu, 1999) take a simple vision of a virtual laboratory as a local computer hosting that may include some simulation capabilities. He describes an interactive virtual laboratory system as a web based system with a multimedia-learning environment, which provides simulations of complex scientific processes that are less likely to be demonstrated in a normal laboratory.

(Ahmed K Noor.et al, 2001) describe virtual labs as virtual environments, which leverage modeling, simulation, and information technologies to create an immersive, highly interactive virtual environment tailored to the needs of researchers and learners. Virtual experiments in the VLs are not exact duplicates of their real-world counterparts and, therefore, can provide educationally valuable features not available in physical experiments (for example, a fatigue test can be simulated in a few minutes).

Simulation software falls into two main categories:

1. Virtual laboratories and
2. Simulations of scientific phenomena.

Virtual laboratories simulate on-screen the experiments that are traditionally performed in real school laboratories as part of biology, chemistry, and other science and engineering subjects. They provide opportunities to use virtual materials, equipment, and tools that are designed to replicate those in an actual laboratory. (Scalise et al., 2011)

A computer simulation, which enables essential functions of laboratory experiments to be carried out on a computer, is called a virtual laboratory (VL) (Harms, 2000)

"The Virtual Laboratory is an interactive environment for creating and conducting simulated experiments: a playground for experimentation. It consists of domain-dependent simulation programs, experimental units called objects that encompass data files and tools that operate on these objects."

In the context of this research the following definition of the virtual laboratory is used

> Virtual laboratories simulate on-screen the experiments that are traditionally performed in real school laboratories as part of biology, chemistry, and other science and engineering subjects. They provide opportunities to use virtual materials, equipment, and tools that are designed to replicate those in an actual laboratory. (Kathleen Scalise et al., 2011)

The figure 2.2 indicates the position of virtual laboratory in the realm of learning environments. The following figure was synthesized from the literature to explicitly position the work in the context of various learning environments.

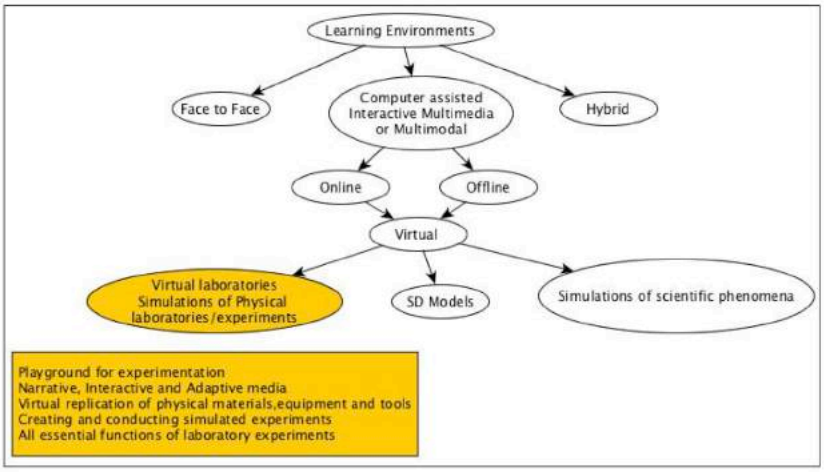


Figure 2.2 Virtual laboratory in realm of learning environments

2.1.3 Pedagogically Useful Features of Virtual Laboratories

Virtual laboratories simulate physical environment and provide opportunities to students to play around the equipment and simulated hardware without any fear of damage. In this section the pedagogically useful features of the virtual labs are discussed and how educators have used these to improve the laboratory learning outcomes of the students is found out.

Educators have been aware of the potential of computer simulation or PC-based virtual experiments in improving the educational process since the early days of computers. Many research papers report a positive impact of computer simulations on students' learning. (Dongil Shin, En Sup Yoon 2002) report that the virtual lab system helps students understand the fundamentals of unit operations and increases educational efficiency with significantly less operating cost for the lab. It is also expected to contribute to increasing students' adaptability to working in real process plants after graduation.

A few studies have compared learning outcomes for remote and hands-on labs (e.g., Corter, Nickerson, Esche, & Chassapis, 2004, 2007; Lindsay & Good, 2005; Sicker, Lookabaugh, Santos, & Barnes, 2005; Sonnenwald et al., 2003). The general conclusion from these studies is that learning outcomes are roughly equivalent no matter which format of lab is used: traditional hands-on labs, remote labs, or simulations. In general, students prefer traditional hands-on labs, but rate the remote labs highly on convenience and ease of use.

Specifically, the importance of engagement with a physical and educational context posted by some versions of constructivist theory suggest that science learning is facilitated by direct student involvement in and increased control of investigations (Applefield, Huber, & Moallem, 2000; Gagnon & Collay, 2006; Hannafin & Land, 1997; Huang et al., 2010). According to this view, students need individual interactions with scientific equipment, so that they can explore, situate, and better remember the concepts that have been learned through lectures or demonstrations. This line of thought argues for individual data collection being the norm in laboratory exercises.

(Corter et al., 2007) showed an advantage for remote and simulated labs for certain lab topics, and documented that students more often collected data individually in these conditions when the collaboration strategy was left up to the individual lab teams. Thus, the remote labs advantage observed might have been due to the fact that students were more likely to work individually to collect data with remote and simulated labs, and working individually entailed more direct and active involvement in the data collection process, leading to enhanced understanding and memory.

Computer simulations can accommodate different learning styles, experiments can be repeated, offering an iterative learning opportunity, and students can use them outside class time for reflection and self-testing (Eckhoff, Eller, Watkins, & Hall, 2002). They promote a safe environment for students to test hypotheses and investigate outcomes of issues that sometimes are difficult or impossible to do with hands-on physical platforms, e.g. high voltage power plants (Hites et al., 1999; McAteer et al., 1996).

(Laghari et al., 1990) describe enhanced health and safety issues associated with using simulation software for electrical circuit design compared to hands-on high-voltage laboratories. Using the software helped to reduce the exposure time to high voltages that the students and the instructor had.

Computer simulations allow students to perform sophisticated experiments virtually that otherwise would require a high physical or technical level. Experimentation can take place at the student's pace (Dobson, Hill, & Turner, 1995). Virtual labs are available any time (Dobson et al., 1995; McAteer et al., 1996). Teachers can save their contact time with the students by fostering the simulations (McAteer et al., 1996). They are fast, safe, clean and cost effective (Eckhoff et al., 2002; Gonzalez & Musa, 2005; McAteer et al., 1996).

The instructors can use all these features and design tasks exploiting these affordances so that the laboratory learning outcomes can be improved. In order to improve the learning outcomes the engineering instructors should design effective experiments. For designing experiments the instructors use various available materials such as frameworks, guidelines and tools. In order to find out if there exist solutions to the problem of designing experiments for virtual laboratories literature review was carried out. In the next section the results of the literature review for the existing solutions is presented.

2.2 Existing Solutions

The answers to the following questions are obtained in order to

1. Understand the current learning design frameworks and guidelines
2. Their suitability in the context of this research viz framing guidelines for the experiment designs for effective use of virtual laboratories
3. To define the scope of the research work and
4. To make decision regarding the nature of the proposed solution.

They are structured around following questions.

LQ1: What is the existing work related to the problem context and what is the gap?

- LQ1a. What are the existing frameworks for learning designs?
- LQ1b. What are the existing guidelines for laboratory experiment designs?
- LQ1c. What are the existing tools for laboratory learning/experiment designs?
- LQ1d. What gaps in the existing solutions are addressed in this research?

2.2.1 Frameworks for Learning Designs for Online Learning Environments

In this section the following literature question is answered

- LQ1a. What are the existing frameworks for learning designs?

Learning design is defined as an application of a pedagogical model for a specific learning objective, target group and a specific context or knowledge domain. The learning design specifies the teaching and learning process, along with the conditions under which it occurs and the activities performed by the teachers and learners in order to achieve the required learning objectives. The core concept of Learning design is that a person is assigned a role in the teaching-learning process and works towards certain outcomes by performing learning activities within a given environment. The environment consists of appropriate learning objects and services used during the performance of the activities.

With the emergence of the Learning Design specification (IMSLD, 2003), a number of applications are now being offered to guide users through the learning design process and help them create effective learning activities with pedagogically informed use of tools and resources, such as the method and tool described by (Paquette et al., 2005).

The tools like LAMS are useful in terms of guiding practitioners through the production of these lesson plans. Another mechanism for supporting practitioners through the different approaches and theories associated with promoting effective learning design is through the use of a 'toolkit' as proposed by (Conole, Fill, 2005). The other frameworks that guide in learning designs are Conversational, 7C, SLDF (Smart Learning Design Framework), ISiS. All these are for assisting the instructors in their learning designs for the classroom lesson plans. One of the most widely used models is the ADDIE model (Analysis, Design, Development, Implementation and Evaluation) proposed by (Peterson, 2003). Some other famous models are ASSURE (Heinich, Molenda, & Russell, 1993), ARCS (Keller, 1987), Dick and Carry Model (Dick, Carry, & Carry, 2001), Kemp (2004) Model, Posner (2001) Model, Tyler (1971) Model, Smith and Ragan (1999) model, and Gerlach and Ely Model (Gerlach & Ely, 1980).

The Learning-for-Use model (Edelson, 2000) is a description of the learning process that can be used to support the design of content-intensive, inquiry-based science learning activities. The model is based on the four principles of constructivism, goal-directed nature of learning, influence of the learning context on the accessibility of knowledge and captures the difference between declarative and procedural knowledge. The Learning-for-Use model characterizes the development of useable understanding as a three-step process consisting of (a) motivation, (b) knowledge construction, and (c) knowledge refinement.

The two frameworks that fit into the context of this research are: 1.The Design Principles Framework for Simulations and Virtual Laboratories proposed by (Kathleen Scalise et al., 2011) and 2. The Science Laboratory Instructional Design (SLID) proposed (Nuri Balta, 2015).

1.The Design Principles Framework for Simulations and Virtual Laboratories

This model through a literature review of 79 studies provides a research-based evidence about best practices in instructional design for virtual laboratories and science-simulation software. The literature synthesis examines research findings on grade 6–12 student learning gains and losses using virtual laboratories and science-simulation software. The five principles that emerge for three dimensions as a Design Principles Framework for Simulations and Virtual Laboratories are as given in Table 2.1. These may be used to design and develop science-simulation and virtual-lab products, as well as make decisions about whether and which Simulations and Virtual Laboratories to adopt, purchase, and use.

Table 2.1: Design Principles Framework for Simulations and Virtual Laboratories

Effective Interfaces	Powerful visualizations	Real-world scientific inquiry
Focal Points	Sense-making	Scientifically oriented questions
Cognitive load	Unbinding constraints	Priority to evidence
Scaffolds	Differentiating instruction	Design and conduct investigations
Hybridization	Relevance	Formulate/Evaluate explanations
Infrastructure	Interpretation	Communicate and justify findings

This framework provides the research-based principles which Educators, policy makers, and instructional leaders need to look at while selecting the simulation or virtual laboratory products. The limitation of this framework in the research context is that it does not provide guidelines for the experiment designs using virtual laboratories. This is not specific to the context of virtual laboratory experiment designs.

2.2.2 The Science Laboratory Instructional Design (SLID)

(Nuri Balta, 2015) have proposed the science laboratory instructional design (SLID) model as shown in the figure. The SLID is expected to enhance the process of teaching and learning science in laboratory setting.

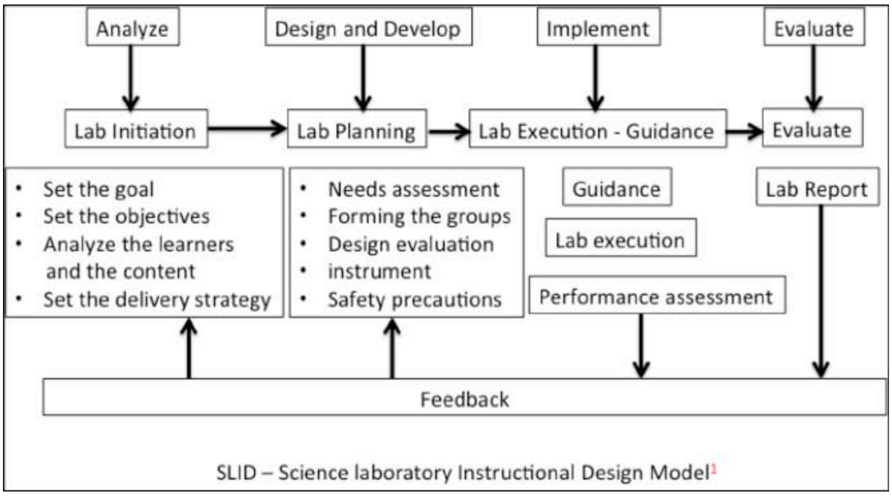


Figure 2.3 - SLID – Science laboratory Instructional Design Model proposed by Nuri Balta 2015

The SLID model specifies the procedural flow that the instructors can use for designing instructions for the laboratory experiments. The model provides a comparison to the phases of the ADDIE model and the laboratory instructional design. The four phases corresponding to the ADDIE model are:

1. Analyze – The corresponding phase in laboratory design is Lab initiation. In this phase the instructors should carry out the following activities: Set the objectives, analyze the learners and content and set the strategy.
2. Design and develop - The corresponding phase in laboratory design is Lab Planning. In this phase the instructors should carry out the following activities:

Needs assessment, forming groups, designing evaluation instrument, safety precautions.

3. Implement - The corresponding phase in laboratory design is Lab Execution. In this phase the instructors should carry out the following activities: guidance, lab execution and performance assessment.
4. Evaluate - The corresponding phase in laboratory design is Lab report.

2.2.3 Gaps in Existing Frameworks

The existing frameworks are Instructional Design models, which give the various components of the Instructional Design but do not specify the how the instructional design should be carried out. The LoTaAs model is proposed as the framework for the solution. This incorporates the components of the SLID that give the procedural steps for the laboratory activities. The Design Principles Framework for Simulations and Virtual Laboratories for the virtual learning and active learning activities is used to provide the "how" component in the instructional design. The guidelines are proposed for the various steps in the experiment design process and also how the designs can be made more effective to improve the students' laboratory learning. All these guidelines are for engineering instructors in the context of virtual laboratories.

2.2.4 Guidelines for Learning Designs in Online Learning Environments

In this section the following literature question is answered

- LQ1b. What are the existing guidelines for laboratory experiment designs?

There are multiple guidelines proposed over the past years for instructional design for different settings such as classroom, physical laboratories, virtual laboratories, multimedia learning environments etc. The guidelines relevant in this research context are discussed and the gaps are identified.

1. (Innwoo Park Michael J, Hannafin, 1993) proposed 20 design principles as guidelines for interactive multimedia design. They have used the three foundations – psychological, technological and pedagogical theories as the fundamental basis for the design of learning systems. Based on these theories they have proposed 20 design principles and their corresponding implications on the learning design.

2. The National Research Council has published several reports identifying how students learn (NRC, 1999, 2005; Glaser 1994), and educational theorists around the world have been calling for instructional practices that include active learning, higher-order thinking, performance assessment, and authentic learning for many years. The scientific inquiry activities and lab procedures advocated by this report are nothing more than applications of these principles to science instruction.

3. (Thomas W. Shiland, 1999) suggest specific ways laboratory activities might be modified (instead of completely changed) to increase understanding in science with constructivism as the basis for the change. The basis of constructivism is that knowledge is constructed in the mind of the learner. The author has expanded to five other propositions or postulates of constructivism, from which implications for lab work, will be derived. These are: 1. Learning requires mental activity. 2. Naive theories affect learning. 3. Learning occurs from dissatisfaction with present knowledge. 4. Learning has a social component. 5. Learning needs application. These five postulates lead to the guidelines for the design of laboratory activities.

4. (Ron Oliver, 2000) provide guidelines as a possible starting point for those seeking to create Web-based learning settings that support constructivist forms of learning. These broad guidelines are: 1. Choose meaningful contexts for the learning 2. Choose the learning activities ahead of the content 3. Choose open-ended and ill-structured

tasks 4. Make the resources plentiful 5. Provide supports for the learning 6. Use authentic assessment activities.

5. (Boud and Prosser, 2001) argue that a learning design needs to address the following four principles in order for the potential of high quality learning to be realized:

Engage Learners: Considering learners' prior knowledge and their desires and building on their expectations

Acknowledge the learning context: Considering how the implementation of the learning design (be it a one class session, over the period of a few weeks, or the entire subject) is positioned within the broader program of study for the learner.

Challenge learners: Seeking the active participation of learners, encouraging learners to be self- critical and supporting learners' applicative skills.

Provide practice: Encouraging learners to articulate and demonstrate to themselves and their peers what they are learning.

6. Based on the principles suggested by (Boud and Prosser, 2001) (Shirley Agostinho et al., 2002) have designed a tool to evaluate the potential for an ICT-based learning design to foster "high-quality learning". The various questions, which form part of the learning design Evaluation Form in the tool, are as follows:

1a. How does the learning design support Learner Engagement?

1b. How well does the learning design support Learner Engagement?

2a. How does the learning design acknowledge the learning context?

2b. How well does the learning design acknowledge the learning context?

3a. How does the learning design seek to challenge learners?

3b. How well does the learning design challenge learners?

4a. How does the learning design provide practice?

4b. How well does the learning design provide practice?

5. Infrastructure and Technology assessment: How do the technologies employed, their supportive systems and particular implementation facilitate the learning design?

6. Description of the Learning Design

7. Summary description of the learning design

8. Suitability for Redevelopment

7. (David Boud and Mike Prosser, 2002) have attempted to specify the characteristics of high quality learning outcomes. They suggested that the four major areas of concentration in a high-quality learning environment should be:

1 How do learning activities support learner engagement? The reasons for the learner wishing to become involved with the learning tasks and the way the tasks require them to reflect or employ their previous interests and understandings.
2 How does this learning activity acknowledge the learning context? In the case of e-learning, there are unique characteristics. Learners are often in a real context and assessment can be made to employ real world skills. Furthermore, assessment can support the transfer between learning context and professional practice.
3 How does the learning activity seek to challenge learners? Novices need supportive structures, experts require information to fill in the missing blanks in an existing knowledge structure, too much ambiguity can turn a novice student away, too little and they become bored. Students might need support to extend the information provided as part of a problem–solving scenario.
4 How does the learning activity provide practice? As with most effective learning contexts the matches between assessment, learning tasks and the transfer tasks might align and model performance. To ensure that it occurs, the feedback must support the ongoing development of the learning.

8. (John G Hedberg, 2003) define various learning tasks as the basis for high quality learning designs. He suggests that if the e-learning experiences are well designed, learners who embrace these environments will gain a greater understanding of their own experiences and ensure that higher-order learning outcomes are achieved. (Roblyer, Md Wiencke, Wr, 2004) carried out a study for validation of the rubric designed and developed by them for assessing the quality of interactions in distance courses.

9. (NACOL Committee on Online Science Kemi Jona & John Adsit with Allison Powell, 2008) have proposed quality guidelines for developing and evaluating student scientific investigations and surrounding course content. The following four curriculum standards were identified as principles of effective laboratory experiences by the National Research Council in America's Lab Report (NRC, 2006, pp.101-102): 1. Clearly Communicated Purposes 2. Sequenced into the Flow of Instruction 3. Integrated Learning of Science Concepts and Processes and 4. Ongoing Discussion and Reflection.

10. (Yu Wang et al. 2009) have given guidelines for the design of Mechatronics laboratory in which they use horizontal integration (HI) among the various disciplines as well as vertical integration (VI) between design and manufacturing. For the design and planning of laboratories they have given six guiding philosophies. These are

The laboratory should be designed to support a set of experiments to enable application of the concepts presented in the lecture part of course.

The laboratory should be designed to use equipment from world-class enterprises and leading and popular technology in the market to the maximum extent possible.

Instead of just a demonstration or validation of learned theory, the laboratory equipment and devices should be developed to be as close as possible to the real-world industrial situations.

Instead of just as an observer, the laboratory should have enough sets of instrumentation and components to provide each student with a significant hands-on experience.

The laboratory should provide enough space and equipment so that teams of two to three students can work together on experiments or projects.

The laboratory should be planned to be in consistent with the orientation of mechatronics education at CDHAW, basically the academic fields of advanced manufacturing automation derived from the concept of ‘‘totally integrated automation (TIA)”of Siemens AG.

11. (Clark Hochgraf and David S Martins, 2013) describe a set of six guiding principles for designing lab exercises. Guiding principles for redesign of labs:

1) Activate students’ self motivation 2) scaffold labs to develop component skills first and then integration skills 3) provide a framework for students to organize new knowledge 4) manage cognitive overload 5) develop practical universal implementation skills 6) use “writing to learn” to promote deeper understanding

The details of the exiting guidelines are summarized in the following Table 2.2

Table 2.2: Summary of existing guidelines

Author	Year	Guideline for	Guideline
1.National Research Council	1999, 2005	Principles of effective laboratory experiences	Clearly Communicated Purposes Sequenced into the Flow of Instruction Integrated Learning of Science Concepts and Processes Ongoing Discussion and Reflection
2.Thomas W. Shiland,	1999	Guidelines for modifications in laboratory activities based on constructivism	1. The learning material cannot simply be presented to the learner and learned in a meaningful way. 2. New knowledge must be related to knowledge the learner already knows. 3. For meaningful learning to occur,

			experiences must be provided that create dissatisfaction with one's present conceptions. 4. Learning is aided by conversation that seeks and clarifies the ideas of learners. 5. Applications must be provided which demonstrate the utility of the new concepts.
3.Anthony Herrington et al.	2001	Quality guidelines for online courses having a checklist of items that can be used to assess quality of pedagogy in online units.	Authentic tasks: The learning activities involve tasks that reflect the way in which the knowledge will be used in real life settings, opportunities for collaboration: Students collaborate to create products that could not be produced individually, learner centered environments: There is a focus on student learning rather than teaching, engaging: Learning environments and tasks challenge and motivate learners and meaningful assessments: Authentic and integrated assessment is used to evaluate students' achievement.
4. Boud and Prosser	2001	Four principles in order for the potential of high quality learning	Engage Learners: Considering learners' prior knowledge and their desires and building on their expectations Acknowledge the learning context: Considering how the implementation of the learning design (be it a one class session, over the period of a few

			weeks, or the entire subject) is positioned within the broader program of study for the learner. Challenge learners: Seeking the active participation of learners, encouraging learners to be self-critical and supporting learners' applicative skills. Provide practice: Encouraging learners to articulate and demonstrate to themselves and their peers what they are learning.
5.Shirley Agostinho et al.	2002	A tool to evaluate the potential for an ICT-based learning design to foster "high-quality learning"	1a. How does the learning design support Learner Engagement? 1b. How well does the learning design support Learner Engagement? 2a. How does the learning design acknowledge the learning context? 2b. How well does the learning design acknowledge the learning context? 3a. How does the learning design seek to challenge learners? 3b. How well does the learning design challenge learners? 4a. How does the learning design provide practice? 4b. How well does the learning design provide practice? 5. Infrastructure and Technology assessment: How do the technologies

			employed, their supportive systems and particular implementation facilitate the learning design? 6. Description of the Learning Design 7. Summary description of the learning design 8. Suitability for Redevelopment
6. David Boud and Mike Prosser	2002	Specify the characteristics of high quality learning outcomes	1. How do learning activities support learner engagement? 2. How does this learning activity acknowledge the learning context? 3. How does the learning activity seek to challenge learners? 4. How does the learning activity provide practice?
7. NACOL Committee on Online Science Kemi Jona & John Adsit with Allison Powell	2008	Guidelines for developing and evaluating student scientific investigations and surrounding course content	Four principles: 1. Clearly Communicated Purposes 2. Sequenced into the Flow of Instruction 3. Integrated Learning of Science Concepts and Processes and 4. Ongoing Discussion and Reflection.
8. Jan Herrington Ron Oliver	2008	Nine guiding principles for multimedia learning designs	1. Provide authentic contexts that reflect the way the knowledge will be used in real life. 2. Provide authentic activities. 3.Provide access to expert performances and the modeling of processes. 4. Provide multiple roles and perspectives. 5. Support collaborative construction of knowledge. 6. Promote reflection to

			enable abstractions to be formed. 7. Promote articulation to enable tacit knowledge to be made explicit. 8. Provide coaching and scaffolding by the teacher at critical times. 9. Provide for authentic assessment of learning within the tasks.
9. N.M. Meyers and D.D. Nulty		Five principles for the design of curriculum units	1. They are authentic, real world and relevant; 2. They are constructive, sequential and interlinked; 3. They require students to use and engage with progressively higher order cognitive processes; 4. They are all aligned with each other and the desired learning outcomes; and 5. They provide challenge, interest and motivation to learn.
10.Kathleen Scalise et al.	2011	Design Principles Framework for Simulations and Virtual Laboratories	Effective Interfaces, Powerful visualizations and Real-world scientific inquiry
11. Clark Hochgraf and David S Martins	2013	Six guiding principles for designing lab exercises	1) Activate students' self motivation 2) scaffold labs to develop component skills first and then integration skills 3) provide a framework for students to organize new knowledge 4) manage cognitive overload 5) develop practical universal implementation skills 6) use "writing

			to learn" to promote deeper understanding

2.2.5 Inferences

After the detailed analysis of the literature on the existing guidelines the following points are inferred.

1. The naive theories affect learning and related prior knowledge is the single most powerful influence in mediating subsequent learning. Learning occurs from dissatisfaction with present knowledge.
   Implication for guideline: Provide opportunities to students to relate new knowledge with prior knowledge
2. Transfer improves when knowledge is situated in authentic contexts
   Implication for guideline: Hence choose meaningful contexts while designing laboratory activities and acknowledge the learning context. Provide authentic contexts that reflect the way the knowledge will be used in real life.
3. Knowledge of details improves, as instructional activities are more explicit.
   Implication for guideline: Design authentic tasks and provide authentic activities. They should be authentic, real world and relevant. They should be constructive, sequential and interlinked and help in the development of practical skills.
4. Learning requires mental activity
   Implication for guideline: Design learning environments that are students centered and which engage and challenge them. They provide challenge, interest and motivation to learn and activate students' self motivation.
5. Knowledge is best integrated when unfamiliar concepts can be related to familiar concepts. Learning is influenced by the supplied organization of concepts to be learned.

Implication for guideline: Promote articulation to enable tacit knowledge to be made explicit and provide a framework for students to organize new knowledge.

6. Feedback increases the likelihood of learning response relevant less on content, and decreases the likelihood of learning response irrelevant less on content.

   Implication for guideline: Provide coaching and scaffolding by the teacher at critical times and scaffold labs to develop component skills first and then integration skills. The activities should have supports for the learning.

7. Learning improves as the amount of invested mental effort increases.

   Implication for guideline: Hence design activities that require students to use and engage with progressively higher order cognitive processes.

8. Learning improves as competition for similar cognitive resources decreases and declines as competition for the same resources increases.

   Implication for guideline: Design activities that manage cognitive overload.

9. Understanding improves, as the activities are more integrative.

   Implication for guideline: Design activities, which have integrated learning of concepts and processes.

10. Learning has a social component

    Implication for guideline: Provide students with opportunities for collaboration and support collaborative construction of knowledge.

11. The activities should foster reflection as it enables abstractions to be formed.

    Implication for guideline: Provide students with opportunities for reflection on their learning

The main premise of all these recommendations is that the learning designs should be based on the constructivist approach and use active learning methods.

2.2.6 Gaps in Existing Guidelines

The existing guidelines are broad and the instructors may find these difficult to implement in their experiment designs in the context of this research. The specific and implementable guidelines that the instructors can use in the various phases of the experiment design are framed through this research work. With SLID model as the basis for procedural steps the "how" component for every phase of the experiment design to incorporate the constructivist approach and active learning methods is provided.

2.2.7 Learning Design Tool

In this section the following literature question is answered

- LQ1c. What are the existing tools for laboratory learning/experiment designs?

In the virtual lab domain lot of work is carried out at K-12 level and the best example is the Go-Lab project. The outcome of this project is an excellent website which has all the resources available for the teachers to integrate these labs in their teaching. Some of the resources available are

1. A comprehensive list of all the online available labs, which the instructors can filter, based on their requirements. The filter parameters are the domain, topic in the domain and the target age group.
2. Links to other similar labs
3. The online tool - Inquiry Spaces is one of the best features available to the teachers. "Inquiry spaces are learning environments that can contain labs, learning resources and apps to enable inquiry learning. Learning resources are typically texts, videos and other materials to assist and assess students. Teachers usually set up an inquiry space for their students. An inquiry space can be shared with other teachers who can repurpose and adapt it to fit their purpose." The teachers can develop their own Inquiry Spaces as per their need. While developing these spaces they are guided through the process so that the implementation is very easy and user friendly.

4. Apps: There are lots of Apps, which the faculties and students can use to make the lab work interesting and effective. Some of the Apps are Hypothesis Scratchpad, Experimental Design tool, Experimental error calculator etc.
5. Big ideas: This again is an interesting feature which helps instructors and students explore various important concepts in science

The limitation of this online set of tools is that it caters to K-12 Science curriculum. Currently there are virtual labs in engineering available for many domains and lot of courses in each domain. The engineering faculties also can use these tools. The main premise on which these tools are built is that the faculties are trained and aware of the educational technology theories especially the guided inquiry learning processes in laboratories.

2.2.8 Gaps in the Existing Tool

1. The tool is for K-12 education and not mainly for engineering education
2. The tool is complex to use
3. The basic assumption made for the tool use is that the faculties are trained in the various instructional strategies especially the guided inquiry
4. The faculties need to spend lot of time in order to understand the various components in the tool
5. Overall the response was that the faculties are not comfortable in using the tool for virtual lab integration in their regular teaching with minimum investment of their time.

2.2.9 Existing Guidelines in the Curriculum

After going through the curriculum document of the University for which the research work is scoped the following guidelines were observed. There are also guidelines on how the lab work should be assessed.

A sample of these is given below.

Electronic Devices Laboratory
Guidelines for Simulation Experiments:

1. One SPICE simulations and implementation for junction analysis
2. One SPICE simulation and implementation for BJT characteristics
3. One SPICE simulation and implementation for JFET characteristics
4. One SPICE simulation and implementation for Optical devices
5. One SPICE simulation and implementation for power devices
6. One SPICE simulation for MOSFET characteristics

2.2.10 Gaps Addressed in the Proposed Solution

In this section the following literature question is addressed:

- LQ1d. What gaps in the existing solutions are addressed in this research?

After the literature review on the existing frameworks, models and guidelines the following was inferred:

1. All the existing frameworks and models are for learning designs for either classroom learning materials or traditional science laboratories.
    a. The proposed guidelines are for virtual laboratory settings.
2. The SLID framework specifies the components of the laboratory experiment ID but not for the virtual learning environment and for the engineering context. It does not specify the "how" component of the instructional design.
    a. The proposed guidelines specify the "how" component for each phase of the virtual laboratory experiment design.
3. The guidelines are not specific so teachers may not find these very useful in implementation of their day-to-day teaching.
    a. The proposed guidelines are specific and implementable.
4. These guidelines should be such that they can come up with the learning material to be given to the students with minimum time and resource demands.

    a. The templates for the virtual laboratory experiment designs are provided so that the instructors can implement the guidelines with minimum time. The online tool also facilitates the experiment design process.

5. Also when implemented the learning material administered should lead to effective laboratory work.
    a. The guidelines on how the experiment designs can be administered to the students so as to improve their laboratory learning outcomes are provided.

2.2.11 Summary and Implications

These gaps in the existing solution establish the need of the comprehensive guidelines for engineering instructors. These guidelines will enable them to design effective virtual laboratory experiments and results in the objectives of this research work.

There exist many frameworks and models for learning designs. The important phases and elements of a laboratory activity have been pointed out, and the importance of alignment between these instructional elements has to be kept in mind in the design of laboratory instruction. Using the SLID model in the laboratory instruction the phases in the experiment design can be defined. It can form the basis of the procedural steps in the proposed guidelines. The inferences from the analysis of existing guidelines can form the basis for the quality aspect of the instructional design as discussed in Section 2.2.3.

2.3 Nature of Proposed Guidelines

The potential benefits of any guidelines depend on the quality of the guidelines themselves. Appropriate methodologies and rigorous strategies in the guideline development process are important for the successful implementation of the resulting recommendations. The quality of guidelines can be extremely variable and some often fall short of basic standards. So to evaluate the initial solution design guidelines literature review was carried out to determine the criteria that decide their quality.

As the first step literature review was carried out to come up with the definition of a valid guideline and later the criteria for the quality of a guideline.

2.3.1 Definition of a Guideline

(Giasemi N. Vavoula et.al, 2004) while developing guidelines for mobile learning state the guidelines as theory-informed 'do and don'ts' that are validated and segmented by audience. They give the definition of guidelines as "“Rules or principles for action, encapsulating some combination of practitioner-determined best practices in a domain and research-based insights into factors relevant in that domain". Another way the guideline is defined is "A guideline is a statement by which to determine a course of action. A guideline aims to streamline particular processes according to a set routine or sound practice." By definition, following a guideline is never mandatory. Guidelines are not binding and are not enforced. They give a future scope of action. It is important to understand that guidelines are not designed to be used like a cookbook. One formula does not work for everybody. Hence, in some circumstances, the purpose guidelines aim to serve is to make adaptable recommendations. The main objective of any guideline is to improve the consistency and outcomes of any intervention. In the context of this research the proposed guidelines aim at improving the quality of virtual laboratory experiment designs and if implemented improve the students' laboratory learning outcomes. The value of a guideline depends on the quality of the evidence on which it is based. This definition of guidelines is used in this research given by (Giasemi N. Vavoula et.al, 2004)

There are two types of existing guidelines which the engineering faculties can refer to. The guidelines available in literature in the form of published papers and articles and guidelines given by curriculum developers.

2.3.2 Criteria of Quality Guideline

The quality of guidelines can be extremely variable and some often fall short of basic standards. (G.Browman et al, 2015) believe that the factors that play important role in the quality of guidelines are credibility and legitimacy. They should not be very contextual. If the context changes guidelines may loose value. People external to the process of guidelines development should review the appropriateness of the guidelines to a particular situation. The independent review adds to the validity of the guidelines. Two other factors that need to be considered are the feasibility and affordability of implementing the guidelines. Similarly participation of all the stakeholders should be involved in the development process. (A. Phillips et al, 2013) stress the importance of an expert panel in the review panel for improving the quality of guidelines. They also point out that the process of identification of the literature on evidence of the effectiveness should be carried out systematically. They state that the explanation and elaboration document should provide the background, rationale and justification for the guidelines as well as provide examples for users. They should be based on theory and practice. According to (WHO guideline development group, 2007) the implementation of guidelines should be considered as part of the development process. They also suggest that it is important to identify the key outcomes that need to be considered when the recommendations are made. (D.Nice, 2014) state that there should be consistency in language and terms across guidelines. The use of jargon and vague words and phrases should be avoided. The guidelines should follow the principles of effective writing. Guidelines should be supported by evidence. For example – "Use simple language." This guideline should be supported by " what constitutes simple language", under what circumstances simple language can be misleading, should have supporting evidence. They propose that any specialized terminology that is used in the recommendations should be defined before using it. The intended audience for the recommendation should be clearly specified and also the setting(s) where the intervention is to be delivered. The recommendations should begin with what needs to be done. They should provide references to the relevant sources, justification for inclusion and limitations of the guidelines. This synthesis of the literature led to eight criteria that constitute the quality of guidelines. The following criteria were finalized after the literature analysis. The following criteria are used to assess the quality of the designed and developed guidelines for effective design of virtual laboratory experiments.

Criterion 1 - Features

1. Guidelines should be supported by evidence. For example – "Use simple language." This guideline should be supported by " what constitutes simple language", under what circumstances simple language can be misleading, should have supporting evidence
2. They should not be very contextual. If the context changes guidelines may loose value
3. Should be based on theory and practice
4. Should provide references to the relevant sources
5. Justification for inclusion
6. Limitations of the guideline

Criterion 2 – Structure

a. The guideline is valid (as per the definition) does it specify the rules or principles for action.
b. The guideline is relevant for the context
c. The guideline is accurate
d. The guideline is comprehensive and specific and not broad

Criterion 3 – Overall scope and purpose

a. The overall objective(s) of the guideline is (are) specifically described.
b. The question(s) covered by the guideline is (are) specifically described.
c. The population to whom the guideline is meant to apply is specified.

Criterion 4 – Stakeholder involvement

a. The guideline development group includes individuals from all relevant groups.
b. The views and preferences of the target population have been sought.
c. The target users of the guideline are clearly defined.

Criterion 5 – Rigor of development

a. Systematic methods were used to search for evidence.
b. The Criterion for selecting the evidence is clearly described.
c. The strengths and limitations of the body of evidence are clearly described.
d. The methods for formulating the recommendations are clearly described.
e. There is an explicit link between the recommendations and the supporting evidence.
f. Experts prior to its publication have externally reviewed the guideline.

Criterion 6 – Clarity of presentation

a. The recommendations are specific and unambiguous.
b. The guidelines are well written and the descriptions are clear and concise
c. Key recommendations are easily identifiable.
d. The different options are clearly presented.

Criterion 7 – Applicability

a. The guideline describes facilitators and barriers to its application.
b. The guideline provides advice and/or tools on how the recommendations can be put into practice.
c. The potential resource implications of applying the recommendations have been considered.

Criterion 8 – Editorial independence

a. The guideline is not biased towards a specific methodology

2.4 Stakeholders of Virtual Laboratories

The various stakeholders of the virtual laboratories are (Gravier, Fayolle, Bayard, Ates, & Lardon, 2008) users (students and trainees), instructors (teachers), developers (developers of lab applications for experiments) and institutions (which develop distance-learning laboratories for their educational purposes). The following table gives the details of the virtual laboratory accessed by the various stakeholders in the context of this research.

2.5 Research Objectives and Scope

2.5.1 Research Objective

The primary objective of this research is to design and develop comprehensive guidelines and templates for the engineering instructors so that they can design experiments for using existing virtual laboratories. Thus they would be able to effectively use the existing virtual laboratories in their regular teaching and achieve their laboratory learning objectives.

The secondary objective is to convert these guidelines to an online tool so as to increase the accessibility of the guidelines.

2.5.2 Scope of Research

Framework: The proposed framework (LoTaAs – Learning Objectives-Laboratory Tasks-Assessment framework) will enable engineering instructors to design effective virtual laboratory experiments. There exist multiple frameworks for learning designs but there is no framework especially for the virtual laboratories and engineering experiment designs. Hence this will contribute to the educational technology field as such a framework is missing.

Method: The methodology used to arrive at the set of guidelines for experiment designs can be followed by others who wish to design and develop guidelines, as there are no guidelines on how to design and develop guidelines.

Tools: As part of the solution the SDVIcE Tool based on the LoTaAs framework is proposed. The SDVIcE Tool is available online at the URL - http://vlabs.iitb.ac.in/vlab_tool/. The SDVIcE tool consists of three sections namely

Introduction, Experiment design for BAE course, and Experiment design for other courses.

Experiment designs: The output of the SDVIcE tool is the experiment designs for effective use of existing virtual laboratories.

In the next chapter 3 the methodology used to carry out the research and arriving at the proposed solution is discussed.

Chapter 3

Research Methodology

3.1 Overall Research Methodology

In this chapter the overall research methodology adopted in the dissertation is presented. The primary objective of this research is to design and develop comprehensive guidelines and templates for the engineering instructors so that they can design experiments for using existing virtual laboratories. The secondary objective is to convert these guidelines to an online tool so as to increase the accessibility of the guidelines. The Needs-Development-Evaluation methodology was selected in order to design and develop the virtual laboratory experiment design guidelines (VLEDG). In the first section insights into the reasons for the choice of the methodology are provided, followed by the characteristics and later section describes the various phases of the chosen methodology. The synthesis of the iterative process of S-D-I-V-E (Scoping-Development-Internal Review-Validation-External Use) is described along with the literature used. The various questions such as research questions (RQ), literature questions (LQ) and design questions (DQ) answered through this dissertation are tabulated and in the last part of the chapter the ethical considerations are discussed.

3.1.1 Needs-Development-Evaluation-Reflection

The main objective of our research is to design and develop comprehensive guidelines for engineering instructors to enable them to use virtual labs effectively by designing quality experiments. A three-step process was followed for arriving at the solution and evaluating the outcomes. This led to the conclusions about the contributions of the research process and reflection, which gives a direction for carrying this work ahead in the future. The three steps of the process are as shown in the Figure 3.1.

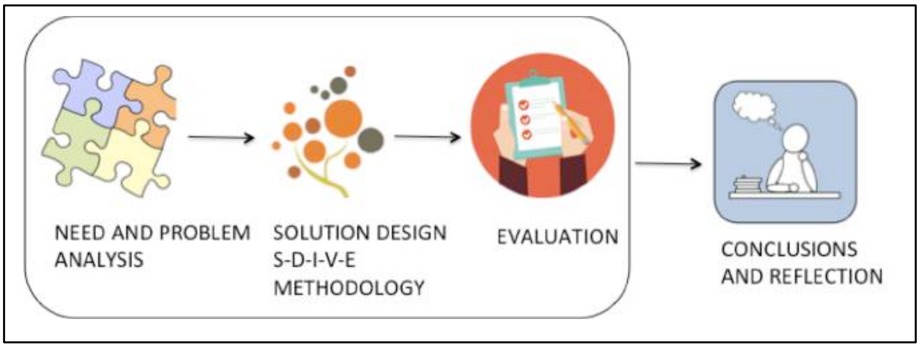


Figure 3.1 Overall Methodology

Phase I - Need and Problem Analysis

In the initial phase of research process the various aspects in the virtual laboratory experiment design for which the engineering instructors perceive the necessity of guidelines were identified. The four studies carried out consisted of

a. One study comprising of Artefact analysis,

b. Two survey studies and

c. One semi-structured interview with engineering instructors.

Phase II – Solution Design S-D-I-V-E Methodology

The methods of guideline development should ensure that the experiments designed according to the guidelines would achieve the desired outcomes. There are a number of guidelines available for evidence-based practice in the field of medical education and practice. These guidelines are developed using standard methods and protocols. The various methods and protocols were analysed and used to synthesize the research method. The main objective of the research was decided as the design and development of framework and guidelines for the experiment designs for virtual laboratories by using the synthesized S-D-I-V-E methodology.

(Anna C Phillips, et.al.2013) in their research project on Guideline for Reporting of Evidence based practice Educational interventions and Teaching (GREET) have followed a protocol for the development of the guidelines as shown in the table 3.1.

Table 3.1: Steps in the GREET protocol

Step	Description
1	Selection of panel
2	Determine the scope of the guidelines
3	Determine the target audience and target population of the guidelines
4	Determine how the evidence will be selected
5	Select and review the evidence to be used in writing the guidelines
6	Write the guideline
7	Submit the guideline for outside review

(George P. Browman et.al. 2015) have described the complete guidelines development cycle with the steps used as given in the figure

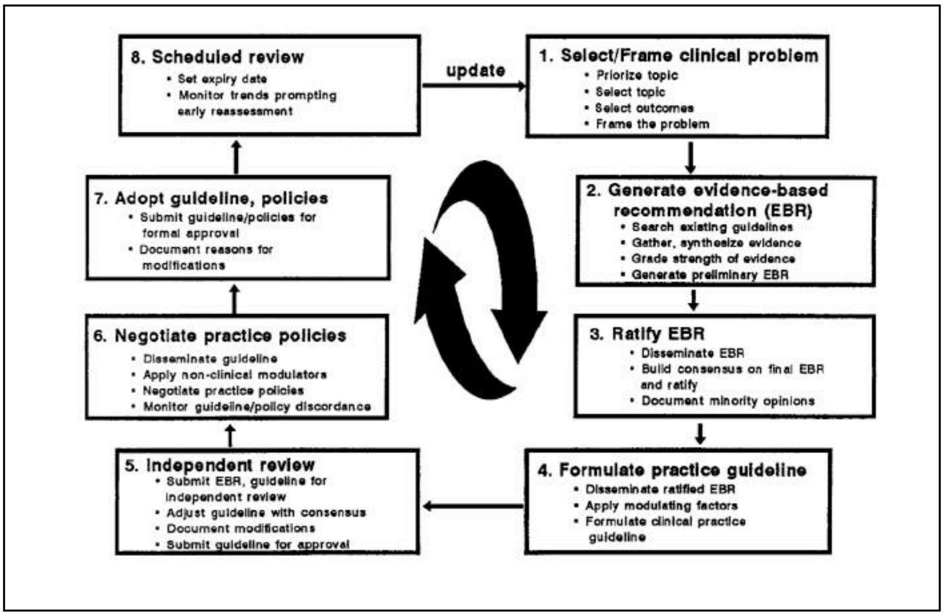


Figure 3.2 Guideline development cycle proposed by George P. Browman et.al. 2015

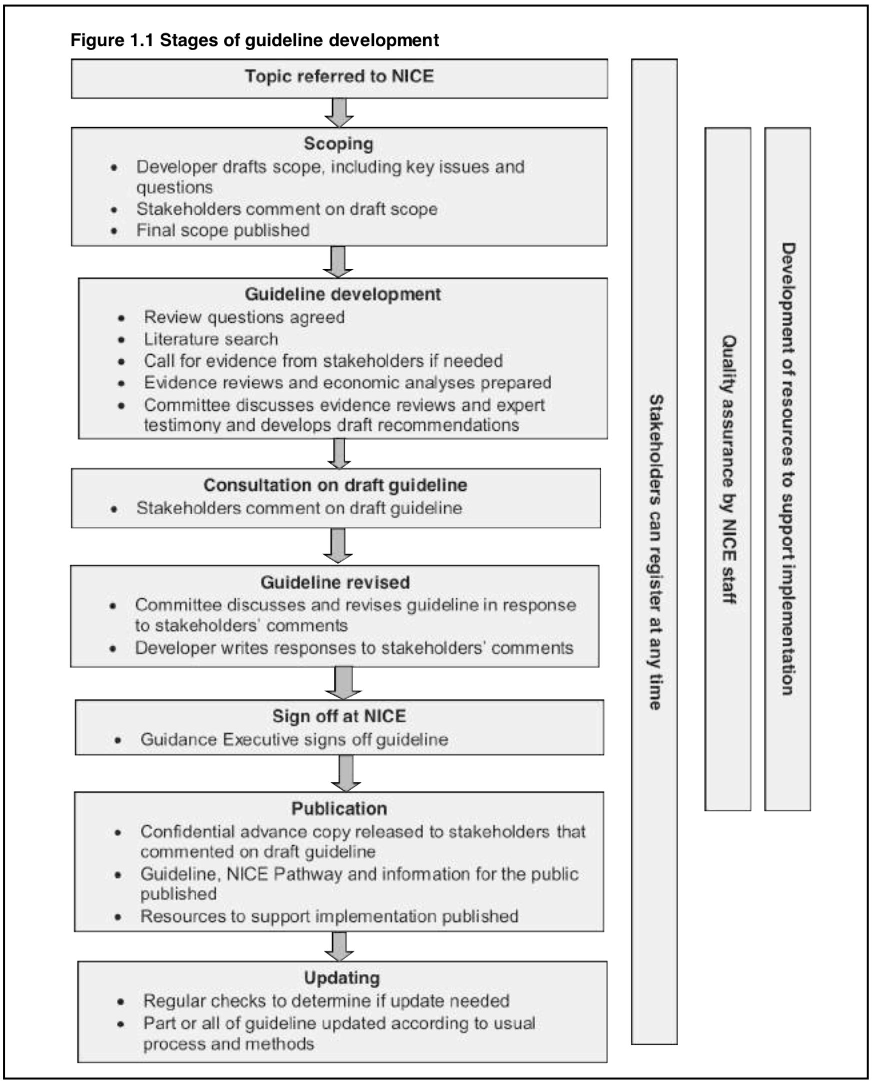


Figure 3.3 Stages of NICE guidelines development process

The National Institute for Health and Care Excellence (NICE) is an independent public body that provides national guidance and advice to improve health and social care in England. NICE guidance offers evidence-based recommendations made by independent Committees on a broad range of topics. The guidelines are based on specific principles and follow the methodology as shown in the figure

The main goal of European Society of Human Reproduction and Embryology (ESHRE) guideline development is the provision of clinical recommendations to improve the quality of health care delivery within the European field of human reproduction and embryology. They follow a twelve-step guideline development process as shown in the figure 3.4.

Figure 3.4 Steps in ESHRE guideline development process

The analysis of these four guideline development methodologies from the literature led us to the decision regarding the various steps for the experiment design guidelines. The following methodology as illustrated in Figure --- was adopted for the design and development of the guidelines for effective virtual laboratory experiment designs. Only those steps relevant in the context of this research were included as part of the synthesized methodology. Some of the steps were modified as per the requirements.

Methodology for Design and Development of Experiment Design Guidelines for Virtual Laboratories

Step I – Scoping: The extent of the research can be defined as per following approach. The following sub steps were carried out as part of this step

1. Writing the scope of the guidelines: This was carried out as per the LoTaAs framework derived from literature review and the four studies with engineering instructors. The decisions regarding the various aspects of guidelines such as which guidelines to be formulated, what criteria to be used for assessing the guidelines and how these guidelines would be reviewed; were taken at this stage.
2. Selection of panel of stakeholders: It was decided that the panel for internal review would consist of two members – one the researcher (ET expert) and the other a subject matter expert (SME). Also the panel consisting of three members for external review would consist of the engineering instructors who will be using the guidelines, subject experts and industry experts.
3. Stakeholders' comments on draft scope: The internal panel would review the scope and arrive at consensus for validity and practicality of the scope of the guidelines.
4. Finalizing the scope: Post the consensus is arrived at; the scope of the guidelines was finalized. The guidelines would be developed as nine sets for virtual laboratories for the course Basic and Advanced Electronics. These nine sets would be as follows: Guidelines would be developed for the following sets.

Set I: Selection of experiment Broad Goal

Set II: Formulation of Learning Objectives at various cognitive levels and skills

Set III: Expository experiment designs at various Difficulty Levels

Set IV: Expository experiment designs incorporating Active Learning methods

Set V: Designing tasks aligned to the learning objectives for Discovery Instructional Strategy

Set VI: Designing tasks aligned to the learning objectives for Well Structured Problem Solving Instructional Strategy

Set VII: Designing tasks aligned to the learning objectives for Problem Based Instructional Strategy

Set VIII: Design of Authentic Assessment Mechanisms

Set IX: Selection of Virtual Laboratory depending on the features

Step II – Guidelines Development: The Following Activities Was Carried Out as Part of this Step

1. Systematic Literature Review for evidence of guidelines: A systematic literature review was carried out in order to formulate the various sets of guidelines. The methodology used for sampling the literature is given in figure--. Initially the literature was reviewed to find out whether guidelines for the various aspects of the experiment design exist. The results of the literature review indicated that there did not exist guidelines for experiment designs for virtual laboratories. Some guidelines exist but are very broad and not specific and also are not in the context of virtual laboratories. Hence the existing guidelines need to be developed/evolved so as to enable engineering instructors to design effective virtual laboratory experiments.

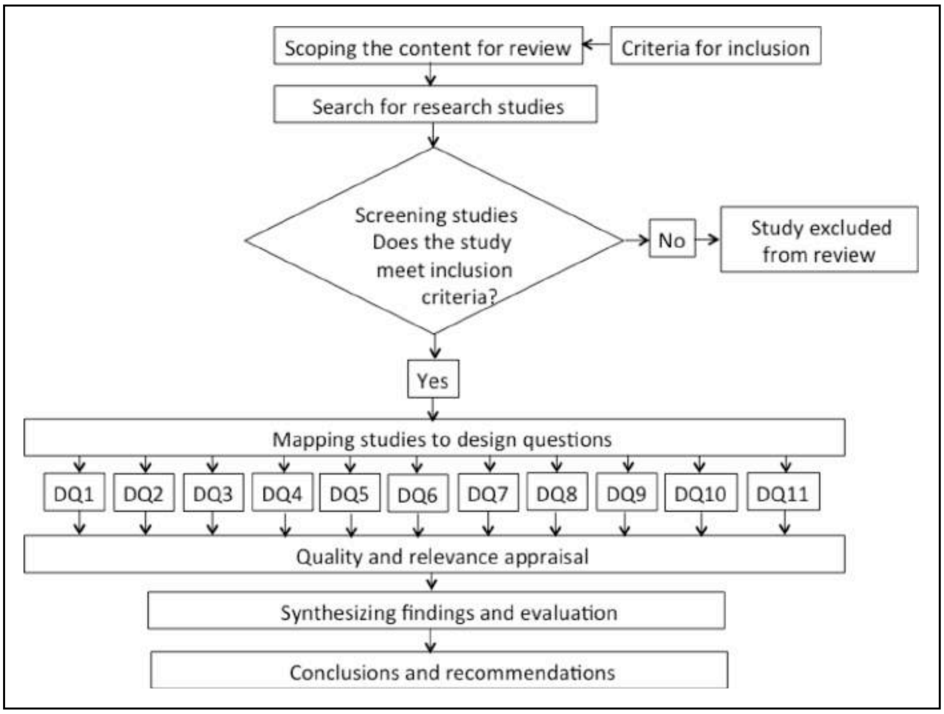


Figure 3.5 Systematic Literature Review

The steps in the Systematic Literature Review process were

1. Deciding the criteria for inclusion of the study
2. Scoping the content for review
3. Search for research study
4. Screening the studies
5. Mapping the studies to the aspect of the experiment design process
6. Quality and relevance appraisal

1. **Deciding the criteria for inclusion of the study**

The review process was started by developing explicit criteria for specifying which studies would be included in the review. The following were the criteria selected for including a particular research study for the review process.

Table 3.2: Parameters used to shortlist contents of review

Criterion type	Inclusion Criteria
Topic	Literature must relate directly to one of the research questions
Recency	Literature should have been published between 2005 and 2015 (although a few older studies of particular relevance to the review objectives were included).
Age-range	Literature should relate to higher education, engineering education
Geographical spread	Literature should relate to Indian engineering education and with examples from other countries with similar education systems or where the context of the study was similar
Research base	Literature must be based upon empirical research (either qualitative or quantitative).
Transparency	The methodology of the research upon which the literature is based must be made explicit (e.g. sample sizes, instruments, analysis).
Reliability/validity	The findings upon which the literature is based must be valid and reliable, taking into account the type of study.

2. Scoping the content for review

After making the decision regarding the criteria for inclusion the search for the literature was scoped based on the selected criteria. Only those articles would be searched which would adhere to these criteria.

3. Search for research study

Next started the literature search using the various available databases such as Google Scholar and Eric. The search terms were restricted to the particular aspect of the Solution design for example for the aspect of the experiment design process the search term used was laboratory, experiment design, virtual lab, learning design. The following is an illustrative example of the study, which was included in the analysis and the criteria it fulfilled.

Example:

The TriLab, a novel ICT based triple access mode laboratory education model

Mahmoud Abdulwahed, Zoltan K. Nagy*

Why this paper included?

The table above shows the criterion used for analysis towards the decision for inclusion of a study.

Table 3.3: Criteria for inclusion of example research study

Criterion type	**Inclusion Criteria**
Topic	The study introduces a novel model of **laboratory education**
Recency	The study has been published in 2011
Age-range	The study is related to higher education, engineering education
Geographical spread	The study is related to engineering education (Chemical Engineering Department, Loughborough University, United Kingdom)
Research base	The study is based upon empirical research (both qualitative or quantitative).
Transparency	The methodology of the research upon which the literature is based is explicitly given (e.g. sample sizes, instruments, analysis)

Reliability/validity	The findings upon which the literature is based are valid and reliable.

4. **Screening the studies**

Each piece of literature was screened against the inclusion criteria (Table). This helped to avoid hidden bias, by having clear consistent rules about which studies were being used to identify the guidelines for the different aspects of the experiment design process. By appraising each study against the same criteria and recording the results, the basis for the review's conclusions was made transparent.

5. **Mapping the studies to the particular aspect of the experiment design process**

The methodology and findings from each included study was outlined, including variables such as population; focus, study design and key characteristics related to the aspect of the experiment design process. Triangulation was provided by two researchers reviewing literature for each aspect, and by independent analysis of the studies that addressed more than one aspect.

6. **Quality and relevance appraisal**

Each study to be included was evaluated in the descriptive map in terms of:

a. The trustworthiness of the results judged by the quality of the study within the accepted norms for undertaking the particular type of research design used in the study (methodological quality).

b. The appropriateness of the use of that study for addressing the particular aspect (relevance).

2. Formulate the draft guidelines: Once it was observed that the existing guidelines were not suitable in the context of engineering laboratories and specifically the virtual laboratories, the draft of the guidelines for all the nine sets were designed and developed with collaborative efforts by the ETR and SMEs.

Step III – Internal Review

Decision regarding criteria

1. Design feedback questionnaire: The draft guidelines were initially reviewed internally and hence the feedback questionnaire was designed. The questions were written based on the selected criteria for the guidelines. The subject expert validated the questions after being framed by the researcher (ETR).
2. Get feedback from internal reviewers: The panel reviewed the draft guidelines internally and arrived at the consensus regarding all the guidelines. The review was carried out based on the designed questionnaire.

Step IV – Validation

The following sub steps were carried out as part of this step

1. Submit guidelines for external review: The draft guidelines were given for review to the external stakeholders. Each set of guidelines would be given to a panel of three members. They were also given the questionnaire to assess the validity and suitability of the guidelines for the context of this research.
2. Adjust or modify guidelines: After the external review depending on the feedback necessary changes were made to the guidelines. The modified guidelines were again reviewed internally and the modification carried out till a consensus was arrived amongst the researcher and internal reviewer.

Step V - Iterative Process of Guideline Refinement

Make the guidelines available for external use

1. Document the guidelines: Once the guidelines were finalized after the double review process, they were systematically written as a document which were presented to the engineering instructors for the initial pilot testing and later use in the experiment designs.
2. Make them available online in the SDVIcE tool: The last step was to convert these paper-based guidelines into the online version in the form of the SDVIcE tool for increasing the accessibility.

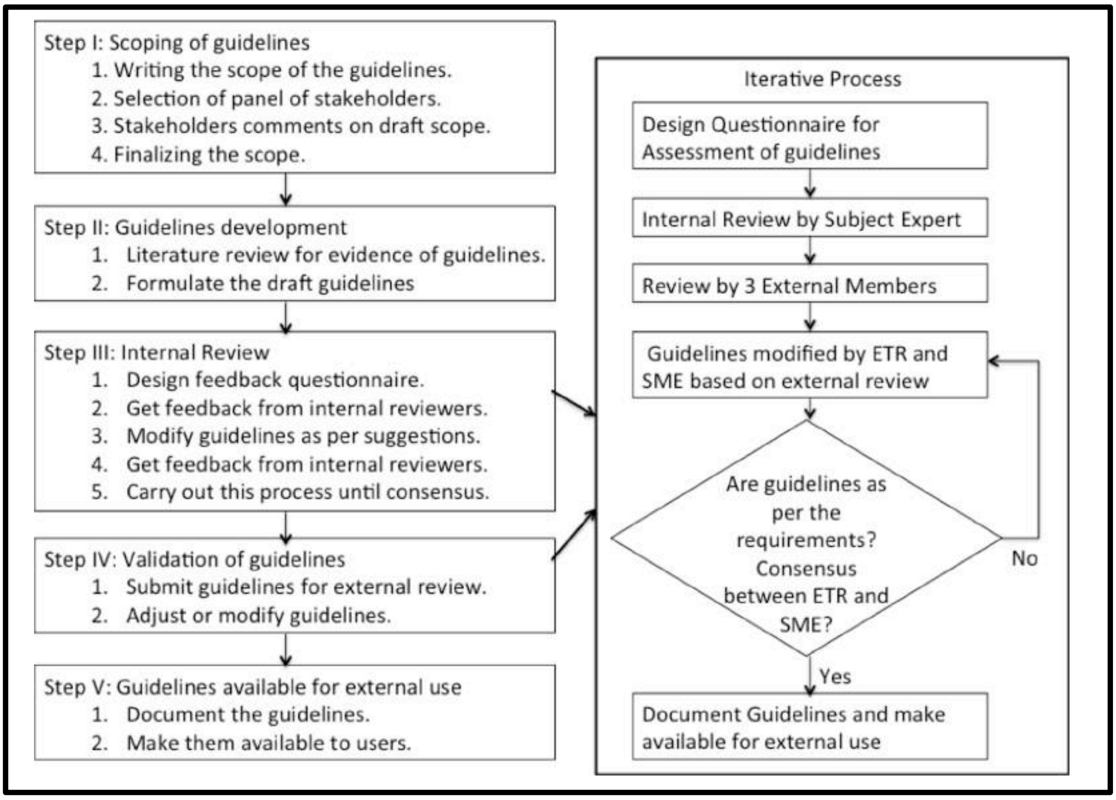


Figure 3.6 S-D-I-V-E (Scoping-Development-Internal Review-Validation-External Use)

Phase III Evaluation

In the final Evaluation phase of the research the summative evaluation of experiment design guidelines for using existing virtual labs was carried out. This constituted of three stages

1. Usability Study

   This SUS survey study was carried out with 58 engineering instructors to find out their perceptions regarding whether they find the experiment design guidelines usable in their design process.

2. Usefulness Study

   This survey study with 58 engineering instructors was carried out to find out if they perceive the experiment design guidelines to be useful in their design process.

3. Effectiveness Study

   a. Effectiveness of guidelines with respect to the output of experiment designs

      This field test study was aimed at finding out if the quality of the experiment designs improves after the 10 engineering instructors use the guidelines in the SDVIcE tool to design four experiments each.

   b. Impact Study: Effectiveness with respect to impact on students' learning

      The impact of the experiment design guidelines is measured by means of three control group experimental group studies.

      - One study is carried out with 29 UG engineering students by the researcher,

      - The second is a replicate study with 142 UG engineering students carried out by SME's and

      - The third again a replicate study with 150 UG and 18 PG engineering students carried out by SME's with experiment design targeting different topics.

Methodology Used for Quality Assurance of the VLEDG

In the evaluation of the solution eight criteria were used to assess the quality of the designed and developed guidelines. The final guidelines were designed and developed such that they would meet all these criteria.

Criterion 1 - Features

Components	How was the particular criterion met in the final guidelines?
Supported by evidence	For each guideline a corresponding example from BAE is provided.
Not be very contextual	The guidelines are designed for the BAE course but they are valid for other domains also.
Based on theory and practice	The evidence from literature is based on theory and practice.
Justification for inclusion	The various studies as part of the need and problem analysis phase provide a justification for inclusion of the guidelines.
Limitations of the guideline	The scope of the guidelines is clearly given.

Criterion 2 – Structure

Components	How was the particular criterion met in the final guidelines?
Specifies the rules or principles for action	The guidelines specify rules for action.
Relevant for the context	The guidelines are designed for the research context.
Accurate	The stakeholders validate the accuracy of the guidelines.
Comprehensive and specific and not broad	The guidelines are comprehensive and not broad. Also examples from BAE are given for each guideline to make them more specific.

Criterion 3 – Overall scope and purpose

Components	How was the particular criterion met in the final guidelines?
Overall objective(s) specified	Objectives of each guideline are specified.
Question(s) covered specified	The design question, which the guideline answers, is specified for each aspect of the experiment design.
Population is specified	The population who are going to use the guidelines is specified. They are the engineering instructors from different domains.

Criterion 4 – Stakeholder involvement

Components	How was the particular criterion met in the final guidelines?
Individuals from all relevant groups	Objectives of each guideline are specified.
Views and preferences of the target population	The design question, which the guideline answers, is specified for each aspect of the experiment design.
Target users of the guideline are clearly defined	The population who are going to use the guidelines is specified. They are the engineering instructors from different domains.

Criterion 5 – Rigor of development

Features	How was the particular criterion met in the final guidelines?
Systematic methods for evidence search	The Systematic literature review methodology was followed for the evidence search.

Clear criteria for selection of evidence	The criteria for inclusion are clearly defined.
Strengths and limitations of evidence	The strengths and limitations of the evidence used are provided.
Methods for formulating the recommendations	A rigorous method (S-D-I-V-E) was followed to refine and formulate the final guidelines.
Explicit link between the recommendations and the supporting evidence.	The literature with theoretical as well as practical evidence for each guideline is provided.
Review by experts	A two level review was carried out for each guideline. Internal review by the ETR and the SME and external review by a panel of three members comprising of Engineering instructors and SMEs.

Criterion 6 – Clarity of presentation

Components	**How was the particular criterion met in the final guidelines?**
Specific and unambiguous	The language used to formulate the guidelines is simple and the use of non-comprehensive jargon and words has been minimized.
Clear and concise	
Easily identifiable	
Clearly presented	

Criterion 7 – Applicability

Components	**How was the particular criterion met in the final guidelines?**
Facilitators and barriers to its application	The information regarding the pros and cons of the guidelines is provided.

Provides advice and/or tools	The guidelines are made available as an online tool for the engineering instructors
Resource implications	The information about the resources that will be required in order to incorporate the guidelines are provided.

Criterion 8 – Editorial independence

a. The guideline is not biased towards a specific methodology

None of the guidelines are biased towards any specific

- Methodology
- Virtual laboratory
- Teaching learning strategy

The dimensions of the criteria highlighted in blue are taken care of for all the guidelines by the S-D-I-V-E methodology followed. The dimensions in black are included in the feedback questionnaire as Five Point Likert Scale Questions.

3.1.2 List of RQs, LQs, DQs and Corresponding Studies/Activities

There are three types of questions to which answers are found out through this research. They are

Research Questions (RQs) – These are questions for which the answers are found out by carrying out studies such as online surveys, face to face interviews, artefact analysis and control group experimental group studies with quantitative and qualitative data analysis.

Design Questions (DQs) – The answers to these questions lead to the design and development of the guidelines for the various aspects of experiment design in the final solution phase by the S-D-I-V-E methodology.

Literature Questions (LQs) – These questions are answered by a review and analysis of the literature. Their answers lead to the research objectives and guide towards the primary objective of this research.

Table 3.4: List of various questions answered in the thesis

Research Phase		RQ/DQ/LQ		Method
Phase I				
Need and Problem Analysis	Specific RQ	RQ1	What are the perceptions of engineering instructors regarding the guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics?	Literature review and Four studies – Study 1,2,3,4.
	Study 1	RQ1a	What are the problems in the experiment designs used in the traditional laboratories?	Artifact analysis
	Study 2	RQ1b	What are the perceptions of engineering instructors about the usefulness and effectiveness of virtual laboratories as compared to the traditional laboratories?	Survey
	Study 3	RQ1c	How can the problems faced by engineering	Semi-structured

			instructors in using virtual laboratories in their teaching be solved?	interviews
	Study 4	RQ1d	What are the various aspects in the experiment design process using virtual laboratories for which engineering instructors need guidelines?	Survey
		LQ3a	What is a guideline?	Literature review
		LQ3b	What are the various criteria for guidelines?	Literature review
		LQ3c	What are the various methods to design and develop guidelines?	Literature review
Research Phase II				
Development		DQ1	What guidelines will help engineering instructors in achieving their laboratory goals by making effective use of virtual laboratories for the course Basic and Advanced Electronics?	Iterative Guidelines refinement procedure (S-D-I-V-E)
		DQ1a	How to select the broad goal depending on the type of topic content to be covered by the virtual laboratory experiment?	Iterative Guidelines refinement procedure (S-D-I-V-E)
		DQ1b	How to formulate valid and	Iterative Guidelines

			clearly defined learning objectives at different cognitive levels as per Revised Blooms' Taxonomy for virtual laboratory experiments aligned to the broad goal?	refinement procedure (S-D-I-V-E)
		DQ1c	How to design virtual laboratory experiment at different difficulty levels with Expository instructional strategy?	Iterative Guidelines refinement procedure (S-D-I-V-E)
		DQ1d	How to incorporate active learning methods in the virtual laboratory experiment design?	Iterative Guidelines refinement procedure (S-D-I-V-E)
		DQ1e	How to design an effective virtual laboratory experiment with Discovery or Guided Inquiry instructional strategy?	Iterative Guidelines refinement procedure (S-D-I-V-E)
		DQ1f	How to design an effective virtual laboratory experiment with Well-Structured Problem Solving Instructional strategy?	Iterative Guidelines refinement procedure (S-D-I-V-E)
		DQ1g	How to design an effective virtual laboratory experiment with Problem-Based instructional	Iterative Guidelines refinement procedure

			strategy?	(S-D-I-V-E)
		DQ1h	How to design authentic assessment for virtual laboratory experiment?	Iterative Guidelines refinement procedure (S-D-I-V-E)
		DQ1i	How to select virtual laboratory with features aligned to the learning objectives of the experiment?	Iterative Guidelines refinement procedure (S-D-I-V-E)
Summative Evaluation		RQ2	Are the refined guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics usable, useful to engineering instructors and effective in improving the quality of experiment designs and students laboratory learning outcomes?	Five studies for summative evaluation of refined guidelines
		RQ2a	What are the perceptions of engineering instructors regarding the usability of the experiment design guidelines?	System usability score based on SUS survey - Study 5
		RQ2b	What are the perceptions of engineering instructors regarding the usefulness of the experiment design	Usefulness analysis based on survey with Five point Likert Scale

			guidelines?	
		RQ2c	What is the effectiveness of the experiment design guidelines in improving the quality of the experiment designs for using virtual labs?	Analysis of experiment designs for quality based on a rubric
		RQ2d	What is the impact of the virtual lab experiments designed using the guidelines on the students' laboratory learning outcomes?	Statistical analysis of difference in students' performance in Post- test in Control Group Experimental Group study carried out by Researcher and SMEs

3.2 Ethical Considerations

All the research studies involved human participants so all the necessary ethical guidelines were followed and utmost care was taken to maintain privacy and confidentiality of the data.

All the participants/stake holders (engineering instructors, subject experts and UG engineering students) were a priori informed about the research and consent was obtained before the actual participation in the surveys, interviews and the experimental studies.

After they had performed the various tasks a written consent was taken from the participants stating that the researcher can use the data of the survey. The questionnaire was administered only after obtaining the consent. They were given enough time to fill up the survey.

In the next chapter the Phase I of the research that is Need and Problem analysis is discussed.

Chapter 4

Need and Problem Analysis

In the previous chapter the methodology that would be followed in order to arrive at the Virtual laboratory experiment design guidelines (VLEDG) was synthesized and discussed. As per the methodology the first phase in the research is the Need and Problem Analysis. In this chapter the details of the four studies carried out as part of this phase are described.

4.1 Problem Analysis: Perceptions of Engineering Instructors Regarding the Use of Virtual Laboratories

In this chapter solution to the primary research question of the Need and Analysis phase is obtained. The primary research question is:

RQ1: What are the perceptions of engineering instructors regarding the guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics?

In order to get practical insights into the broad problem four studies were carried out with engineering practitioners who face various problems in their laboratory teaching.

The results of the literature analysis points out to the fact that comprehensive and detailed guidelines for designing virtual laboratory experiments do not exist. In order to assist the engineering instructors to design student-centered, effective experiments for the virtual laboratories specific guidelines are necessary. The engineering instructors have been using experiment designs to achieve their laboratory learning objectives in the physical laboratories for many decades. In order to find out if the same designs can be used for the virtual laboratories as well the analysis of the experiment designs used currently in the context of this research was carried out. In the first section the details of the artefact analysis study of 98 experiment designs used in traditional laboratories for the past five years for UG engineering for the BAE course are presented. The review of literature indicates the shortcomings of the current laboratory experiment designs used in physical environment. Thus the main objective of the artefact analysis was to find out the problems in the experiment designs currently used in physical laboratories.

4.2 Study 1: Analysis of the Existing Traditional Laboratory Experiment Designs for the Course Basic and Advanced Electronics Under Mumbai University (Experiment Designs Used in Traditional Laboratories)

4.2.1 Objective

The main objective of this study on artefact analysis was to find out the quality of the experiment designs used by the engineering instructors to carry out the laboratory work in traditional laboratories in the context of this research. The literature on laboratory experiments points out the various problems related to traditional laboratory experiment designs.

4.2.2 Literature Review

Engineering laboratory instruction has reached a crisis level due to inadequate instructional resources and lack of challenge and initiative provided to the students in performing routine or predefined experiments. Realistic and challenging goals must be set so that the students can become able experimenters.

In most school laboratory activities, the student's laboratory guide, handbook, or worksheet, sometimes delivered in electronic form, continues to play a central role in shaping the students' behaviors and learning. The guide focuses students' attention on the questions to be investigated and on what is to be done, observed, interpreted, and reported. It plays a major role in defining goals and procedures. The analyses of the laboratory guides suggests that to date, many students engage in laboratory activities in which they follow recipes and gather and record data without a clear sense of the purposes and procedures of their investigation and their interconnections. (Johnstone and Wham, 1982) point out that the quantity of information presented in the laboratory guide is so substantial, that the details can distract the learner from the main goals of the practical task. The students are not provided with opportunities to develop higher order cognitive abilities (Lunetta and Tamir, 1979). Also the tasks assigned do not make the students to discuss the scientific knowledge associated with the investigation. Most of the tasks follow a "cookbook" approach (Roth, 1994).

There are serious discrepancies between recommended teaching learning practices and their implementations. Large numbers of teachers are not using authentic and practical assessment on a regular basis, as they perceive that they do not have the time and skills to implement such assessment methodologies successfully. Also they are reluctant due to a lack of knowledge regarding students' laboratory learnings, ways in which the outcomes can be achieved and designing experiments to achieve the goals. There is a lack of understanding regarding: how to assess the students' learning effectively and efficiently when they are engaged in inquiry and practical work, how to engage students with different skills and knowledge in practical experiences that result in meaningful learning and how to promote a more effective laboratory learning environment.

4.2.3 Hypothesis

H1a. The quality of experiment designs used in the current engineering instructional laboratories for the course Basic and Advanced Electronics needs to be improved.

4.2.4 Research Question

RQ1a: What are the problems in the experiment designs used in the traditional laboratories?

4.2.5 Methodology

After reviewing the curriculum document of the University in the context and scope of the research work it was observed that the learning outcomes for the theory course are defined clearly in the curriculum document but they are not clearly specified for the laboratory work. The instructors therefore face many difficulties in carrying out and assessing the lab work. The usual methodology followed is that the instructors refer to the previous years lab manual and implement the same experiment designs. So as pointed out in literature the cookbook methodology continues for years together. Another problem is that each and every institute affiliated to the University follows a different methodology for the conduction of lab work. There is a need for standardization of the lab work carried out in engineering laboratories. ABET and other accreditation bodies have specified the labwork learning objectives to be fulfilled in the four years of UG engineering course. These problems need to be resolved by a systematic design of the labwork instructional design specifying the learning outcomes of each experiment.

4.2.6 Sample

The following methodology was used to carry out the sampling of the engineering laboratory manuals. The course Basic and Advanced Electronics is a mandatory course in all universities in the state of Maharashtra for the UG degree in the domain of Electronics engineering. The curriculum is available on the online portals of the universities and institutes. The curriculum document gives a list of experiments related to the various topics covered in the theory. Some institutes have a separate laboratory course with the same name as the theory course. The laboratory manuals of some institutes are available on their portals. Such manuals were downloaded and reviewed. For those institutes where the lab manuals were not available online a request was sent to the instructors conducting these courses.

A random sampling procedure was used to select the manuals for analysis. The sample for the study constitutes a total of ninety-eight experiments from ten laboratory manuals.

4.2.7 Data Analysis

The content analysis methodology was used to analyse the experiments and measure their quality.

4.2.8 Results

The following table 6.4 gives the results of the content analysis of the 98 experiments randomly selected in the research context.

Table 4.1: Results of artefact analysis

Components of the experiment in the laboratory manuals	Percentage of experiments in which component specified	Percentage of experiments in which component not specified	
Broad goal	100	0	
Learning objectives	100	0	
Background theory	100	0	
Apparatus to be used	100	0	
Circuit/System design	95	5	
Procedure	96	4	
Information about what data to be collected	90	10	
Data Analysis and Results	70	30	
Results Interpretation	20	80	
Conclusion	0	100	
Criteria/Broad goal/Focus area	**Reinforce theoretical concepts**	**Practical Skills and Instrumentation**	**Modeling**
	89%	70%	10%
	Data Analysis	**Learn from failure**	**Experimentation**
	10%	5%	7%
Instructional strategy used **(Percentage of manuals)**	Expository (83%)	Inquiry and Discovery (Guided inquiry) (0%)	Structured problem solving (10%) Problem-Based

			(7%)
Cognitive level of learning objectives	Lower level – Recall and Understand – 76%	Level – Apply and Analyze – 18%	Higher level – Evaluate and Create – 6%
Task profiles	Objects domain – 95%	Ideas domain – 5%	
Assessment Questions	Given 80%	Not given 20%	
Assessment Questions	Based on theory 90	Based on labwork 10	
Rubrics for assessment	Specified 10	Not specified 90	
Rubric parameters	Circuit implementation and measurement	Interpretation of result	Experiment report submission

The following can be inferred from the analysis of the existing experiment designs used in the traditional laboratory work.

1. Broad Goal of the experiment:

- In 90% of the experiment designs the Broad goal is stated as " To study ….a particular topic"
- In 5% of the experiment designs the Broad goal is " To analyse ….a particular circuit"
- In the remaining 5% of the experiment designs the Broad goal is " To design ….a particular circuit"

2. Instructional strategy:

- 83 % of the experiment designs have used Expository Instructional Strategy, which has its limitations as pointed out by literature.
- 10% of the experiment designs have used Structured problem solving Instructional Strategy
- 7% of the experiment designs have used Problem-Based Instructional Strategy
- 0% of the experiment designs have used Discovery Instructional Strategy

3. Learning Objectives:

- 76% experiments had learning objectives at lower cognitive levels,
- 18% experiments had learning objectives at apply and analyze level and only 6% experiment designs had learning objectives at higher levels of evaluate and create.

4. Laboratory task designs:

- In 95% of the experiment designs the tasks the students are required to perform in the laboratory are in the objects domain and 5% in the ideas domain.
- In 90% of the tasks students had to follow certain instructions and carry out a particular procedure. The students were not provided with the opportunity to carry out challenging tasks. Most of the tasks were at the lower cognitive levels and very few at the higher cognitive levels.
- Most of the tasks were defined and the students did not have opportunity to make decisions regarding the tasks they need to carry out to arrive at certain results.

5. Laboratory Assessment:

- In 90% of the experiment designs the assessment questions asked were based on theory taught in the classroom. The students' knowledge, skills or cognitive abilities were not assessed.
- Only 10 % of the experiment designs specified the rubric to be used for the assessment of labwork carried out by the students.
- Only 5% of the experiment designs had assessment questions aligned to the students laboratory work.
- None of the experiment designs had formative assessment incorporated.
- 100% of the assessment of the lab work was done based on the manual submitted at the end of the semester.
- None of the experiment designs had any other methodology for assessing the students lab work such as presentations, reports etc.

6. Learning Objectives of the experiment:

- For 89% of the experiment designs the learning objective was reinforcement of theoretical concepts.

- For 70 % of the experiment designs the learning objective was development of practical skills
- For only 7% of the experiment designs the learning objective was developing the skill of experiment design amongst the students.
- For only 5% of the experiment designs the students had opportunity to learn from failure.

7. Difficulty level of the experiments

- 90 % of the experiment designs were at the low difficulty level
- 5% of the experiment designs were at the Medium difficulty level
- 5% of the experiment designs were at the High difficulty level

8. Incorporation of active learning methods and constructivist approach
   None of the experiment designs had incorporated the active learning methods and constructivist approach.

4.2.9 Conclusions Study 1

1. There is a need for an improvement in the overall quality of the experiment designs used by engineering instructors.
2. In majority of the experiment designs the Broad goal was "To study" a particular topic.
3. In majority of the experiment designs the target learning objectives were at lower cognitive levels. Hence engineering instructors should design the experiments with higher cognitive levels.
4. Most of the experiment designs were of cookbook nature following the expository instructional strategy. The Discovery strategy is shown to be effective in achieving the laboratory goals (De Jong, T. Van Joolingen, W. R., 1998, T.Shiland, 1999, R.Felder et al., 2000, 2004, K.Paul et al., 2006, D.Klahr et al., 2007, J.Wirth et al., 2009, T.Gupta et al., 2015). Similarly the Well-structured problem solving has been proved effective by the studies by (R.Felder et al., 2000, 2004, M. Yukhymenko et al., 2014, N.Balta, 2015, C.Miller et al., 2007, T.Gog et al., 2008). There are many proponents of

Problem-based instructional strategy in the virtual laboratory (R.Felder et al., 2000, 2004, A. Nonclercq et al., 2010, J.Kim, 2012, W.Akili, 2011, D.Lowe et al., 2012, C. Akdeniz, 2012) and it has been shown to be effective in achieving the laboratory learning objectives. Hence the instructors need to design experiments with various instructional strategies such as Discovery, Well-structured problem solving, Problem-based etc. which have been proved effective by various research studies in the literature.

5. When the labwork task is implemented it can be observed what the students actually do on the task, and assessment of what they actually learn can be carried out. All labwork involves students in handling objects and observable things. However tasks require students to do different kinds of things, for example, to use something, or to make something, or to observe or measure something. So a task cab be classified according to what students are intended to do with objects and observable things (Robin Millar et al. 1998). The tasks such as use a laboratory device, display a component, construct a circuit, and observe the readings on a particular meter etc. are tasks in the objects domain. The tasks such as report an observation, identify patterns from observations, explore relationships between variables, predict an output, give reasons for a particular results etc. are tasks in the cognitive or ideas domain. It is very essential that the tasks assigned to the students in the laboratory should provide opportunities to work in both the domains and also provide a link between these two domains as shown in the figure

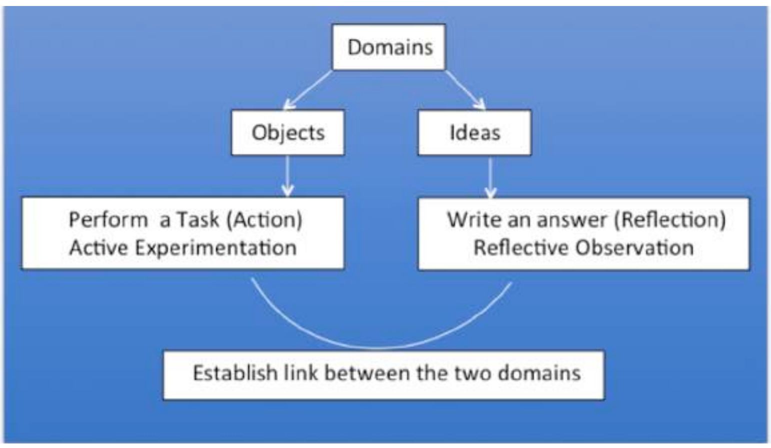


Figure 4.1 Two domains of laboratory tasks

It is observed that in the current laboratory experiment designs there are very few tasks, which provide opportunities to students to link the two domains of objects, and ideas or concepts domain, which is a very important aspect for development of knowledge and skills amongst the students. There is a need for redesigning the laboratory tasks so that students feel challenged in carrying out the lab work and are able to link the two domains.

6. The tasks should provide students with opportunities to make certain decisions so as to arrive at the desired results instead of making them follow the specified procedures.
7. The assessment is one of the most important aspects in the learning process. It provides the students with the motivation to excel and hence the laboratory assessment needs to be authentic and should assess the students' knowledge, skills and cognitive abilities.
8. The formative assessment needs to be incorporated so as to help the students understand their level of learning.
9. The assessment must be aligned to the learning objectives and hence if the learning objectives are at higher cognitive levels the assessment questions too should be at higher cognitive levels.
10. The experiments need to be designed at various difficulty levels so that the students' skills such as investigative, inquiry etc. and cognitive abilities such as problem solving, analysis, etc. are developed through the laboratory work.
11. There are no experiment designs, which incorporate the constructivist approach and active learning methods.

4.2.10 Discussion

The results of the analysis indicate that majority of the engineering instructors are not aware of the various instructional strategies that can be used in the laboratory instructions. These strategies can help in achievement of the desired laboratory learning objectives and can lead to the development of required skills amongst the students. The complete experiment design process should be based on sound educational technology theories and there is a need to formalize the experiment design process. The results point out the problems of students' learnings and skill development in the physical laboratories. This led to the decision of further exploration of the possibility of whether these problems can be resolved using the virtual laboratories.

In the areas of engineering education due to various shortcomings of the traditional laboratories, virtual laboratories have appeared as a potential alternative to traditional laboratories (Serb, G. P. et al., 2008). (Woodfield et al., 2005) reported improved student learning as a result of use of virtual chemistry laboratory. The improved learning efficiency led to this improvement. In the virtual laboratory students are not bogged down by minute details of the process or technique and so it enables the development of higher order thinking skills (Woodfield et al., 2005). Majority of comparative studies have concluded that simulation is a good substitute for hands-on labs in teaching course concepts and their application. Some researchers have proposed that simulation might be most effective when it is integrated as a complementary part of a course involving hands-on labs (Abdulwahed & Nagy, 2011; Parush, Hamm, & Stubb, 2002). (Engum, Jeffries, & Fisher, 2003) convey that the virtual laboratories are as effective as traditional laboratories as the learning outcomes in both formats were found to be similar. The literature clearly indicates that the virtual laboratories have the potential and affordances that can resolve the problems in the traditional labs.

These inferences form the basis of the second study in which the perceptions of the engineering instructors regarding the usefulness and effectiveness of virtual laboratories were gathered. The virtual laboratories are being used in UG engineering education in the context of this research. The details of this study are presented in the next section.

4.3 Study 2: Engineering Instructors' Perceptions About Virtual Laboratories

4.3.1 Objective

The main objective of this survey study was to get an insight into the perceptions of the engineering instructors about the usefulness and effectiveness of virtual laboratories.

4.3.2 Research Question

RQ1b: What are the perceptions of engineering instructors about the usefulness and effectiveness of virtual laboratories as compared to the traditional laboratories?

4.3.3 Hypothesis

H1a: The engineering instructors perceive that virtual laboratories are more useful compared to the traditional laboratories

4.3.4 Methodology

In order to gather the perceptions of the instructors at diploma and degree level engineering workshops were conducted at the premises of the institutes. The researcher initially gave a 30-minute presentation to the instructors describing the virtual labs and then the engineering instructors were asked to work with the virtual labs in their domain for about an hour. They were asked to perform one experiment in the virtual lab with simulation for their choice of course. This was done so that the instructors could find out the difference in the traditional labs and virtual labs.

Multiple workshops at various engineering institutes were conducted. All the groups worked with virtual labs with simulations.

After they had performed one experiment a written consent was taken from the participants so that the researcher could use the data of the survey. After obtaining the consent the questionnaire was administered. They were given enough time to fill up the survey. The survey was administered in a pencil and paper format.

4.3.5 Sample

The total number of participants who responded to the survey and gave their feedback was 430.

4.3.6 Instrument

The survey questionnaire consisted of nine questions with five questions of five point likert scale format, one a Yes/No type and one with open-ended responses. There were three questions to find out the demographic information of the participants, one question to find out if the engineering instructors face problems in the traditional laboratories and four questions to find out the perceptions of the instructors regarding the attractiveness, usefulness and effectiveness of virtual labs. There was one question to find out if the instructors are aware of the virtual labs and one to find out if they have used or are using these labs in their teaching.

Table 4.2:Questions in the survey

S.No	Type of question	Question
Q1.		Your Name

Q2.		How many years of experience do you have in engineering education?
Q3.	Open-ended	What are the courses you have taught or going to teach?
Q4.	(Yes/No)	Do you face problems while conducting laboratory sessions?
Q5.	(Five point Likert scale)	I am aware of the virtual laboratories.
Q6.	(Five point Likert scale)	I use virtual laboratories in my laboratory teaching.
Q7.	(Five point Likert scale)	I feel that the virtual laboratories are more effective than traditional laboratories.
Q8.	(Five point Likert scale)	I feel that the virtual laboratories are more useful than traditional laboratories.
Q9.	(Five point Likert scale)	I will use the virtual laboratories in my future laboratory teaching.

4.3.7 Data Analysis

By combining the responses to the two scales of strongly agree and agree and strongly disagree and disagree the analysis of responses to likert scale questions was carried out. All the 430 participants responded to the survey.

4.3.8 Results of Analysis of Likert Scale Data

The engineering instructors who responded to the survey were having teaching experience ranging from one year to fifteen years and were from the domains of Mechanical, Electrical, Civil, Chemical, Electronics, Electronics and Telecommunication, Computer Science and Information Technology.

From the data analysis of the responses to the questions the following was inferred

- 100% instructors have responded that they face various problems while conducting the lab work in the traditional laboratories.
- 60% of the faculties were aware of Virtual Laboratories
- 5% are using these labs
- 93% feel Virtual labs are more useful than traditional labs.
- 93% feel Virtual labs are more effective than traditional labs.
- 100% felt that they would use these labs in future.

4.3.9 Results of Analysis of Open-Ended Response

The main purpose of this survey was to find out if the engineering instructors perceive virtual laboratories to be a useful technology for their teaching. The results of the survey indicate a positive perception of the engineering instructors.

4.3.10 Conclusions of Study II

The main purpose of this study was to get an insight into the perceptions of the engineering instructors regarding the usefulness and effectiveness of the virtual laboratories as compared to the traditional laboratories. The target objective was to find out if the instructors were having a positive perception towards the virtual labs. This study gave a direction to the further work, as the next task was to find out the problems the engineering instructors face while using the virtual laboratories.

It was observed that although all the instructors were aware of the virtual laboratories and 93% perceived that these are more useful and effective than the traditional labs only 5 percent were using the virtual labs in their teaching.

4.3.11 Discussion

The results of the study indicate that although the engineering instructors perceive the virtual labs to be useful and effective they are not using them in their regular teaching. The review of literature on virtual labs also suggests that the advocates of simulated labs feel that the virtual labs are not only necessary, but also valuable.

They perceive the simulated labs as a way to deal with the problem of increasing expenses of hands-on laboratories. They reduce the amount of time it takes to learn thus increasing the efficiency of lab work. They are seen as being at least as effective as traditional hands-on labs (Shin et al. 2002). (Parush et al. 2002) believe that the students using a simulator are able to review and understand the various processes in the experiment better than traditional labs. (Faria and Whiteley 1990; Smith and Pollard 1986; Whiteley and Faria 1989) argue that the virtual labs foster creation of an active mode of learning that improves students' performance. The detractors argue that excessive exposure to simulation will result in a disconnection between real and virtual worlds (Magin and Kanapathipillai 2000). The literature also reveals that there are instructors who are convinced about the usefulness of the virtual labs but also instructors who do not see these labs as effective tools. This led to the objectives of the next study, which is getting in-depth knowledge regarding the various problems faced by the instructors who were using the virtual labs in their teaching. This was a qualitative study with 13 instructors out of the 5 percent (22 instructors) sample who responded to the survey and was using the virtual labs in their teaching.

In the next section the details of this follow-up study with the engineering instructors are discussed in order to find out the problems the engineering instructors face while using virtual laboratories in their teaching and how these problems can be resolved.

4.4 Study 3: Problems Faced by Instructors in Using Virtual Laboratories

The 13 instructors from the previous study were interviewed individually through a semi-structured interview method. The questions asked in this study were the outcome of the artefact analysis carried out in study 1.

4.4.1 Objective

The primary objective of the semi-structured interviews was to get an insight into the problems faced by engineering instructors while they use virtual laboratories in their teaching. There was a need to find out whether the engineering instructors perceive that suitable guidance will help them in using virtual labs effectively in their teaching. The results of the artefact analysis carried out in the study 1 indicate the necessity of an improvement in the quality of the experiment designs used in traditional laboratories. So the second objective of this study was to find out the perceptions of engineering instructors regarding how they can improve the quality of the experiment designs and how such designs can be administered.

4.4.2 Hypothesis

H1b. The engineering instructors perceive that the problems they face in using virtual laboratories in their teaching can be solved.

RQ1c: How can the problems faced by engineering instructors in using virtual laboratories in their teaching be solved?

4.4.3 Methodology

A qualitative study using semi-structured face-to-face interviews with 13 engineering instructors was conducted. Each instructor was interviewed on an average for 10 minutes. During the interview, initially the instructors were asked questions related to their demographic information. As the interview progressed they were asked questions related to the virtual lab they were using and the problems they faced while using the virtual labs in their teaching and how did they solve these problems. Thus the interview data covered multiple engineering domains and a range of virtual labs. The instructors' response to each question was taken as the unit of analysis. During analysis to identify the range of problems that instructors have with virtual labs only the responses having problems were considered.

The face-to-face interview is quite time consuming but for the best data consistency, this required a single researcher to visit each institution personally and to conduct separate, individual interviews with each participant. Although this was the most elaborate and labor-intensive of all options and took significantly longer to conduct, superior data quality, high flexibility, high completion rate and establishment of relationships with the participants were convincing reasons for this approach. Besides, it was considered important to go beyond meetings and questionnaires and to visit as many coursework laboratories as possible in order to integrate first-hand experience into the survey.

Following the style of a face-to-face interview, the researcher recorded the interviews. Visits to each institute were conducted over a 1 – 3 day time frame, depending on the number of participants. All survey interviews took place over a four-month period, between July 2014 and October 2014.

4.4.4 Sample

The sampling strategy employed to draw sample from the accessible population was purposive sampling. Those instructors were shortlisted who satisfied the parameters for representativeness – (i) Engineering instructors who have taught using or are teaching using virtual laboratories, (ii) but are novice users. The sample consisted of 13 engineering instructors (male = 4, female = 9) from multiple domains like Mechanical, Electrical, Electronics, Electronics and Telecommunication and Computer Science from colleges across western India. They had teaching experience in the range of 5-20 years and had prior experience of teaching using virtual labs.

4.4.5 Instrument

The instrument used for the semi-structured face-to-face interviews had open-ended questions. The following were the interview questions

1. Your Name
2. How many years of experience do you have in engineering education?
3. What are the various problems you face in conducting experiments in the traditional labs?
4. Which of the problems of traditional labs do you feel can be resolved by using virtual labs?
5. What instructional resource do you refer for designing the laboratory experiments for your course?
6. Do you think your laboratory goals are achieved with the current experiment designs?
7. Do you think you can achieve your laboratory goals by using virtual labs?
8. What are the various sections you design for the laboratory experiments?
9. What kind of guidance you think will help you in designing the virtual laboratory experiments?
10. Are you aware of the various instructional strategies that can be implemented in the experiment designs?
11. Have you designed experiments incorporating the different instructional strategies? Why?
12. Will you be able to design experiments at different difficulty levels?

13. Will you be able to design experiments for learning objectives at higher cognitive levels?
14. Will you be able to design tasks aligned to the learning objectives at higher cognitive levels?
15. Will you be able to design experiments incorporating active learning methods?
16. Will you be able to design authentic assessment for the laboratory work?
17.

4.4.6 Data Analysis

The thematic content analysis procedure was used to find out the major problems faced by the instructors and how these problems can be resolved. Thematic Content Analysis (TCA) is a descriptive presentation of qualitative data. A satisfactory TCA portrays the thematic content of interview transcripts (or other texts) by identifying common themes in the texts provided for analysis (Rosemarie Anderson, 2007). TCA is the most foundational of qualitative analytic procedures and in some way informs all qualitative methods. In conducting a TCA, the researcher's epistemological stance is objective or objectivistic. (Helene Joffe, 2012) the end result of a thematic analysis should highlight the most salient constellations of meanings present in the dataset. A theme refers to a specific pattern of meaning found in the data.

The following steps were carried out in order to come up with a list of common themes in order to find the most common problems faced by majority of the participants and ways of solving the problems.

1. Before beginning a Thematic Content Analysis (TCA), multiple copies of the responses were made. The interviews were recorded and their transcript was generated using a text editor.

2. All descriptions that are relevant to the topic of "Problems" marked with a Highlighter.

3. From the highlighted areas, each distinct unit of meaning was marked. Meaning units are separated by a break or change in meaning. The units may vary in text length.

4. The units are cut out units and similar units put together in a pile. (On a Word file, copied and pasted on to another document.)

5. Each pile is labeled as initial categories (themes) using key words or phrases copied from highlighted texts. The categories are revised as coding of data is continued.

6. If obvious information is missing from text, categories that are missing are identified.

7. The complete response is read again and again to identify distinct units, grouping and regrouping similar and dissimilar units, and re-labeling categories.

8. All meaning units per category were read again and redistributed units as appropriate. The categories were re-labeled as appropriate. Some categories were subdivided as appropriate.

9. The categories were collapsed or subdivided as appropriate considering carefully whether the categories are too small or too large.

10. Finally all the categories were further analysed as a whole to find whether there are too many categories (or too few) to render meaning to the highlighted texts.

11. For each additional response the Thematic Content Analysis (TCA) is repeated as above.

12. When all TCAs are complete, each TCA is read separately. Then, while retaining meaning units, categories/themes are combined for all responses. The categories are collapsed or subdivide as appropriate. Then they are re-labeled as appropriate.

13. All the previous steps are carried out until satisfactory categories are obtained and they reflect the responses as a whole. Once the categories and themes obtained are satisfactory they are finalized.

4.4.7 Results

1. How many years of experience do you have in engineering education?

The engineering instructors had experience ranging from one year to twenty-five years.

2. What are the various problems you face in conducting experiments in the traditional labs?

The following themes emerged for “problems” from the TCA.

1. Problems with existing guidelines
2. Instructors inexperience in learning designs for laboratory work
3. No Standardization of laboratory work
4. Misalignment of laboratory goals and learning objectives
5. Non achievement of laboratory learning objectives
6. Non uniformity in laboratory tasks
7. Non authentic assessment
8. Plagiarism practices amongst students
9. Need for virtual laboratory guidelines

1. Problems with existing guidelines

The existing guidelines for virtual laboratory experiment designs are very broad and not implementable. The instructors are not able to take certain decisions due to the lack of proper guidelines.

2. Instructors inexperience in learning designs for laboratory work

The instructors who are in their early years of career refer to the previous years journal for carrying out laboratory work. They are not trained in the scientific experiment design especially for the virtual laboratory.

3. No Standardization of laboratory work

There is no standardization of laboratory work. Each instructor and each institute follow their own methodology. Although this gives autonomy in various decisions related to labwork it leads to different learning outcomes of students. There are no specific guidelines to help instructors in their decisions related to experiment designs.

4. Misalignment of laboratory goals and learning objectives

The broad level laboratory goals are specified by international accrediting bodies such as ABET but the instructors are not able to design lab work aligned to these goals. They are not able to design experiments with learning objectives aligned to these broad goals due to lack of suitable guidelines on how these can be achieved using virtual laboratories.

5. **Non achievement of laboratory learning objectives**

   The experiment designs carried forward for years together in engineering are leading to non-development of necessary skills, knowledge and attitude amongst the students.

6. **Non uniformity in laboratory tasks**

   The resources available at each institute are different and so the tasks the students perform in the lab are different at different institute although the course may be the same. So students of say X institute may be good at certain learning outcomes related questions while students of Y institute have not achieved the outcomes and so are not able to answer the questions. The tasks the students perform should be designed such that uniformity is maintained.

7. **Non authentic assessment**

   It is a normal practice that the instructors from various institutes are invited to assess the labwork during the term end examination. As each instructor member decides her own learning objectives for a particular course the assessment also is not standardized. The guidelines for assessment too are quite broad.

8. **Plagiarism practices amongst students**

   These journals are being used since many years without any modifications to the experiments and so students are indulging in plagiarism.

9. **Need for virtual laboratory guidelines**

   There is a need for guidelines on various phases of laboratory work for the virtual laboratory environment in order to achieve the desired learning objectives.

3. Which of the problems of traditional labs do you feel can be resolved by using virtual labs? Why?

The engineering instructors perceive that some of the problems faced by them in the traditional laboratories can be resolved by using the virtual laboratories.

Table 4.3: Problems that can be resolved using virtual labs

S.No.	Problem	Percent Instructors	Reason
1	No Standardization of laboratory work	53.85	If there are guidelines available online and Instructors use the virtual laboratories, which is uniform all through, the lab work may be standardized.
2	Non achievement of laboratory learning objectives	46.15	Due to certain virtual lab features those learning objectives that are not achievable in traditional labs may be achieved using the virtual labs.
3	Non uniformity in laboratory tasks	61.54	If there are guidelines available online and Instructors use the virtual laboratories there can be uniformity in the laboratory tasks.
4	Non authentic assessment	69.23	If there are guidelines available online regarding the design of authentic assessments and Instructors use the virtual laboratories this problem can be resolved.
5	Plagiarism practices amongst students	69.23	The students may be given different but similar set of tasks and assessment questions in order to resolve this problem.

4. What instructional resource do you refer for designing the laboratory experiments for your course?

The analysis of their responses indicates that the engineering instructors use the following for designing the laboratory experiments.

Table 4.4: Resources used for experiment designs

Resource used for experiment designs	**Instructor Percentage**
Books	15.38
Reference books	**46.15**
White papers	7.69
Application notes	7.69
Websites	**46.15**
Other university lab manuals	23.08
Previous years Journals	**92.31**
Syllabus	30.77
Subject knowledge	7.69
IC datasheets	7.69
User manuals	7.69
With the help of other department faculty	7.69
Protocols of experiment	15.38
Research articles	7.69

As observed from the Table majority of the instructors (92.31%) use previous years lab manuals for designing the experiments. 46.15% use either reference books or websites.

Table 4.5: Responses to Questions Q6 and Q7

Questions	Agree	Disagree
Q6: Do you think your laboratory goals are achieved with the current experiment designs?	10/13	3/13
Q7: Do you think you can achieve your laboratory goals by using virtual labs?	11/13	2/13

9. What are the various sections you design for the laboratory experiments?

Table 4.6: Various sections in the experiment

S.No.	Factor	Instructor Percentage
1.	Aim/ Broad Goal	100
2.	Apparatus	100
3.	Circuit Diagram	100
4.	Theory	100

5.	Procedure	100
6.	Observation	100
7.	Conclusion	100

Table 4.7: Responses to Q9 to Q15

Questions	Percentage agree	Percentage disagree
Q9. Are you aware of the various instructional strategies that can be implemented in the experiment designs?	15.38	84.62
Q10. Have you designed experiments incorporating the different instructional strategies? Why?	7.69 Designed experiment with Problem solving	92.31 Not trained and no resource available to design such experiments.
Q11. Will you be able to design experiments at different difficulty levels?	30.77	69.23
Q12. Will you be able to design experiments for learning objectives at higher cognitive levels?	15.38	84.62
Q13. Will you be able to design tasks aligned to the learning objectives at higher cognitive levels?	15.38	84.62
Q14. Will you be able to design experiments incorporating active learning methods?	7.69	92.31
Q15. Will you be able to design authentic assessment for the laboratory work?	7.69	92.31

16. What kind of guidance you think will help you in designing effective virtual laboratory experiments?

1. **Suitable and accessible guidelines for virtual laboratory experiment designs**

Majority of engineering instructors responded that the problems they faced using virtual labs can be resolved if they are provided with suitable guidelines. Also these guidelines should be accessible so that they can use them on a need basis.

2. **Guidelines for alignment of broad goals and learning objectives**

   The instructors especially the novice ones commented that they are aware of the criticism of the traditional lab work regarding non development of the skills, knowledge and attitude amongst the students but not trained enough to design experiments aligned to the broad goals. They need guidelines for the designing experiments to tackle the problem of achievement of the laboratory goals as given by accreditation bodies such as ABET.

3. **Guidelines for formulating learning objectives**

   The instructors gave a feedback that the guidelines about how to formulate learning objectives aligned to the goals of the laboratory work will help them in designing experiments so that the necessary skills can be developed amongst the students. Also these will help them in formulating learning objectives at higher cognitive levels, which is missing in the current lab manuals.

4. **Guidelines for designing virtual laboratory tasks**

   The tasks the students carry out in the traditional labs provide opportunities to handle and manipulate real life laboratory equipment. The simulation labs on the contrary cannot provide the actual physical handling and hence the instructors feel that the guidelines should be provided so that they can design tasks in virtual labs environment corresponding to the traditional labs.

5. **Guidelines for designing virtual laboratory assessment**

   The assessment in traditional labs is carried out in two phases. In the first the students are graded based on the laboratory written reports submitted after the completion of each experiment and the second phase in the form of either a practical examination or oral examination at the end of the semester. This assessment methodology too is criticized as being non authentic. The guidelines should be provided regarding how the assessment in the virtual labs can be carried out so that it is more authentic and the grades are allotted based on the learning of the students rather than the written report

4.4.8 Conclusion and Discussion

The results of the study provide the inputs regarding the problems faced by engineering instructors while using virtual labs in their teaching. They also indicate the need for guidelines to help engineering instructors in using virtual labs effectively and arriving at certain important decisions related to laboratory work.

4.5 Study 4: Phases in the Virtual Laboratory Experiment Designs for which Engineering Instructors Need Guidelines

After the results of the first survey with engineering instructors it was concluded that they are ready to adopt the virtual labs in their teaching and perceive that these are useful and effective and they wish to use these labs in their regular teaching. But very few instructors are actually using the virtual labs.

4.5.1 Objective

The follow up qualitative study with semi structured interview format was conducted to find out from the instructors who are using the virtual labs the problems they face while using these labs in their teaching. The results of the qualitative study suggest that the instructors need guidelines for using virtual labs in their teaching and the various phases for which these guidelines are required. In order to further verify the necessity and adequacy of the guidelines emerging from the interview data analysis a confirmatory study with 95 engineering instructors through an online survey method was carried out.

The objective of the study 4 was to confirm the results obtained from study 3 regarding the various phases of the experiment design for which engineering instructor's need guidelines for using virtual laboratories in their regular teaching. The second objective was to find out if there are additional aspects for which engineering instructors require guidelines for using virtual laboratories.

4.5.2 Hypothesis

H1d. The engineering instructors perceive that guidelines for certain phases of experiment design will help them in using virtual labs effectively in their regular teaching.

4.5.3 Research Questions

RQ1d: What are the various aspects in the experiment design process using virtual laboratories for which engineering instructors need guidelines?

4.5.4 Sample

The participation was limited to the tertiary sector, i.e. universities in the state of Maharashtra. However, many of the above target questions may also be applicable to other sectors. Engineering disciplines are considered fundamentally practice-based and have a mandatory requirement for experimentation with laboratory equipment and hardware for accreditation. Therefore, focusing on engineering instructors appears reasonable. Besides, virtually all coursework-related, practical laboratory work (other than research) takes place in undergraduate years. The only engineering disciplines, which are intentionally excluded from the review, are purely software-based programs, which require little (if any) experimentation with hardware.

The survey was administered to 200 engineering instructors, as they are the main stakeholders. Of the total 200 engineering instructors 95 instructors responded to the survey.

4.5.5 Limitations of Survey Implementation

The engineering instructors were not randomly selected, but volunteered, which is unavoidable due to practical considerations. The number of participants per institution varied, which skews the share of contribution to the overall results between institutes. This leads to the conclusion that survey participants do not statistically represent all engineering instructors under Mumbai University.

However, drawing data from non-random sample of participants is not expected to affect the quality of results, since it is known that no bias has been introduced through this approach and the sample of participants is large and diverse enough to support conclusive findings.

4.5.6 Implementation

The choice of the most suitable mode of implementation is critical for the success of a survey. Of all available options, such as online survey, mail-out survey, telephone interview and face-to-face interview, the online survey was eventually selected after careful consideration. The online survey implementation is the most convenient mode and hence selected for the purpose of this study.

Following the identification of appropriate engineering instructors contacts at all universities offering engineering degrees, participation in the survey was invited in mid-2014 through an email. It was clearly communicated that participating instructors should have active involvement in practical laboratory sessions with coursework students.

It was also clearly stated that all data collected is confidential to the researcher and would only be disclosed in amalgamated form. Participation by instructors was encouraged but not mandatory. The survey process took place over a six-month period, between December 2014 and May 2015. The instructors could respond to the online survey during the same period.

4.5.7 Survey Instrument

With target questions, scope, target audience and methodology defined, the survey instrument was developed in the form of a paper-based questionnaire for maximum flexibility. This was then converted to online Google form. The design process was conducted by the survey administrator (researcher) and guided and facilitated through the involvement of an educational technology expert. Input was also sought from other project stakeholders, and all questionnaires have undergone several review cycles before their external release.

Table 4.8: Questions in the Survey

S.No	Type of question	Questions
Q1.		Your Name
Q2.		How many years of experience do you have in engineering education?
Q3.	Open-ended	What are the various problems you face in conducting experiments in the traditional labs?

Q4.	Open-ended	Which of the problems of traditional labs do you feel can be resolved by using virtual labs?
Q5.	Open-ended	What instructional resource do you refer for designing the laboratory experiments for your course?
Q6.	Open-ended	What are the various sections you design for the laboratory experiments?
Q7.	Open-ended	What kind of guidance you think will help you in designing the virtual lab experiments?
Q8.	Open-ended	What are the various phases in the experiment design for which you need guidance?
1	(Five point Likert scale)	I think my laboratory goals are achieved with the current experiment designs.
2	(Five point Likert scale)	I think I can achieve my laboratory goals by using virtual labs.
3	(Five point Likert scale)	I am aware of the various instructional strategies that can be implemented in the experiment designs.
4	(Five point Likert scale)	I have designed experiments incorporating the different instructional strategies.
5	(Five point Likert scale)	I will be able to design experiments at different difficulty levels.
6	(Five point Likert scale)	I will be able to design experiments for learning objectives at higher cognitive levels.
7	(Five point Likert scale)	I will be able to design tasks aligned to the learning objectives at higher cognitive levels.
8	(Five point Likert scale)	I will be able to design experiments incorporating active learning methods.
9	(Five point Likert scale)	I will be able to design authentic assessment for the laboratory work.

4.5.8 Quantitative and Qualitative Questions

An important factor in survey design is to consider how responses will be eventually analyzed, and what question type would be most helpful in achieving this aim while allowing respondents to give answers which have not been pre-defined by the survey designer. Questions requiring qualitative answers are often helpful where a-priori classification of answers is either not possible or not practical, or where the creativity of the respondent is meant to be encouraged. Prior to the release of the survey, all questionnaires were internally tested with focus groups in several iterations. In each version, practical and conceptual weaknesses were identified and revised, if appropriate.

4.5.9 Data Analysis

The quantitative data obtained from the Yes/No and Numerical type of questions was statistically analyzed through cross-tabulation, descriptives and frequencies. The questions related to subjects taught, number of years of experience etc. were manually analyzed and classified.

Qualitative data is considered any response that is 'unstructured' and can therefore not be directly statistically analyzed without an intermediate, interpretive step, such as free-form answers. The analysis of qualitative data was done using thematic content analysis procedure. **4.5.10 Analysis of Responses to Open Ended Question**

The thematic content analysis (TCA) procedure was used to find out the major problems faced by the instructors and aspects of experiment design for which they need guidelines.

4.5.11 Results

Q3: What are the various problems you face in conducting experiments in the traditional labs?

Q4: Which of the problems of traditional labs do you feel can be resolved by using virtual labs?

The following themes emerged for "problems" from the TCA.

Table 4.9: Problems perceived by engineering instructors

Type of problem	**Problems**	**Problems that can be resolved using virtual labs**	
		Percent Agree	**Percent Disagree**
Logistic	Lack of resources	90	10
	Limitations of traditional labs	85	15
	Lack of instructors training to adopt active learning strategies	63	37
	Average	**80**	**20**
Cognitive	Non development of required skills	89	11
	Lack of proper assessment	90	10
	Lack of achievement of learning objectives	82	18
	Non development of higher order skills	92	8
	Lack of basic/fundamental knowledge in students	75	25
	Parasitism in work teams	87	13
	Surface approach to learning	92	8
	Average	**86.71**	**13.28**
Affective	Poor learning experience	70	30
	Labs not able to cater to diverse student population	78	22
	Passive and uncritical attitude of students with low understanding	62	38
	Absence of competitiveness amongst students	85	15
	Ineffective in generating student enthusiasm and passion for learning	90	10

	Average	**77**	**23**

Q5: What instructional resource do you refer for designing the laboratory experiments for your course?

The analysis of their responses indicates that the engineering instructors use the following for designing the laboratory experiments.

Table 4.10: Resources used for experiment design

Resource used for experiment designs	**Instructor Percentage**
Books	**94.74**
Reference books	86.32
White papers	36.84
Application notes	31.58
Websites	**94.74**
Other university lab manuals	67.37
Previous years Journals	**95.79**
Syllabus	**100**
Subject knowledge	77.89
IC datasheets	89.47
User manuals	84.21
With the help of other department faculty	56.84
Protocols of experiment	63.16
Research articles	47.37

As observed from the Table majority of the instructors use books, websites, previous years lab manuals and syllabus for designing the experiments and very few use either reference books or research articles. As each instructor uses his/her own method for the experiment design there is lack of standardization of the experiment designs. The experiment designs are being carried forward for years together with very little modification in the designs.

Q6: What are the various sections you design for the laboratory experiments?

Table 4.11: Sections in experiment

S.No.	Factor	Instructor Percentage
1.	Aim/ Broad Goal	100

2.	Apparatus	100
3.	Circuit Diagram	100
4.	Theory	100
5.	Procedure	100
6.	Observation	100
7.	Conclusion	100

Table 4.12: Results of the Five point Likert Scale questions (1-9)

Five point Likert scale Questions	**Percent agree**	**Neutral**	**Percent disagree**
I think my laboratory goals are achieved with the current experiment designs.	82.11	5.26	12.63
I think I can achieve my laboratory goals by using virtual labs.	91.58	3.16	5.26
I am aware of the various instructional strategies that can be implemented in the experiment designs.	10.53	7.37	82.11
I have designed experiments incorporating the different instructional strategies.	5.26	12.63	82.11
Design of experiments			
I will be able to design experiments at different difficulty levels.	26.32	14.74	58.95
I will be able to design experiments for learning objectives at higher cognitive levels.	12.63	10.53	76.84
I will be able to design tasks aligned to the learning objectives at higher cognitive levels.	12.63	13.68	73.68
I will be able to design experiments incorporating active learning methods.	5.27	22.11	72.63
I will be able to design authentic assessment for the laboratory work.	37.89	13.68	48.42
Average	**19**	**14.9**	**66.1**

Q7: What kind of guidance you think will help you in designing the virtual lab experiments?

Table 4.13: Nature of guidance required

S.No.	Type of guidance	Percent Instructors
1.	Face-to-face training	90
2.	Online resource	91.5
3.	Help from expert	90.4
4.	Online guidance	96
5.	Videos explaining the design	83

Q8: What are the various aspects in the experiment design for which you need guidance?

After the analysis of the qualitative data the following conclusions were arrived at. The engineering instructors perceive that guidelines will help in designing quality virtual laboratory experiments. The various phases for which they feel these guidelines will help are

1. Selection of virtual lab with affordances or features, which will make it possible to carry out the experiment in the stipulated time and achieve the desired, learning objectives
2. Selection of learning outcomes expected from students after performing the experiment.
3. Selection of various tasks, which the students need to perform to achieve the desired, learning outcomes
4. Selection of assessment questions aligned to the tasks and learning objectives in the virtual lab selected
5. Selection of suitable assessment method to verify if the desired learning outcomes have been achieved

4.5.12 Results of the Study 4

1. The engineering instructors had experience ranging from six months to 30 years.
2. Nearly 80 percent of the engineering instructors perceive that the logistic problems faced by them in the traditional laboratories can be resolved by using the virtual laboratories.
3. Nearly 87 percent of the engineering instructors perceive that the problems faced by them in the traditional laboratories to achieve the learning outcomes in the cognitive domain can be resolved by using the virtual laboratories.
4. Nearly 77 percent of the engineering instructors perceive that the problems faced by them to achieve the learning outcomes in the affective domain in the traditional laboratories can be resolved by using the virtual laboratories.
5. All the engineering instructors refer to the syllabus of the course to design the experiments and nearly 96 percent engineering instructors use the experiment design of the previous years.
6. All the engineering instructors have designed experiments with expository instructional strategy.
7. Nearly 82 percent engineering instructors perceive that they can achieve their laboratory learning outcomes by using the current experiment designs.
8. Nearly 92 percent engineering instructors perceive that they can achieve their laboratory learning outcomes by using virtual laboratories.
9. Only 10 percent engineering instructors are aware of the various instructional strategies.
10. Only 5 percent engineering instructors have designed experiments incorporating the different instructional strategies.
11. On an average only 19 percent engineering instructors perceive that they can design experiments at different difficulty levels, learning objectives at higher cognitive levels, tasks aligned to the learning objectives at higher cognitive levels, incorporate active learning methods and authentic assessment.

4.5.13 Conclusions

The results of the study 4 lead to the following conclusions

1. The problems faced by engineering instructors in traditional laboratories in the achievement of certain learning objectives can be resolved using the virtual laboratories.
2. The engineering instructors need guidelines for designing experiments for virtual laboratories as each instructor is referring to different resources with majority using previous years manuals.
3. There is a need of guidelines for the following
    a. Designing experiments incorporating the different instructional strategies
    b. Designing experiments at different difficulty levels,
    c. Formulating learning objectives at higher cognitive levels,
    d. Designing tasks aligned to the learning objectives at higher cognitive levels,
    e. Incorporating active learning methods and
    f. Designing authentic assessment.

4.6 Summary

The results of the three studies and the artefact analysis indicate that the engineering instructors need guidelines for designing effective experiments for using virtual laboratories.

1. There is a need for improvement in the **quality of the experiment designs** used in traditional laboratories by engineering instructors.
2. The experiments are designed using adhoc methods and mostly the experiments are carried out with same manuals being used for many years

without any modifications to the designs. Hence there is a **need to standardize the experiment design process** and provide guidelines to instructors for the scientific experiment design process.

3. Most of the experiment designs were of cookbook nature following the expository instructional strategy. This is because majority of the engineering instructors are not aware of the various instructional strategies that can be used in the laboratory instructions. These strategies can lead to the development of required skills amongst the students. Thus there is a need of **guidelines for engineering instructors to incorporate the various instructional strategies** in their experiment designs.
4. The instructors need **guidelines for decision regarding the broad goals of the experiment** depending on the type of content to be covered by the experiment.
5. In majority of the experiment designs the target learning objectives were at lower cognitive levels. Hence engineering instructors should design the experiments with higher cognitive levels. Thus there is a need of **guidelines for engineering instructors to formulate learning objectives** at higher cognitive levels.
6. There are very few tasks, which provide opportunities to students to link the two domains of objects, and ideas, which is a very important aspect for development of knowledge and skills amongst the students. Thus there is a need of **guidelines for engineering instructors to design tasks, which** provide opportunities to students to link the two domains of objects and ideas.
7. There are very few experiment designs, which incorporate the constructivist approach and other active learning methods. Thus there is a **need of guidelines to instructors to incorporate the active learning methods** in their experiment designs.
8. The assessment questions asked are not aligned to the tasks performed and learning objectives hence the assessment is not authentic. Thus there is a **need of guidelines to instructors to design authentic assessment** in the virtual laboratory.

The analysis of the problem and the results of the various studies give rise to the following conclusion that there is a need for improvement in the quality of the experiment designs by providing suitable guidelines.

Table 4.14: Aspect of experiment design for which guidelines needed

Aspect of experiment design for which guidelines needed	**Conclusions from Studies**
Decision regarding the broad goals of the experiment	Study 1,3,4
Formulate learning objectives at higher cognitive levels	Study 1,3,4
Design experiments at different difficulty levels for Expository Instructional Strategy	Study 1,3,4
Incorporate the active learning methods in experiment designs for Expository Instructional Strategy	Study 1,3,4
Design experiments with Well-Structured Problem Solving Instructional strategy	Study 1,Literature
Design experiments with Discovery Instructional strategy	Study 1, Literature
Design experiments with Problem-based Instructional strategy	Study 1, Literature
Design authentic assessment	Study 1,3,4
Use virtual lab features to achieve learning objectives	Study 3, 4

4.7 Conclusions and Discussion

In this chapter the first phase of the research that is the Need and Problem Analysis was presented. Initially the analysis was carried out to find out the problems faced by engineering instructors in carrying out their experimental work using virtual labs and how these can be resolved. The results of the four studies establish the need of the research work that is development of guidelines. The guidelines are required for various aspects in the experiment design process and components as follows:

1. Decision regarding the broad goals of the experiment.
2. Formulate learning objectives at higher cognitive levels.
3. Design experiments at different difficulty levels for Expository Instructional Strategy.
4. Incorporate the active learning methods in experiment designs for Expository Instructional Strategy.
5. Design experiments with Well-Structured Problem Solving Instructional strategy.
6. Design experiments with Discovery Instructional strategy.
7. Design experiments with Problem-based Instructional strategy.
8. Design authentic assessment.
9. Use virtual lab features to achieve learning objectives.

In the next chapter 5 the various design questions are described and answers to each one through the systematic literature review and S-D-I-V-E methodology are presented. The details of the proposed solution that is the nine sets of design guidelines for effective virtual laboratory experiments are discussed.

Chapter 5

Proposed Solution

In this chapter the details of the proposed solution that is the nine sets of guidelines for the effective and quality experiment designs for virtual laboratory with examples from the Basic and Advanced Electronics (BAE) course for each and every aspect are discussed.

5.1 Solution Design

The results of the four studies and the subsequent literature review establish the need of this research work that is development of guidelines for engineering instructors for designing effective virtual laboratory experiments. The guidelines are required for various aspects in the experiment design process and components as follows:

1. Decision regarding the broad goals of the experiment.
2. Formulate learning objectives at higher cognitive levels.
3. Design experiments at different difficulty levels for Expository Instructional Strategy.
4. Incorporate the active learning methods in experiment designs for Expository Instructional Strategy.
5. Design experiments with Well-Structured Problem Solving Instructional strategy.
6. Design experiments with Discovery Instructional strategy.
7. Design experiments with Problem-based Instructional strategy.

8. Design authentic assessment.
9. Use virtual lab features to achieve learning objectives.

As per the problem and need analysis the engineering instructors need guidelines for the following

Need for improvement in the **quality of the experiment designs**

1. **Need guidelines for decision regarding the broad goals of the experiment.** (Study 3, 4)
2. **Need of guidelines for engineering instructors to formulate learning objectives** at higher cognitive levels. (Study 2, 3, 4)
3. **Need of guidelines for engineering instructors to design experiments at different difficulty levels for Expository Instructional Strategy** (Study 2, 3, 4)
4. **Need of guidelines to instructors to incorporate the active learning methods** in their experiment designs **for Expository Instructional Strategy**. (Study 3,4)
5. **Need of guidelines for engineering instructors to incorporate the Discovery Instructional strategy** in their experiment designs. (Study 2,3,4)
6. **Need of guidelines for engineering instructors to incorporate the Well-Structured Problem Solving Instructional strategy** in their experiment designs. (Study 2,3,4)
7. **Need of guidelines for engineering instructors to incorporate the Problem-based Instructional strategy** in their experiment designs. (Study 2,3,4)
8. **Need of guidelines to instructors to design authentic assessment** in the virtual laboratory. (Study 2, 3, 4)
9. **Need guidelines for decision regarding selection of virtual laboratory depending on the necessary features** (Study 3,4)

5.1.1 Specific Design Question

DQ1: What guidelines will help engineering instructors in achieving their laboratory goals by making effective use of virtual laboratories for the course Basic and Advanced Electronics?

The results of the Need and Problem Analysis phase lead to the following design sub questions.

DQ1a: How to select the broad goal depending on the type of topic content to be covered by the virtual laboratory experiment?

DQ1b: How to formulate valid and clearly defined learning objectives at different cognitive levels as per Revised Blooms' Taxonomy for virtual laboratory experiment/s aligned to the broad goal of the experiment?

DQ1c: How to design virtual laboratory experiment at different difficulty levels with Expository instructional strategy?

DQ1d: How to incorporate active learning methods in the virtual laboratory experiment design?

DQ1e: How to design an effective virtual laboratory experiment with Discovery or Guided Inquiry instructional strategy?

DQ1f: How to design an effective virtual laboratory experiment with Well-Structured Problem Solving Instructional strategy?

DQ1g: How to design an effective virtual laboratory experiment with Problem-Based instructional strategy?

DQ1h: How to design authentic assessment for virtual laboratory experiment?

DQ1i: How to select virtual laboratory with features aligned to the learning objectives of the experiment?

As part of the Design and Development phase the answers to the following design sub questions were obtained. The answers to these questions form the proposed solution, which is the Virtual Laboratory Experiment Design Guidelines (VLEDG). In order to arrive at the guidelines based on the Learning Objectives-Tasks-Assessment (LoTaAs) framework by a systematic literature analysis.

A Learning Design describes the educational process;the complete teaching/learning experience. Learning Designs are "pedagogically informed learning activities which make effective use of appropriate tools and resources" (Gráinne Conole and Karen Fill,). The learning designs for effective virtual laboratory experiments will facilitate the achievement of desired learning objectives and lead to meaningful learning through authentic task and assessment designs. The guidelines provided in this document will help instructors to expedite this process of effective learning designs for engineering instructional virtual laboratories. These guidelines are based on the Design and Development of Effective Virtual laboratory experiments framework (LoTaAs).

The following figure illustrates the components of the LoTaAs framework that forms the basis of the guidelines.

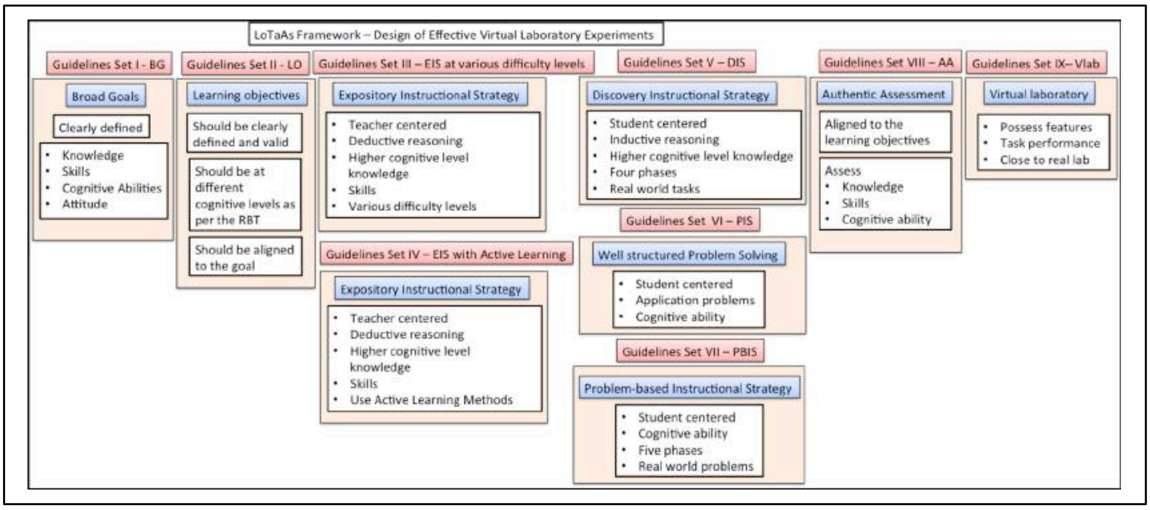


Figure 5.1 LoTaAs Framework for VLEDG

These guidelines consist of nine sets as follows:

1. Selection of broad goal of the experiment - Guidelines Set I

2. Formulation of learning objectives - Guidelines Set II
3. Experiment design at different difficulty levels with Expository Instructional Strategy - Guidelines Set III
4. Experiment design incorporating active learning methods with Expository Instructional Strategy - Guidelines Set IV
5. Experiment design with Discovery Instructional Strategy - Guidelines Set V
6. Experiment design with Well Structured Problem Solving Instructional Strategy - Guidelines Set VI
7. Experiment design with Problem-based Instructional Strategy - Guidelines Set VII
8. Design of authentic assessment Guidelines Set VIII
9. Selection of suitable virtual laboratory - Guidelines Set IX

The scientific experiment design process is carried out by following a well-formulated step-by-step methodology instead of adopting an adhoc method. The following figure illustrates the scientific experiment design process synthesized from the literature.

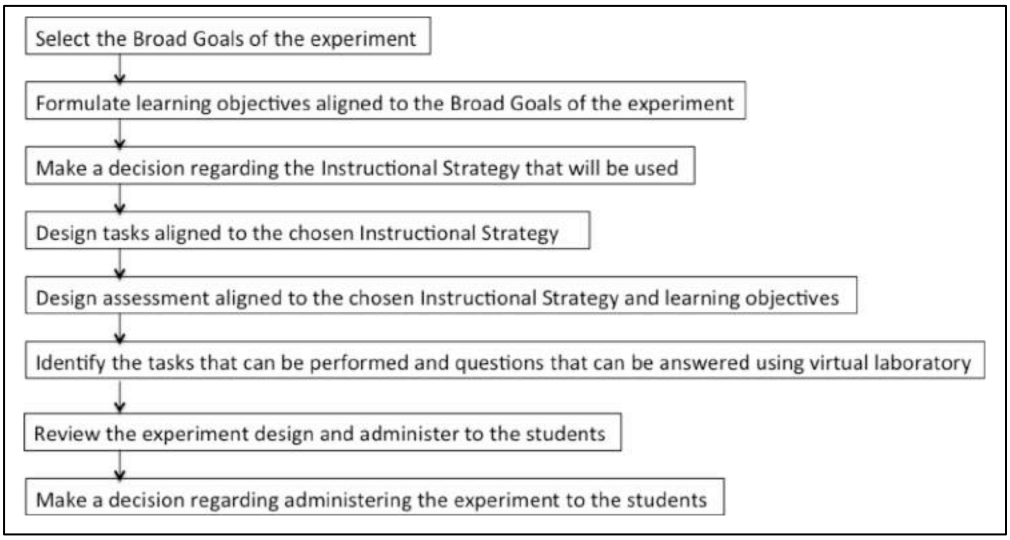


Figure 5.2 Step-wise scientific experiment design process

5.2. Answering Design Questions DQ1a and DQ1b

In this section answer to the following design questions are obtained

DQ1a: How to select the broad goal depending on the type of topic content to be covered by the virtual laboratory experiment?

DQ1b: How to formulate valid and clearly defined learning objectives at different cognitive levels as per Revised Blooms' Taxonomy for virtual laboratory experiment/s aligned to the broad goal of the experiment?

Learning goal (LG) or Broad Goal identification can greatly inform curriculum, teaching, and evaluation practices. The complex laboratory course setting, however, presents unique obstacles in developing appropriate LGs. Learning goals are explicit statements about abilities, attitudes, skills, and knowledge that should be acquired by a student through completion of some instructional event.

The laboratory is a unique learning environment that enables and consolidates "learning through doing". It is important that the specific objectives of the laboratory context for learning are clearly specified, for both students and assessors. These objectives should form the basis for all assessment decisions made.

The analysis of the current experiment designs indicates that the engineering instructors specify the Broad Goal or Aim of the experiment as " To study….a particular topic". (Jennifer M. Duis et al., 2013) refer to the learning goals as learning outcomes or performance objectives. There are various terms used such as learning goals, learning objectives, broad goals, focus areas, performance outcomes etc. The Table gives the detailed analysis of the literature with respect to the laboratory learning goals specified by various educators and researchers.

Table 5.1: Analysis of literature on learning objectives

(Uri Ganiel Avi Hofsteln Physics laboratories Israel, 1982)	{Patrik Garnett Chemistry Laboratories Australia, 1994)	(Robin Millar et.al.,2002) Science and Engineering laboratories		ABET criteria (2002) Engineering laboratories
1.Constructing experimental setup and other manipulative skills.	Conceptual learning	Content	Process	Instrumentation Sensory Awareness
2. Observing and measuring.	Techniques	Identify objects and phenomena	Learn how to use a standard laboratory instrument or apparatus or equipment	Models
3.Ordering and organizing work.	Manipulative skills	Learn a fact or facts	Learn how to carry out a standard procedure	Experiment
4. Organizing and processing data (including graphs).	Investigation skills	Learn a concept	Learn how to plan an investigation to address a specific question or problem	Data Analysis
5. Drawing conclusions and critical discussion.	Affective outcomes	Learn a relationship	Learn how to process data	Design
		Learn a theory/model	Learn how to use data to support a conclusion	Learn from Failure
			Learn how to communicate the results of labwork	Creativity
				Psychomotor
				Safety
				Communication

				Teamwork
				Ethics in the Lab

Table 5.1 contd: Analysis of literature on learning objectives

Cooper, M. (2005)	**(Jennifer M. Duis, 2013)** **Natural sciences and engineering**	**(AAPT, 2014)** **Physics**
To illustrate the concepts and principles	Basic laboratory skills	Constructing knowledge
To enable the teaching of procedures or skills	Communication and record keeping	Modeling
To introduce students to the world of professional scientists and engineers	Maturity and responsibility	Designing Experiments
To provide a focus for student-student and student-tutor interaction	Context	Developing technical and practical laboratory skills
To motivate students	Integration and application of knowledge/experience	Analyzing and visualizing data
To familiarize students with the use of important instruments, equipment, and techniques		Communicating Physics

5.2.1 Synthesis of Literature

The analysis of the laboratory goals proposed by various authors and international bodies leads to the result that there is a commonality amongst them. The following goals and objectives can be synthesized to be important and necessary in laboratory learning.

1. Learning concepts and principles
2. Learn how to carry out observations, measurements, constructing experimental set up, ordering and organizing experimental work and other standard procedures by using the sensory awareness
3. Develop basic laboratory skills such as practical skills, investigations skills, manipulative skills and psychomotor skills
4. Learn how to use laboratory equipment, apparatus and instruments
5. Learn how to carry out data visualization, organization, processing and analysis
6. Learn how to carry out modeling
7. Learn how to plan an investigation and design experiments to solve a problem
8. Learn how to integrate, construct and apply knowledge and experience
9. Learn how to arrive at conclusions based on results of data analysis
10. Develop affective outcomes such as maturity, responsibility, work in teams, safety and ethics
11. Develop the skill of communicating the results of the experiment in a suitable format and also communicating and interacting with peers

5.2.2 Gaps in Literature for Laboratory Goals and Learning Objectives

1. The literature does not differentiate between the Broad goal of the experiment and objectives or outcomes.
2. The literature does not specify how the instructors can make a decision regarding the goal depending on the type of content to be covered by the particular experiment

3. It specifies the “what should be” but not “when” and “how” of the goals.
4. It does not specify how the laboratory learning objectives can be formulated and how they can be aligned to the chosen broad goal of the experiment.
5. It does not specify how the laboratory learning objectives at higher cognitive levels can be formulated.
6. The literature does not specify which goals and which learning objectives can be achieved using the virtual laboratories.

5.2.3 Implication for Design and Development

The results of the literature review lead to the following conclusions for the design and development of the guidelines for the broad goal and learning objectives.

1. There is a need to differentiate between the broad goal and learning objectives of laboratories.
2. The guidelines should specify how the instructors could make a decision regarding the goal depending on the type of content to be covered by the particular experiment.
3. The guidelines should specify when a particular goal should be selected.
4. The guidelines should specify how the laboratory learning objectives can be formulated and how they can be aligned to the chosen broad goal of the experiment.
5. The guidelines should specify how the laboratory learning objectives at higher cognitive levels could be formulated.
6. The guidelines should specify which goals and which learning objectives can be achieved using the virtual laboratories.

Taking these pointers the guidelines were designed and developed for the broad goal and learning objectives of the virtual laboratories with examples from the BAE course. In the following section these guidelines are presented.

5.2.4 Guidelines Set I – Selecting the Broad Goal of the Virtual Laboratory Experiment

Objectives of the guidelines

This set of guidelines will help the engineering instructors make a decision regarding broad goals of the laboratory experiment.

As you can see from the figure 5.3 the goal of the experiment may be one or more of the four dimensions (J.Duis et al., 2013). This is the most important step, as all the further steps will depend on what you wish to achieve from the experiment.

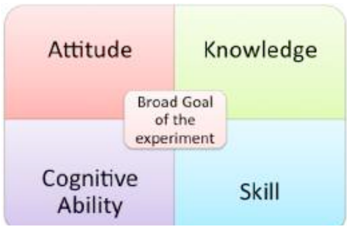


Figure 5.3 Four dimensions of Broad Goal of experiment

You may decide either one or multiple dimensions for your experiment. The further experiment design should be such that the goals are achieved. There are three main domains of learning and all teachers should know about them and use them to design their lessons (A. Hofstein and V.Lunetta, 2016). These three domains are

- Cognitive (knowledge based)
- Affective (emotive based)
- Psychomotor (action based)

Taxonomy is used to classify things. The objectives that dealt with cognition could be divided into subsets. These subsets were arranged into taxonomy and listed according to the cognitive difficulty — simpler to more complex forms. The Revised Bloom's taxonomy of educational objectives (Bloom, et al. 1956) defines levels of objectives in the cognitive domain.

Knowledge

The knowledge dimension has four components that are Facts, Concepts, Principles and Procedures (I.Park et al., 1993).

What is a fact?

It is logically associated pieces of information. Some examples are names, dates, and events. For the Basic and Advanced Electronics laboratory environment the examples of facts are components, equipment etc.

What is a concept?

A concept is defined by a set of shared features found in each example of the concept. That is, every example of a concept shares certain 'must have' features with all other examples of the concept. In addition to these 'must have' features, the examples can have other features, which other examples of the concept may or may not have. The can have features describe the many ways examples of a concept can be different. For the Basic and Advanced Electronics laboratory environment the examples of concepts are PN Junction diode, Transistor etc.

What is a principle?

A principle is basically either cause-and-effect or relationships. It explains or predicts why something happens in a particular way. For the Basic and Advanced Electronics laboratory environment the examples of principles are Ohms law, Barkhausen criterion for oscillation etc.

What is a procedure?

It is a set of ordered steps, sequenced to solve a problem or accomplish a goal. For the Basic and Advanced Electronics laboratory environment the examples of procedures are - A sequence of steps carried out to perform an experiment, A sequence of steps carried out to analyse a circuit etc.

Topic: PN Junction Diode

Table 5.2: BAE Example for classification of knowledge.

Facts	Concepts	Procedures	Principles
Definition, Symbols	Construction and internal Working, Piecewise linear model, Space charge capacitance C_T of diode, Breakdown mechanism	Diode under no bias, forward bias and reverse bias	V-I Characteristics, Diode operating point, Diode current equation, Relationship between Diode Current and Diode Voltage, Effect of temperature on diode characteristics

If the Broad Goal you wish to achieve is develop students' knowledge then you classify the selected topic into the four types of Facts, Concepts, Principles and Procedures as given in the example above. Normally the experiments are not designed for the knowledge dimension of facts.

Skill

This is the ability to do something well and also termed as expertise. The various skills that can be developed in the laboratory environment are practical skills, manipulative skills, investigative, inquiry process skills etc. (T.Shiland, 1999). The design of the experiment will depend on the type of skill you wish to achieve. We will be providing you with guidelines on how to design the experiment for the above four skills.

Cognitive Ability

This is the ability of an individual to perform the various mental activities most closely associated with learning and problem solving (I.Park et al., 1993). We will provide guidelines for designing experiments to achieve the cognitive abilities of Analysis, Problem Solving, Application and Inquiry.

Attitude

This is predisposition or a tendency to respond positively or negatively towards a certain idea, object, person, or situation (C. Akdeniz,2016) . Attitude influences an individual's choice of action, and responses to challenges, incentives, and rewards. This is related to the affective domain and we will be providing guidelines only on the affective component of teamwork.

The knowledge dimension has four components – facts, concepts, principle and procedures. For each of these components there are six levels depending on the difficulty of the learning. These levels as per the Revised Blooms taxonomy are: Remember, Understand, Apply, Analyze, Evaluate and Create.

The experiment design will vary depending on what target level you decide to achieve.

DQ1a: How to select the broad goal depending on the type of topic content to be covered by the virtual laboratory experiment?

Select you Broad Goal

1. Select the topic from your course for which you wish to design virtual laboratory experiment
2. Identify the knowledge components such as concepts, principles, and procedures of the topic.
3. Make a decision regarding which of the concepts, principles and procedures you wish to convert to a virtual laboratory experiment.
4. Identify the skills you wish to develop.
5. Identify the cognitive ability you wish to develop.
6. Select the ones you wish to target through the experiment.

Table 5.3: Broad Goals synthesized from literature

Broad goal					
Knowledge	Concept	Procedures	Principles		
	Understand	Understand	Understand		
	Apply	Apply	Apply		
	Analyze	Analyze	Analyze		
	Evaluate	Evaluate	Evaluate		
		Create			
Skill	Practical	Manipulative	Investigative	Inquiry process	Communicating results
Cognitive	Problem				

Ability	Solving				
Attitude	Team Work				

Example from Basic and Advanced Electronics Virtual laboratory

Topic: PN Junction Diode

1. Content type procedure – Procedure to Bias the PN Junction diode in forward Bias condition

2. Select the broad goals Instrumentation for this sub topic.

3. They will learn how to construct the experimental set up (construct the circuit), how to use laboratory equipment such as DC Regulated Power Supply, Voltmeter and Ammeter and components such as PN Junction diode and resistor.

You have completed the first step in your experiment design.

The next step in the experiment design is to formulate the learning objectives for your experiment.

5.2.5 Guidelines Set II – Formulating Learning objectives

Objectives of the Guidelines

This set of guidelines will help the engineering instructors to formulate learning objectives for the virtual laboratory experiment at various cognitive levels, skills and abilities aligned to the broad goal.

What Is a Learning Objective?

The second step in the experiment design process is the formulation of learning objectives aligned to the Broad goal of the experiment. Well-written learning objectives are the heart of any experiment design. They should provide a clear picture of the outcome or performance you expect as a result of the experiment.

The learning objectives should identify a learning outcome (I.Park et al., 1993). The objective needs to state what the learner is to perform, not how the learner learns. Whether they are called learning objectives, behavioral objectives, instructional objectives, or performance objectives terms that refer to descriptions of observable student behaviour or performance that are used to make judgments about learning - the ultimate aim of all teaching. The learning objectives are competency-based as they designate exactly what students need to do to demonstrate mastery as part of a subject (S.Papadakis and E. Ghiglione, 2009) They are brief, clear, specific statements of what learners will be able to perform at the conclusion of instructional activities.

(S.Papadakis and E. Ghiglione, 2009) The purpose of learning objectives is to:

a) Facilitate overall the course, session and activity development by encouraging goal-directed planning.

b) Inform students of the standards and expectations.

c) Provide a framework for evaluating student progress.

d) Make implicit the educational contract between teacher and students.

The learning objectives should be precise (A. Herrington et al., 2001). It is sometimes difficult to strike a balance between too much and too little precision in an objective. There is a fine line between choosing objectives that reflect an important and meaningful outcome of instruction, objectives that trivialize information into isolated facts, and objectives that are extremely vague. The purpose of an objective is to give different people the same understanding of the desired instructional outcome (J. Enkenberg, 2001).

How to Formulate a Learning Objective?

As per the definition of learning objectives they need to be very specific and measurable hence you should not use verbs such as understand, visualize etc. instead use action verbs such as identify, list, describe, solve etc. ((S.Papadakis and E. Ghiglione, 2009).

Similarly the learning objective should be concerned with the learner and not the teacher hence avoid using verbs such as teach, show, demonstrate etc.

Examples of valid and clearly defined learning objectives for the course Basic Electronics

1. Student should be able to analyse the BJT amplifier circuits
2. Student should be able to describe the effect of the value of β on the output of the amplifier

DQ1b: How to formulate valid and clearly defined learning objectives at different cognitive levels as per Revised Blooms' Taxonomy for virtual laboratory experiment/s aligned to the broad goal of the experiment?

Formulate your learning objectives by following the steps:

1. Start the learning objective with the phrase "Student will be able to"

2. Make a decision regarding the cognitive level you wish to achieve through the experiment as per the Revised Bloom's taxonomy

3. The cognitive level of Remember is not normally chosen for a laboratory experiment. Try to formulate learning objectives at higher cognitive levels, as the virtual laboratory is more suitable for these objectives.

4. Choose action verbs appropriate to the chosen cognitive level by referring to the Tables LOa, LOb and LOc.

5. Check whether the learning objective is aligned to the broad goal of the experiment by referring to the Tables LOa, LOb, and LOc.

6. Check whether the learning objective can be achieved in the BAE virtual lab by referring to the Tables LOd.

7. There can be multiple learning objectives for one broad goal

Table 5.4: LOa - Cognitive level and action verbs - Broad Goal - Develop students Knowledge

Level	Action Verbs
Create	design, combine, devise, modify, plan, Modify the design
Evaluate	assess, conclude, contrast, evaluate, Reason out for the choice
Analyse	analyze, infer,examine, dissect, ascertain, Test a prediction
Apply	Apply, calculate, solve, predict, Explore relation between
Understand	Describe, Explain, Give example of, Select, Reason out for selection, Reason out for the observation

Table 5.5 - LOb - Broad Goal – Develop Skills

Skill	Actions
Manipulative skills	Observations, Measurements, Manipulations, Recording results, Calculations, Explaining experimental techniques, Explaining about various decisions and Working according to the design
Investigative skills	Transforms results into standard form (tables), Determine relationships (could include graphs), Discuss accuracy of data, Formulate generalizations, Discuss limitations/assumptions of experiment, Explain relationships and Formulate new questions/problems
Inquiry Process Skills	Formulate question or problem to be investigated, Formulate hypothesis, Determining replications, Identifying treatments, Defining dependent variable, Defining independent variable, Design experiment,

	Design observation and measurement procedures, Predict results, Predict applications based on results, Formulate follow up hypotheses and Apply experimental technique to new problem
Communicating results	Describing the results in a suitable format, presenting the results to peers and instructors.

Table 5.6: LOc - Broad Goal – Cognitive Abilities

Cognitive Ability	Actions
Well Structured Problem Solving	Come up with solutions to well structured problems through experimentation
Ill structured problem solving	Come up with solutions to ill structured or open ended problems through experimentation

Table 5.7 - LOd – Learning objectives achievable using virtual laboratories

Broad goal		
		Highest Level of Learning objectives achievable in Vlab
Knowledge	Concept	Analyze
	Procedure	Create
	Principle	Evaluate
Skill		Practical
		Manipulative
		Investigative
		Inquiry process
Cognitive ability		Problem Solving
Attitude		Team Work

Example from Basic and Advanced Electronics

Broad goal: Knowledge - Procedures

Learning objectives:

1. Student should be able to construct the circuit of the PN Junction diode in Forward biased condition
2. Student should be able to select the correct components
3. Student should be able to select the suitable equipment
4. Student should be able to carry out observations by using the equipment.

Selection of Instructional Strategy

The next step in the experiment design process is the selection of Instructional Strategy depending on the learning objectives you wish to achieve. You may design more than one experiment for one topic based on the target objectives with different instructional strategies. After selecting the Instructional Strategy you will be designing the tasks to be assigned to the students depending on the Instructional Strategy selected.

Important Tip

You may even design one experiment per learning objective with each one with a different instructional strategy. The students too can perform multiple experiments on a single topic as the time required to perform a virtual laboratory experiment is very less compared to the traditional laboratory. Also another advantage of the virtual laboratory is that it is available to the students online anytime anywhere.

Instruction is a combination of teaching and learning activities. The instructional Strategies determine the approach a teacher may take to achieve learning objectives. We provide guidelines for designing experiments based on the following four instructional strategies. We provide guidelines so that the experiment designs become more effective and you can achieve your learning objectives. As part of the design you will be designing tasks or activities that the students need to carry out as part of the experiment.

1. Expository
2. Scientific Discovery
3. Well Structured Problem Solving
4. Problem-based

Refer to the following table in order to make a decision regarding the selection of the Instructional Strategy depending on the broad goal of your experiment.

Table 5.8 - BG1 – Develop students' knowledge

Broad Goal Develop students Knowledge	Cognitive Level	Suggested IS
Concepts	Understand	EIS
	Apply	EIS
	Analyze	EIS with modifications
Procedures	Understand	EIS
	Apply	EIS
	Analyze	EIS with modifications
	Evaluate	EIS with modifications
	Create	EIS with modifications
Principles	Understand	EIS
	Apply	EIS
	Analyze	EIS with modifications
	Evaluate	EIS with modifications

Table 5.9: BG2 – Develop students' Skills, Cognitive abilities and Attitudes

Broad Goal	Type	Suggested IS
Skill	Practical	EIS
	Manipulative	EIS with modifications
	Investigative	EIS with modifications
	Inquiry process	DIS

Cognitive Ability	Problem Solving	PIS PBIS
	Inquiry	DIS
Attitude	Team Work	DIS PBIS
	Communicating results	EIS, DIS, PIS, PBIS

5.3 Answering Design Question DQ1c

In this section the answer to the following design question is obtained:

DQ1c: How to design virtual laboratory experiment at different difficulty levels with Expository instructional strategy?

The most popular, and yet the most heavily criticized, style of laboratory instruction is the expository (also termed traditional or verification) style. Within the expository learning environment the instructor defines the topic to be investigated, relates the investigation to previous work, and directs the actions of the students. The students repeat the teacher's instructions or read the directions from a manual. The procedure the students follow is well stated so they may experience the predetermined outcome that is already known to both the students and the instructor. The results obtained are typically used only for comparison against the expected result.

(G.Wang, F.Wayne, 2010) point out that the traditional expository laboratory has been designed so that the activities can be performed simultaneously by a large number of students, with minimal involvement from the instructor, at a low cost, and within a two- to three-hour time span. It has evolved into its present form from the need to minimize resources, particularly time, space, equipment, and personnel.

The predominant feature of the expository lesson is its "cookbook" nature, which emphasizes following specific procedures to collect data. Virtually no attention is given to the planning of the investigation or to interpreting the results. This manner of instruction has been criticized as placing very little emphasis on thinking, being an ineffective means of conceptual change, and being unrealistic in its portrayal of scientific experimentation.

Domin conducted a content analysis of eleven commercially available general chemistry laboratory manuals and concluded that the majority of them require students to operate predominantly at the three lower levels of Bloom's taxonomy, namely, knowledge, comprehension, and application. Virtually no activities require students to operate at any of the three higher cognition levels, analysis, synthesis, or evaluation (Domin, Daniel S., 1999). This is consistent with the results from content analyses of laboratory manuals from biology and physics.

(Amos Dreyfus, 2007, Schwab 1960,Pella 1961,Tamir 1975) believe that full laboratory exercise is composed of three main parts (planning, practical performance and interpretation of results); (Carl Wieman, 2015) has given a comparative analysis of the cognitive tasks carried out in experimental physics and those in instructional laboratories. The following table gives the synthesis of these phases and the role of instructor and students for each of the phases.

Table 5.10: Phases in laboratory exercises

Phase of the experiment	What instructors do?	What students do?
1. Definition of the problem; suggesting and formulating hypotheses	Specify the details	Read the content
2. Suggesting technical procedures	Specify the details	Read the content
3. Planning of the experimental design	Specify the details	Read the content
4. Technical preparation of the experiment (assembling tools, preparing solutions, etc.)	Specify the details and make arrangements for the same	Read the content
5. Actual performing of the experiment and gathering of data	Specify how the steps	Carry out the data collections and

	are to be carried out	follow the specified procedure
6. Statistical analysis of results	Specify what analysis should be done	Carry out the data analysis and follow the specified procedure
7. Interpretation of results	Do not specify the details	Come up with their interpretation of the results obtained
8. Reporting or presenting the procedures and results	Specify the details	Read the content and present the results as specified by the instructors
9. Conclusions or Summing up of acquired knowledge.	Do not specify the details	Come up with their conclusions

5.3.1 Gaps in Literature for Expository Experiment Design Process

The following can be inferred from the existing literature regarding the expository experiment design process:

- The literature gives the various steps in the expository experiment process but does not specify how to implement the steps.
- It does not specify how the active learning methods and constructivist approach can be implemented in the process.
- It does not specify how the various phases in the experiment can be designed.
- It does not specify how the experiment can be designed at different difficulty levels so that the students feel challenged while performing the same.
- It is not specific to the virtual laboratory environment and how the features of this environment can be utilized to incorporate various active learning methods.

These gaps in the literature are addressed and the guidelines proposed with examples from the BAE course for the engineering instructors. Using these guidelines the instructors can design experiments at various difficulty levels with Expository Instructional Strategy for the virtual laboratories. The next section covers the details of these guidelines.

5.3.2 Guidelines Set III - Designing Experiments at Various Difficulty Levels for the Expository Instructional Strategy

The experiment design with Expository Instructional strategy can be made more effective by slight modifications in the various tasks and designing the experiment at different difficulty levels.

The four important phases in the experiment design process are

1. Conception, planning and design of experiment
2. Execution of experiment
3. Analysis and interpretation
4. Applications

5.3.3 Guidelines to Design Phase I of the Expository Instructional Strategy

1. Conception, planning and design of experiment

In this phase you will be carrying out the following activities

a. Formulate question or problem to be investigated.
b. Decide the broad goal of the experiment

c. Formulate learning objectives
d. Determine replications
e. Identify treatments/ Suggesting technical procedures
f. Technical preparation of the experiment (assembling tools, preparing solutions, constructing circuits etc.)
g. Define dependent variable
h. Define independent variable
i. Design experiment
j. Design observation and measurement procedures
k. Predict results

You can design these activities yourself or make the students perform them depending on the difficulty level of the experiment you wish to set.

The example from BAE course is given below

Table 5.11: Steps in Design of Phase I

Activities	Example from course Basic Electronics
a. Formulate question or problem to be investigated.	What is the nature of voltage and current relationship in a PN junction diode?
b. Decide the broad goal of the experiment	Reinforce the theoretical concept of V-I plot of PN junction diode
c. Formulate learning objectives	1. Student should be able to plot the graph of voltage vs. current in a PN junction diode 2. Student should be able to analyse the graph 3. Student should be able to identify the various regions in the graph 4. Student should be able to describe the mathematical model
d. Determine replications	The plot can be obtained for multiple diodes having different specifications
e. Identify treatments/ Suggesting technical procedures	Circuit diagram of the experiment
f. Technical preparation of the experiment (assembling tools, preparing solutions,	1.In order to carry out the experiment use the Virtual lab available at the URL – www.docircuits.com

constructing circuits etc.)	2. You will have to register for using the lab 3. After registration login and start the Circuit Simulator. 4. Construct the circuit by dragging and dropping the necessary components and equipment
g. Define dependent variable	Current flowing through the diode (Id)
h. Define independent variable	Voltage across the diode (Vd)
i. Design experiment	1. You can carry out the DC analysis of the circuit by selection of proper simulation settings. 2. After constructing the circuit click on the simulation tab and select the DC analysis 3. Select the suitable settings for the DC analysis as per the necessary plot 4. After the selection of settings is done click on the run button to obtain the graph of voltage vs. current.
j. Design observation and measurement procedures	1. If you obtain the proper graph identify the linear and non-linear regions in the graph. 2. Measure the values of voltage and current in the linear and non-linear regions of the graph 3. Calculate the values of static and dynamic resistance of the diode. 4. If you do not get the proper graph identify the errors and rectify them 5. The problems may be in the selection of Simulation settings, type of analysis to be carried out, range of values of components and equipment chosen.
k. Predict results	1. You should obtain a graph as per the figure given.

This example is of a pure Expository Instructional Strategy in which you specify each and every step. But this is not effective hence you need to modify certain steps to incorporate constructivist approach and increase the difficulty level of the experiment.

The following modifications will increase the difficulty level of the experiment.

Table 5.12: Modifications to increase difficulty level in Phase I

Phase of the experiment	Difficulty levels	Guidelines on how to implement the difficulty levels
Definition of the problem and Hypotheses	A1 – Low level	Define a problem which requires very little formal knowledge
	A2 – Medium level	Define a problem which requires formal knowledge
	A3 – High level	Define a problem which requires specific formal knowledge

BAE Example – Increase difficulty level

The BAE example is at Low difficulty level. Modifying the problem as given below can increase the difficulty level of the BAE example experiment:

A2 – Medium level – What are the diode specifications on which the V-I Characteristics depend on?

A3 – High level - Of the given two diodes which one is more suitable for the purpose of rectification?

Table 5.13: Modifications to increase difficulty level in Phase I

Phase of the experiment	Difficulty levels	Guidelines on how to implement the difficulty levels
Technical suggestions	B1 – Very low level	Specify the equipment and materials required
	B2 – Low level	Specify the equipment and materials required but make the students carry out the assembling and ask them to give justification for the particular choice
	B3 – Medium level	Make the students prepare the tentative list of equipment or materials they would need for the experiment
	B4 - High level	Make the students prepare the tentative list of equipment or materials they would need for the experiment and also ask them to give justification for the particular choice

5.3.4 Guidelines to design Phase II of Expository Instructional Strategy

2. Execution of experiment

   During this phase the following activities need to be carried out.

   - Specify Observations to be taken or data to be gathered
   - Specify the Measurements to be carried out
   - Describe the Manipulations possible
   - Specify the various Calculations to be carried out

You can design these tasks/activities or make the student carry out various tasks depending on the target knowledge and skills and the difficulty level of the experiment you wish to set. In order to assess whether the students are carrying out the tasks/activities various assessment questions may be asked or prompts may be designed to provide opportunities for students to reflect on the results of the tasks/activities.

BAE Example

The example from BAE course and topic PN Junction diode is given below

Table 5.14:Steps in Design of Phase II

Activities	1. Example from course Basic Electronics
Specify Observations to be taken or data to be gathered	2. Observe the graph obtained 3. Measure the values of voltage across the diode at five different points (2 in linear region, 3 in non-linear region)
Specify the measurements to be carried out	Convert the observed values from graph to the voltage scale
Describe the manipulations possible	1. Now change the diode in the circuit and obtain the graph

	2. Repeat the procedure for the second diode selected
Specify the various calculations to be carried out	1. Calculate the value of Static Resistance of the diode as per the formula Rs = Vd/Id. 2. Calculate the value of Dynamic Resistance of the diode as per the formula Rd = ΔVd /ΔId. 3. Determine the relationship between Rs and Rd.

This example is of a pure Expository Instructional Strategy in which you specify each and every step. But this is not effective hence you need to modify certain steps to incorporate constructivist approach and increase the difficulty level of the experiment.

Increase Difficulty Level of the Experiment

The following modifications will increase the difficulty level of the experiment.

Table 5.15: Modifications to increase difficulty level in Phase II

Phase of the experiment	Difficulty levels	Guidelines on how to implement the difficulty levels
Actual performance	D1 – Low level	Instructor performs the experiment and students take down the data points
	D2 – Medium level	Students perform the experiment and collect the data as per the instructors guidelines
	D3 – High level	Students make decisions regarding the performance of the experiment and collection of the data

In the BAE example experiment the difficulty level can be increased by the following modifications.

Table 5.16: Modifications to increase difficulty level in Phase II – BAE example

Activities	4. Example from course Basic Electronics
Make the students specify Observations to be taken or data to be gathered	What observations you will carry out?
Make the students specify the measurements to be carried out	What measurements will you carry out?
Make the students describe the manipulations possible	How will you compare the two PN junction diodes based on their characteristics?
Make the students specify the various calculations to be carried out and also carry out the calculations	What parameters will you measure from the graph obtained? Carry out the necessary measurements.

5.3.5 Guidelines to Design Phase III of Expository Instructional Strategy

3. Analysis and interpretation

   During this phase the following activities need to be carried out.

   - Transform results into standard form (tables).
   - Determine relationships (could include graphs)
   - Discuss accuracy of data.
   - Report about procedures and results
   - Interpretation of results

   You can design these activities and make the student carry out various tasks depending on the target knowledge and skills and the difficulty level of the experiment you wish to set. In order to assess whether the students are carrying out the tasks/activities various assessment questions may be asked or prompts may be designed to provide opportunities for students to reflect on the results of the tasks/activities.

BAE Example

The example from BAE course and topic PN junction diode is given below

Table 5.17: Modifications to increase difficulty level in Phase III – BAE example

Activities	Example from course Basic Electronics
Transform results into standard form (tables).	Tabulate the values of Vd and Id
Determine relationships (could include graphs)	Observe the graph of Vd vs. Id and describe the nature of the plot.
Discuss accuracy of data.	Did you get the graph as per the requirements? If not what modifications are required in order to obtain the necessary graph?
Report about procedures and results	What type of analysis did you carry out? Why? What simulation setting did you choose? Why?
Interpretation of results	What can you infer from the graph obtained?

This example is of a pure Expository Instructional Strategy in which you specify each and every step. But this is not effective hence you need to modify certain steps to incorporate constructivist approach and increase the difficulty level of the experiment.

Increase Difficulty Level of the Experiment

Table 5.18: Modifications to increase difficulty level in Phase III

Phase of the experiment	Difficulty levels	Guidelines on how to implement the difficulty levels
Results and analysis of results	E1 – Low level	Instructors specify the expected results and type of analysis to be carried out and students carry out the analysis
	E2 – Medium	Students make the decisions regarding the expected results but type of analysis to be carried

	level	out is specified by the instructors
	E3 – High level	Students make the decisions regarding the expected results and type of analysis to be carried out

In the BAE example experiment the difficulty level can be increased by the following modifications

Table 5.19: Modifications to increase difficulty level in Phase III – BAE example

Activities	Example from course Basic Electronics
Transform results into standard form (tables).	What will you do with the values obtained from the graph?
Determine relationships (could include graphs)	What relationship did you derive from the observations?
Discuss accuracy of data.	Did you get the graph as per the requirements? If not what modifications are required in order to obtain the necessary graph?
Report about procedures and results	What type of analysis did you carry out? Why? What simulation setting did you choose? Why?
Interpretation of results	What can you infer from the graph obtained?

5.3.6 Guidelines to design Phase IV of Expository Instructional Strategy

4. Applications

During this phase the following activities need to be carried out.

- Predict applications based on results

- Formulate follow up hypotheses
- Apply experimental technique to new problem
- Summing up of acquired knowledge

BAE Example

The example from BAE course and topic PN junction diode is given below

Table 5.20: Modifications to increase difficulty level in Phase IV – BAE example

Activities	Example from course Basic Electronics
Predict applications based on results	What are the various applications where PN junction diode can be used?
Formulate follow up hypotheses	Justify with the help of an experiment that the PN junction diode is suitable for the purpose of rectification.
Apply experimental technique to new problem	Design the experiment for the above purpose.
Summing up of acquired knowledge	Write a summary of your learnings from the two experiments.

5.4 Answering Design Question DQ1d

In this section the answer to the following design question is obtained

DQ1d: How to incorporate active learning methods in the virtual laboratory experiment design?

Active learning is generally defined as any instructional method that engages students in the learning process. In short, active learning requires students to do meaningful learning activities and think about what they are doing (Bonwell, C.C., and J. A.

Eison, 1991). The core elements of active learning are student activity and engagement in the learning process. (Timothy J. Garrison, 2015) gives following suggestions for the implementation of active learning laboratories, which are referred to as interactive laboratories.

- Get the students engaged by guiding them through the important process of synthesizing, evaluating, predicting, and reflecting on a scenario.
- Create an atmosphere of curiosity.
- Setup and debug the experiments ahead of time.
- Focus the experiments on a single concept.
- Keep the experiments short.
- Collect data in real time and display live results.
- Couple the interactive labs with other active learning methods such as peer instruction questions.
- Get the students vested in seeing the outcome of the experiment.
- Use the labs to create interest for a discussion or a series of conceptual questions.
- Include some form of response system.
- Ask the students to continually make predictions, evaluate the data, perform analyses, and reflect on the results. They should identify the delineating limitations in the experiment, sources of error, suggestions for improvement, alternate methods for exploring the concept, etc. The experiments should be made active rather than having students passively follow a lab manual.

The advantage of implementing the active learning strategies is that the students are involved in meaningful learning and have a deeper approach to learning than a surface approach. Two of the most important educational goals are to promote retention and to promote transfer (which, when it occurs, indicates meaningful learning). Retention is the ability to remember material at some later time in much the same way it was presented during instruction. Transfer is the ability to use what was learned to solve new problems, answer new questions, or facilitate learning new subject matter (Mayer & Wittrock, 1996). A focus on meaningful learning is consistent with the view of learning as knowledge construction in which students seek to make sense of their experiences. In constructivist learning, students engage in active cognitive processing, such as paying attention to relevant incoming information, mentally organizing incoming information into a coherent representation, and mentally integrating incoming information with existing knowledge (Mayer, 1999). When the goal of instruction is to promote transfer, assessment tasks should involve cognitive processes that go beyond recognizing and recalling. Although assessment tasks that use these two cognitive processes have a place in assessment, these tasks can, and often should, be supplemented with those that utilize the full range of cognitive processes required for transfer of learning. The laboratory work can be designed so as to promote meaningful learning by providing opportunities to students to use all these cognitive processes.

Constructivist teaching is based on constructivist learning theory. It is based on the belief that learning occurs as learners are actively involved in a process of meaning and knowledge construction as opposed to passively receiving information. The implications of constructivist approach to laboratory activities are

1. Learning requires mental activity. The process of knowledge construction requires mental effort or activity (Saunders, W. L., 1992); material cannot simply be presented to the learner and learned in a meaningful way (Driver, R., 1988).
2. Naive theories affect learning. New knowledge must be related to knowledge the learner already knows (Ausubel, D. P., 1964). The learner has preconceptions and misconceptions, which may interfere with the ability to learn new material (Resnick, L. B., 1983). These personal theories also affect what the learner observes (Hodson, D.1988, Champagne, A. B.et.al.,1989). Personal theories must be made explicit to facilitate comparisons (Driver, R., 1983).
3. Learning occurs from dissatisfaction with present knowledge. For meaningful learning to occur, experiences must be provided that create dissatisfaction with one’s present conceptions (Hodson, D., 1992). If one’s present conceptions make accurate predictions about an experience, restructuring (meaningful learning) will not occur (Saunders, W. L., 1992).

4. Learning has a social component. Knowledge construction is primarily a social process in which meaning is constructed in the context of dialogue with others (Driver, R., 1983). Cognitive growth results from social interaction (Champagne, A. B, 1991). Learning is aided by conversation that seeks and clarifies the ideas of learners (Carr, M., et.al.,1994).
5. Learning needs application. Applications must be provided which demonstrate the utility of the new conception (von Glasersfeld, E., 1991).

(Biggs, 1996, 1999) proposed the operational framework for teaching based on the principle of constructivism. This framework at the unit level has the following components (Biggs, 2014)

1. Describe the intended learning outcomes (ILOs) for the unit, using one verb (or at most two) for each outcome. The ILO denotes how the content or topics are to be dealt with and in what context.
2. Create a learning environment using teaching/learning activities (TLAs) that require students to engage each verb. In this way the activity nominated in the ILO is activated.
3. Use assessment tasks (ATs) that also contain that verb, thus enabling one with help of predetermined using rubrics to judge how well students' performances meet the criteria.
4. Transform these judgments into final grades.

5.4.1 Synthesis of Literature

1. The laboratory activities should lead to meaningful learning amongst the students.
2. Design of laboratory learning needs to consider how to bring in and build on students' prior learning. The laboratory activities should be based on the principle of constructivism.

3. The principle of constructive alignment should be incorporated while designing laboratory activities.
4. The laboratory activities should make the students to do meaningful learning activities and think about what they are doing.
5. Get the students engaged by guiding them through the important process of synthesizing, evaluating, predicting, and reflecting on a scenario.
6. Couple the interactive labs with other active learning methods such as peer instruction questions.
7. Use the labs to create interest for a discussion or a series of conceptual questions.
8. Ask the students to continually make predictions, evaluate the data, perform analyses, and reflect on the results. They should identify the delineating limitations in the experiment, sources of error, suggestions for improvement, alternate methods for exploring the concept, etc. The experiments should be made active rather than having students passively follow a lab manual.

5.4.2 Gaps in Literature for Incorporating Constructivist Approach and Active Learning Methods in Laboratory Experiment Design

1. The literature suggests that the instructors should use active learning methods in the experiment design but do not give specific ways in which these can be implemented.
2. It specifies the "what" but not the "how" of the constructivist approach and active learning methods.
3. It does not specify how the various features of the virtual laboratories can be used so that the active learning methods can be implemented in virtual labs.
4. It brings out the importance of constructive alignment but do not specify how the instructors can incorporate it in the experiment design.

These gaps in the literature are addressed and the guidelines proposed with examples from the BAE course for the engineering instructors. Using these guidelines the instructors can design experiments incorporating active learning methods with Expository Instructional Strategy for the virtual laboratories. The next section covers the details of these guidelines.

5.4.3 Guidelines Set IV - Incorporating Active Learning Methods in the Experiment Design with Expository Instructional Strategy

The Expository Instructional Strategy can be made more effective by simple modifications in the design of the various phases incorporating active learning methods and a constructivist approach. The following guidelines provide the details of the changes during various phases to convert the traditional expository design to a more effective design.

Phase 1: Conception, Planning and Design of Experiment

During this phase the following activities need to be carried out.

- Formulate question or problem to be investigated.
- Decide the broad goal of the experiment
- Formulate learning objectives
- Determine replications
- Identify treatments/ Suggesting technical procedures
- Technical preparation of the experiment (assembling tools, preparing solutions, constructing circuits etc.)
- Define dependent variable
- Define independent variable
- Design experiment
- Design observation and measurement procedures
- Predict results

You can design these activities yourself or make the student carry out these. Here is one example from the course Basic Electronics for the expository instructional strategy with tips on how active learning can be incorporated in each phase of the design.

1. **Conception, planning and design of experiment**

- **Formulate question or problem to be investigated.**

  Example from BAE: What is the nature of voltage and current relationship in a P junction diode?

- **Decide the broad goal of the experiment**

  Example from BAE: Reinforce the theoretical concept of V-I plot of PN junction diode

- **Formulate learning objectives**

  Example from BAE:

  1.Student should be able to plot the graph of voltage vs. current in a PN junction diode

  2.Student should be able to analyse the graph

  3.Student should be able to identify the various regions in the graph

  4.Student should be able to describe the mathematical model

- **Determine replications**

  Example from BAE: The plot can be obtained for multiple diodes having different specifications

- **Identify treatments/ Suggesting technical procedures**

  Example from BAE: Circuit diagram of the experiment and DC analysis

  Guideline 1: Instead of giving the circuit diagram ask the students to construct their own circuit. When the students construct the circuit they work in the objects domain that is they perform an action. In order that they also work in the ideas or concepts domain ask the students questions such as what is the purpose of a particular component in the circuit, why is the equipment connected in series or parallel etc. Such questions will make the students reflect on their action and they will work in the cognitive domain. They will reflect on the reason for the particular action. This leads to authentic and deep learning as opposed to surface learning.

  Task: Construct the circuit on paper necessary to carry out the given experiment.

- **Technical preparation of the experiment (assembling tools, preparing solutions, constructing circuits etc.)**

  Example from BAE: 1.In order to carry out the experiment use the Virtual lab available at the URL – www.docircuits.com

  2. You will have to register for using the lab

  3. After registration login and start the Circuit Simulator.

  4. Construct the circuit by dragging and dropping the necessary components and equipment

  Guideline 2: Instead of specifying the details of how to come up with the circuit ask the students to explore and identify the simulator available online in order to carry out the experiment. Let them explore the simulator and come up with the circuit on their own.

Tasks: Explore the various online virtual labs available and identify the one most suitable to carry out the given experiment. Construct the appropriate circuit using the selected simulator.

- **Define dependent variable**

  Example from BAE: Current flowing through the diode (Id)

  Guideline 3: Ask the students to identify the dependent variable.

  Task: What parameter of the PN junction diode will you measure for the given experiment? How will you carry out the measurement?

- **Define independent variable**

  Example from BAE: Voltage across the diode (Vd)

  Guideline 4: Ask the students to identify the independent variable.

  Task: What parameter of the PN junction diode will you vary for the given experiment? How will you vary the parameter?

- **Design experiment**

  Example from BAE: 1. You can carry out the DC analysis of the circuit by selection of proper simulation settings.

  2. After constructing the circuit, click on the simulation tab and select the DC analysis

3. Select the suitable settings for the DC analysis as per the necessary plot

4. After the selection of settings is done click on the run button to obtain the graph of voltage vs. current.

Guideline 5: Ask he students to explore the various types of analysis that can be carried out with the selected virtual lab and select the type of analysis suitable for the given experiment. Ask the students to select the most suitable settings and carry out the necessary action to obtain the results.

Task: Explore the various types of analysis that can be carried out with the virtual lab you have selected. Decide the type of analysis you will carry out for finding out the V-I plot of the PN junction diode. Select the suitable settings and obtain the plot.

- **Design observation and measurement procedures**

  Example from BAE:

  1 Measure the values of voltage and current in the linear regions of the graph.

  2 Calculate the values of static and dynamic resistance of the diode.
  $Rs = V/I$ and $Rd = \Delta V/\Delta I$.

  3 If you do not get the proper graph identify the errors and rectify them

  4 The problems may be in the selection of Simulation settings, type of analysis to be carried out, range of values of components and equipment chosen.

Guideline 6: Do not specify each and every step but ask the students to identify the linear and non-linear regions in the graph, recall the formula for the static and dynamic resistance and measure them.

Task: Identify the linear and non-linear regions in the graph. State the formula for the static and dynamic resistance of the PN junction diode. Measure them from the obtained graph. Do the values match the desired? Why?

- **Predict results**

  Example from BAE: 1. You should obtain a graph as per the figure given.

  Guideline 7: Do not specify the type of graph the students should get but ask them to predict the result.

  Task: Did you get the graph as per the desired results? If not what modifications will you carry out in order to get the necessary graph? Carry out the modifications and obtain the graph.

Phase 2: Execution of Experiment

During this phase the following activities need to be carried out.

- Specify Observations to be taken or data to be gathered
- Specify the Measurements to be carried out
- Describe the Manipulations possible
- Explain the methods for Recording the results
- Specify the various Calculations to be carried out
- Specify the ways of Explaining experimental techniques

- Describe methods for Explaining about various decisions
- Working according to the design
- Specify Observations to be taken or data to be gathered

Example from BAE: Observe the graph of voltage across diode and current flowing through the diode obtained.

Guideline 8: Do not specify the parameters but ask the students to identify them.

Task: Which variables will you plot on the graph? Select the two axes for the variables? Select the suitable settings for the two axes.

- Specify the measurements to be carried out

Example from BAE: Measure the values of voltage across the diode and the current at five different points (2 in linear region, 3 in non-linear region)

Guideline 9: Ask the students to identify the measurements they need to carry out.

Task: What observations you will carry out? What measurements will you carry out? What parameters will you measure from the graph obtained? Carry out the necessary measurements.

- Describe the manipulations possible

Example from BAE:

- Explain the methods for recording the results
- Specify the various calculations to be carried out

Example from BAE:

1. Calculate the value of Static Resistance of the diode as per the formula Rs = Vd/Id.

2. Calculate the value of Dynamic Resistance of the diode as per the formula
3. Rd = ΔVd /ΔId.
4. Determine the relationship between Rs and Rd.

Guideline 10: Do not specify the complete details but ask the students to carry out the necessary steps to arrive at the result.

Task: Now change the diode in the circuit and obtain the desired graph. Select the necessary settings and the suitable variables for the plot. Repeat the procedure for the second diode selected.

Phase 3: Analysis and Interpretation

During this phase the following activities need to be carried out.

- Transform results into standard form (tables).
- Determine relationships (could include graphs)
- Discuss accuracy of data.
- Report about procedures and results
- Interpretation of results
- Statistical analysis of results
- Formulate generalizations.
- Discuss limitations/assumptions of experiment.
- Explain relationships.
- Formulate new questions/problems.

You can design these activities and make the student carry out various tasks depending on the instructional strategy you wish to incorporate, target knowledge and skills and the difficulty level of the experiment you wish to set. In order to assess whether the students are carrying out the tasks/activities various assessment questions may be asked or prompts may be designed to provide opportunities for students to reflect on the results of the tasks/activities.

- Transform results into standard form (tables)

  Example from BAE: Complete the following Table for the values of Vd and Id.

  Table – Observation table

S.No.	Forward Bias		Reverse Bias	
	Vd (volts)	Id (mA)	Vd (volts)	Id (μA)

Guideline 11: Do not give the detailed data table but ask the students to form their own table. Make them write the headings of the rows and the columns.

Task: Tabulate the data you measure from the graphs obtained. Specify the headings of the rows and columns along with the units of each variable.

- Determine relationships (could include graphs). Discuss accuracy of data. Report about procedures and results

  Example from BAE: Obtain the graph as given in the figure. The graph has a linear region and non-linear region. The cut-in voltage of the PN junction diode should be 0.7 Volts. The graph should be linear after this voltage and later becomes non-linear. The slope of the graph changes after the cut-in voltage.

Guideline 12: Do not specify the results the student should get from the experiment instead ask the students to find out whether they get the desired results.

Task: Observe the graph you have obtained after running the simulation and describe the nature of the plot. Is the nature of the graph as per desired? If not what modifications are required in order to obtain the necessary graph? What type of analysis did you carry out? Why? What simulation setting did you choose? Why?

•

terpretation of results

Example from BAE: What can you infer from the graph obtained?

Phase 4: Applications

During this phase the following activities need to be carried out.

- Predict applications based on results
- Formulate follow up hypotheses
- Apply experimental technique to new problem
- Summing up of acquired knowledge

- Predict applications based on results

  Example from BAE: The PN junction diode is used for the following applications – As a Rectifier, Clipper, Clamper and Switch.

Guideline 13: Do not specify the applications to the students but ask them to explore and find out the applications themselves.

Task: What are the various applications where PN junction diode can be used?

- Formulate follow up hypotheses
- Apply experimental technique to new problem
- Summing up of acquired knowledge

Guideline 14: Based on the results of the experiment ask the students to come up with a new concept to be verified. The concept may be related to the same device or some other similar device. Ask them to set up the complete experiment to verify the new concept.

Task: Identify another concept from the same topic of PN junction diode or characteristics of other types of diodes such as Zener Didoe, Light Emitting Diode etc. Set up and perform all the tasks to verify the selected concept. OR Identify similar concept for the BJT and perfrom the complete experiment to verify the nature of Input or Output characteristics.

Carry out the following modifications in the tasks to achieve higher cognitive level learning objectives.

Guideline 15 – LO at analyze and evaluate levels

Phase I -

In the step technical preparation of the experiment the student may be given different circuits and asked to analyze them and identify the most suitable circuit design for the particular experiment.

In the step design observation and measurement procedures the students may be asked to analyze the various ways of carrying out measurements and identify the most suitable procedure.

Guideline 16 – LO at create level

In the technical preparation of the experiment the student may be asked to design his or her own circuits.

In the step design observation and measurement procedures the students may be asked to come up with their own observations and procedures.

Guideline 17 – LO at analyze and evaluate levels

Specify Observations to be taken or data to be gathered

Specify the measurements to be carried out

Describe the manipulations possible

Specify the various calculations to be carried out

These are the steps in which the students may be asked to carry out multiple observations, measurements and calculations. These steps are also most suitable for developing the investigative, manipulative and analysis skills.

Guideline – LO at create level

To achieve the learning objective at create level the students may be asked to design their own observations, measurements and calculations.

Guideline – LO at analyze and evaluate levels

In order to achieve the learning objectives at these levels the students may be asked to plot multiple graphs and measure various parameters for each of the graph. They may be asked to calculate the values of parameters with the theoretical values and then compare the values obtained from calculations and obtained practically. Based on the results they may be asked to draw inferences from the results obtained.

BAE example – PN junction diode

Ask the students to plot the graph of V-I characteristics for different diode specifications. Ask the students to adjust one specification for example the internal resistance of the diode Rs to different values and plot the V-I characteristics. Make the students analyse the change in the nature of the graph for the different values. This can be repeated for each of the specification on which the nature of the graph depends. These tasks are helpful in developing the higher level learning objectives of analysis and evaluation.

BAE Example

The example from BAE course and topic PN junction diode is given below

Table 5.21:Tasks for higher level learning objectives – BAE example

Activities	Example from course Basic Electronics
Predict applications based on results	What are the various applications where PN junction diode can be used?

Formulate follow up hypotheses	Justify with the help of an experiment that the PN junction diode is suitable for the purpose of rectification.
Apply experimental technique to new problem	Design the experiment for the above purpose.
Summing up of acquired knowledge	Write a summary of your learnings from the two experiments.

Guideline 16: Have students suggest sources of error in the lab and modifications to eliminate these sources of error, and raise questions about the lab. Comparisons of data between groups in class and between classes may raise questions about sources of variation. Students can produce questions by substituting, eliminating, or increasing or decreasing a variable.

Guideline 17: Have students make predictions and explain them before the lab. Having students make predictions creates interest in the outcome. In addition, have students explain the basis for their predictions using their present ideas. Ideally, the problem presented will be one, which creates dissatisfaction with their present understanding. Challenge students to come up with alternative hypotheses.

Guideline 18 Give the students an opportunity to discuss their predictions, explanations, procedures, and data table before doing the lab, and give them an opportunity to present their results after the lab. The process of formulating an opinion to express and share with a group promotes reflection.

Guideline 19: Give students opportunity to demonstrate applications after the lab. Students need opportunities to use new ideas in a wide range of contexts.

In this section the details of the guidelines to incorporate active learning methods in the virtual laboratory experiment design with example of learning objective at analysis level are provided. In the Appendix – the templates for the experiment design with learning objective at evaluate and create level are presented.

5.5 Answering Design Question DQ1e

In this section the answer to the following design question is obtained

DQ1e: How to design an effective virtual laboratory experiment with Discovery or Guided Inquiry instructional strategy?

The origin of discovery (or guided-inquiry) laboratory teaching has been traced back to the early 20th century British science educator Henry Armstrong, who taught chemistry by a heuristic method in which students were required to generate their own questions for investigation. No laboratory manual was used and the instructor provided minimal guidance. The student was placed into the role of discoverer.

By studying a specific example of a phenomenon, students are able to develop a general understanding of the underlying principle in the discovery approach (Watson, 1978). The authentic scientific discovery learning is characterized by the need to design scientific experiments (van Joolingen & de Jong, 1997).

Since computer simulation has the capacity to provide learners with an exploratory learning environment, it has been regarded as a powerful tool for scientific discovery learning (SDL). Scientific discovery is usually interpreted as the processes of mindful coordination between hypothesized theories and evidence collected by experiments (Klahr & Dunbar, 1988; Kuhn et al., 1992). SDL is a knowledge construction approach that is based on scientific discovery activities. Three main interlocked spheres exist in the processes of effective SDL (see Zhang, 2000):

1. Problem representation and hypothesis generation, which heavily relies on the activating and mapping of prior knowledge and the meaning-making activities;
2. Testing hypotheses with valid experiments; and
3. Reflective abstraction and integration of the discovery experiences.

(Kathleen Scalise et.al., 2011) have proposed a Design Principles Framework for Simulations and Virtual Laboratories with three main patterns - Effective interfaces, Powerful visualizations and real-world scientific inquiry. The following principles are suggested for the scientific inquiry.

1. Make students identify the problem and write hypotheses.
2. Do not pose questions as given and avoid cookbook method.
3. Specify clear objectives and let the students be aware of them.
4. Include assessment that measures students' knowledge.
5. Make students collect data, make observations, influence results and apply information.
6. Make students set up parameters, operate virtual equipment and record data.
7. Make students recognize experimental outcomes as clues to scientific phenomena.
8. Engage students in certain decision-making tasks.
9. Provide scaffolds to relate observations and conclusions to explanations.

5.5.1 Gaps in guidelines derived from literature for implementing Discovery instructional strategy in laboratories

1. The literature does not specify how the tasks and assessment can be designed for the discovery instructional strategy.
2. It does not specify how the discovery strategy can be incorporated for the virtual laboratories and engineering education.

In the next section the guidelines for designing tasks to be assigned to the students during various phases of the Discovery Instructional Strategy are presented. There are examples from BAE course for each of the virtual laboratory tasks.

5.5.2 Guidelines Set V - Designing virtual lab experiment with Discovery instructional strategy

Throughout the history of science and engineering education, four distinct styles of laboratory instruction have been prevalent: expository, inquiry, discovery, and problem-based. These styles can be differentiated by three descriptors: outcome, approach, and procedure. Expository, discovery, and problem-based activities all have predetermined outcomes. The discovery approach, like inquiry, is inductive. By studying a specific example of a phenomenon, students are able to develop a general understanding of the underlying principle. In the past decade, the research on discovery learning has evolved from concept discovery learning towards more sophisticated and authentic scientific discovery learning characterized by the need to design scientific experiments (van Joolingen & de Jong, 1997). Since computer simulation has the capacity to provide learners with an exploratory learning environment, it has been regarded as a powerful tool for scientific discovery learning (SDL).

Discovery (guided-inquiry) learning differs from inquiry (open-inquiry) learning with respect to the outcome of the instruction and to the procedure followed. Whereas in true inquiry instruction the outcome is unknown to both the instructor and the students, in a discovery learning environment the instructor guides the students toward discovering the desired outcome. This is accomplished by giving the students directions for what they are expected to do. Use the following template to design an experiment with the discovery instructional strategy.

Phases in the experiment design for Discovery Instructional Strategy

The laboratory experiment should be designed considering the following four important phases in the process

Phase 1: Initiation Phase

The Initiation Phase is the first phase in all levels of inquiry. It is primarily designed to stimulate and motivate students' curiosity through questioning.

Guideline: In this phase provide students with an opportunity to experience a phenomenon or something new that challenges a previous belief or assumption. You may ask questions such as

Have you ever seen…?, Did you notice…?, What did you observe…?

Example from BAE:

Figure 5.4 BAE exmaple - Initiation phase

Have you seen these components? Can you identify them? What are these used for in Electronics?

Design the initiation phase for your experiment.

Phase 2: Exploration Phase

The Exploration Phase is the second phase of inquiry. In this phase, questions are eliminated or narrowed down to those types of questions students can actually physically answer through experimentation or research.

Guideline: In this phase assign tasks to the students to identify the relevant variables. Students can be asked to identify controlled and uncontrolled variables. Assign tasks in which students will design the procedure or reduce the procedure to the essential parts. If the procedure cannot be designed safely, then the students might be asked to explain why certain steps in the procedure are done in a certain way. Assign tasks where students make predictions and explain them before the lab. Having students make predictions creates interest in the outcome. In addition, have students explain the basis for their predictions using their present ideas. Ideally, the problem presented will be one, which creates dissatisfaction with their present understanding. Challenge students to come up with alternative hypotheses. In this phase ask questions such as: What happened when…?, What did you…?, What could we do to find out…?, What questions do you have…?

Example from BAE: Find out one application of these components. Design the circuit for the particular application. Select the appropriate inputs to be given to the circuit.

- What output do you expect from the circuit?
- What did you do to find the application of the component?
- What happened when you gave the chosen input?
- What could we do to find out the change in output if a different component is used?

Design the exploration phase for your experiment.

Phase 3: Experimentation Phase

The third phase of inquiry is the Experimentation Phase. This is where students form into groups to conduct an experiment. Students collect data and information, and then formulate a method of presentation.

Guideline: Make the students come up with tasks and corresponding assessment questions for data collection and tabulation, data analysis, reporting the results, analysis of the obtained results, drawing conclusions from the obtained analysis of results. Ask relevant questions and provide hints so that the students are guided towards the solution. What did you find out about…?, How is it the same as or different from…?, What do you know about the characteristics of…?

Example from BAE: Construct the designed circuit in the virtual lab. Apply the chosen input to the circuit and observe the output.

- What output did you obtain?
- How is it the same as or different from your predicted output?
- What do you know about the characteristics of the chosen component?

Design the exploration phase for your experiment.

Phase 4: Presentation Phase

The last phase of inquiry is the Presentation Phase. Groups or individuals take the information gathered in the experiment and put it into some form of presentation. PowerPoint presentations or project display boards are types of presentations that may be used.

Guideline: Make the group or student to share the data with an audience and allow time for questions concerning procedures, data, information, etc. Can you explain why…?,Why do you think…?,What other factors may be included in…?,Can you find a way to…?,How did you arrive at a solution to…?

Example from BAE: Share the details of your experiment with your peers. The details such as the application you have designed, the circuit construction, the details of the functions of other components used, input applied, output obtained.

Can you explain why your results do not match with your peers?

Why do you think the peers have a better design than yours?

What other factors you should have considered while designing the circuit?

Can you find a way to come up with a better solution?

How did you arrive at the new better design?

Design the presentation phase for your experiment.

5.6 Answering Design Question DQ1f

In this section the answer to the following design question is obtained

DQ1fr: How to design an effective virtual laboratory experiment with Well-Structured Problem Solving Instructional strategy?

The basic components of a problem include the initial state (givens), a desired end state (goal), and means to get from the initial state to the end state, (operations) (Chi, Feltovich, & Glaser, 1981; Ormrod, 2004). Problems can differ vastly in their structure. On one extreme of the continuum are problems that are a straightforward application of concepts or principles, that clearly state the givens and desired goal, and for which all information needed to solve the problem "correctly" is presented. These are referred to as well-structured problems (Jonassen, 1997; Pretz, Naples, & Sternberg, 2003).

(David H. Jonassen, 1997) state that the most commonly encountered problems, especially in schools and universities, are well-structured problems. Typically found at the end of textbook chapters, these well-structured application problems require the application of a finite number of concepts, rules, and principles being studied to a constrained problem situation. These problems have also been referred to as transformation problems (Greeno, 1978), which consist of a well-defined initial state, a known goal state, and constrained set of logical operators.

The characteristics of well-structured problems are (Wood, 1983):

- These problems present all elements of the problem and are presented to learners as well-defined problems with a probable solution.
- The parameters of problem are specified in the problem statement.
- They engage the application of a limited number of rules and principles that are organized in a predictive and prescriptive arrangement with well-defined, constrained parameters.
- They involve concepts and rules that appear regular and well-structured in a domain of knowledge that also appears well-structured and predictable.
- They possess correct, convergent answers; possess knowable, comprehensible solutions where the relationship between decision choices and all problem states is known.
- They have a preferred and prescribed solution process.

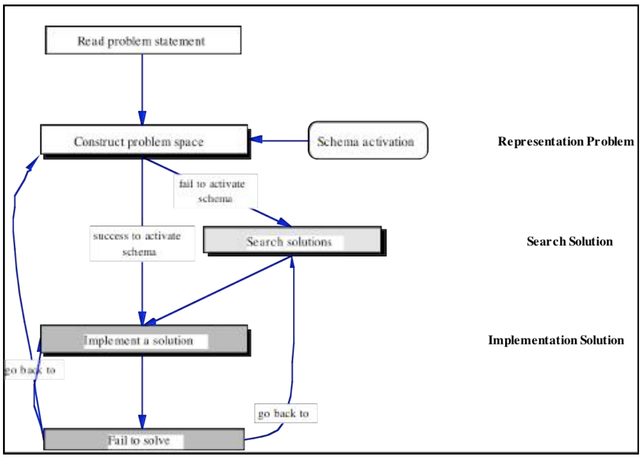


Figure 5.5 Well-structured problem solving

5.6.1 Literature Review

(David H. Jonassen, 1997) describe instructional design steps for the well-structured problem solving. These are

- Step 1: Review Prerequisite Component Concepts, Rules, and Principles: The concepts, principles, and procedures that are required to solve a problem (the component skills necessary to build their problem schema) should be reviewed or presented as concept
- Step 2: Present Conceptual or Causal Model of Problem Domain: Mayer (1989) concluded that providing concrete, conceptual models for learners improves conceptual retention, reduces verbatim recall, and improves problem-solving transfer.
- Step 3: Model Problem Solving: Worked examples help learners to construct useful problem schemas. They can help learners categorize problems with similar solutions and construct solutions to novel problems by analogy to the example (Anderson, Farrell, & Sauers, 1984; Sweller & Cooper, 1985). Learning from worked examples help learners form appropriate representations of concepts and problem situations in the domain.
- Step 4: Present Practice Problems: The combination of worked examples plus extended practice is most likely to facilitate the acquisition of problem schemas and the transfer of those schemas to novel problems. Present the

practice problems to the learner in the form in which they will be assessed (Cooper & Sweller, 1987; Sweller & Cooper, 1985).

- Step 5: Support the Search for Solutions: The following supports may be made available to learners to assist them in generating and testing plausible solutions. One approach is to provide analogical problems (Jonassen, Ambruso, and Olesen, 1992). Another support strategy is to provide advice or hints on breaking down the problem into sub problems.

  Provide adequate feedback about learners' attempts to solve the problem. Feedback should constitute more than simple knowledge of results such that if their answers are incorrect, they can determine where the problem-solving process went wrong and provide either coaching or the correct solution process from that point in the problem.

  The scaffolds should be faded out as soon as possible. That is, they should not be made consistently available to learners. Provide students the opportunity to use these scaffolds in arriving at a solution.
- Step 6: Reflect on Problem State and Problem Solution: Learners should note the characteristics of the problem as presented: the situation, the knowns and unknowns, and the problem as stated. They should then reflect on the solution processes that were most effective and ineffective in solving the problem. Learners can even create tables or databases of problem types and solutions (Sweller, 1988).
- Developing strong associations between the type of problem encountered and the types of solutions used is very likely to help learners to develop stronger problem schemas which will help them to become better problem solvers in the future.

5.6.2 Gaps in literature for implementing Well-Structured problem solving instructional strategy in laboratories

- The literature gives the details of the problem solving instructional design but for the classroom content.

- There is a need for guidelines in the context of laboratory problem solving and specifically for the virtual laboratories.

5.6.3 Guidelines Set VI - Designing virtual laboratory experiment with Well-Structured problem solving instructional strategy

The well-structured application problems require the application of a finite number of concepts, rules, and principles being studied to a constrained problem situation. The laboratory experiment can be designed as a well-structured problem solving activity. Use the following template to design an experiment with the well-structured problem solving strategy.

Describe the Problem

Guideline: The well structured problems have the elements such as the initial state, a desired end state and means to get from the initial state to the end state. The problem should be presented to learners as well-defined problem with a probable solution (the parameters of problem specified in problem statement). The problem should have following characteristics:

- The problem should be such that the students need to have the knowledge of a limited number of rules and principles.
- The concepts, rules and principles should be regular and well structured in a domain of knowledge that is also well structured.
- The problem should possess correct and convergent answers.
- The problem should possess knowable and comprehensible solutions where the relationship between decision choices and all problem states is known or probabilistic.

- The problem should have a preferred and prescribed solution process.

Step 1: Formulate Learning Objectives

Guideline: Articulate the learning outcomes of the problem. What do you want students to know or be able to do as a result of performing the experiment? State the learning objectives of the experiment.

- Decide the broad goal of the experiment
- Formulate learning objectives

Example from BAE:

Broad Goal: Develop the skill of well-structured problem solving

Learning Objectives:

1. The student should be able to determine the gain of a BJT CE Amplifier.
2. The student should be able to compare the values obtained from theoretical calculations and practical observations.

Step 2: Review prerequisite Concepts, Rules, and Principles

A Transistor can operate in any one of the 3 regions namely Cut-off, Saturation & Active. As per application requirements transistor has to be operated in one of the above regions in absence of input signal. Hence we need to set up (bias) the values of current (IC) and voltage (VCE) such that the transistor is operating in the desired region. These values, set using external components & sources, are known as the Q point values. Ideally once set, the Q point should be stable. But it is not and the factors affecting it are:

1. Temperature.
2. Device variations.

Voltage divider bias: The circuit is as shown in the figure below. Here we use resistors R1 & R2 to form a potential divider which then provides a fixed base voltage. A resistance in the emitter circuit is also present. Because of this resistor RE there exists a feedback in the circuit which also causes AC degeneration.

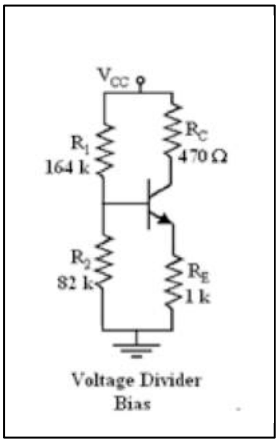


Figure 5.6 BAE problem circuit diagram BJT Voltage Divider Bias

Step 3: Model Problem Solving

Consider the common-emitter BJT amplifier circuit shown in Figure 1. Assume VCC =15V,β=150,VBE =0.7V, RE =1kΩ,RC =4.7kΩ,R1 =47kΩ,R2 =10kΩ, RL =47kΩ,Rs =100Ω.

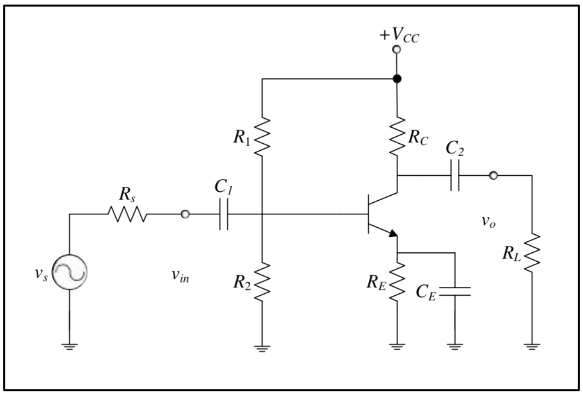


Figure 5.7 BJT CE Amplifier

(a) Determine the Q-point.

(b) Sketch the DC load line. What is the maximum (peak to peak) output voltage swing available in this amplifier?

(c) Verify the result obtained by theoretical calculations practically by simulating the circuit and carrying out suitable analysis.

Theoretical Solution

(a) Analyzing the DC Voltage-divider bias circuit, we have

$$\begin{aligned} V_{TH} &= \frac{R_2}{R_1+R_2}V_{CC} \\ &= \frac{10\text{k}}{10\text{k}+47\text{k}}(15) = 2.63 \text{ V} \end{aligned}$$

$$\begin{aligned} R_{TH} &= \frac{R_2 R_1}{R_1+R_2} \\ &= \frac{(10\text{k})(47\text{k})}{10\text{k}+47\text{k}} = 8.2456 \text{ k}\Omega \end{aligned}$$

$$\begin{aligned} I_B &= \frac{V_{TH}-V_{BE}}{R_{TH}+(\beta+1)R_E} \\ &= \frac{2.63-0.7}{8.2456\text{k}+(151)(1\text{k})} = 12.12\,\mu\text{A} \end{aligned}$$

$$I_C = \beta I_B$$
$$= (150)(12.12\mu) = 1.8179 \text{ mA}$$
$$I_E = (\beta+1)I_B$$
$$= (151)(12.12\mu) = 1.83 \text{ mA}$$

$$V_E = I_E R_E$$
$$= (1.83\text{m})(1\text{k}) = 1.83 \text{ V}$$
$$V_C = V_{CC} - I_C R_C$$
$$= 15 - (1.8179\text{m})(4.7\text{k}) = 6.456 \text{ V}$$
$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$
$$= 15 - (1.8179\text{m})(4.7\text{k}) - (1.83\text{m})(1\text{k}) = 4.626 \text{ V}$$

As $I_B > 0$ and $V_{CE} > 0.2$ V, the transistor is in active region of operation.

The Q-point lies at $I_{CQ} = 1.8179$ mA

$V_{CEQ} = 4.626$V

(b) For ideal cut-off

$V_{CE(off)} = V_{CC}$=15V For ideal saturation

$$I_{C(sat)} = \frac{V_{CC}}{R_C + R_E} = \frac{15}{5.7\text{k}} = 2.63 \text{ mA}$$

The plot of DC load line is shown in figure below

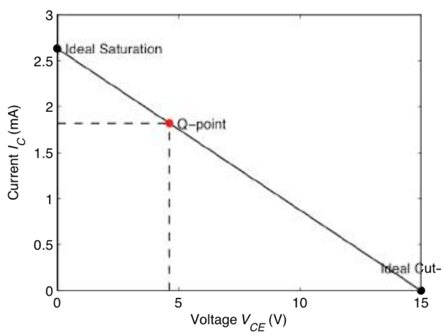


Figure 5.8 DC Load line

We see that the Q-point lies closer to saturation (VCE = 0.2 V) than cut-off (VCE = 15 V). Hence the maximum available peak to peak output voltage swing = 2(VCE Q − 0.2) = 8.852 V.

(c) The following is the circuit constructed using the virtual lab. The Q point is obtained using the DC Analysis without sweep and the figure gives the DC load line obtained by carrying out the DC Analysis with sweep.

Step 4: Present Practice Problems

Problem 2: Find the bias point and the DC load line of the circuit below. (Si BJT with β = 200, VA = 150 V, ignore Early effect in bias calculations). Verify the result obtained by theoretical calculations practically by simulating the circuit and carrying out suitable analysis.

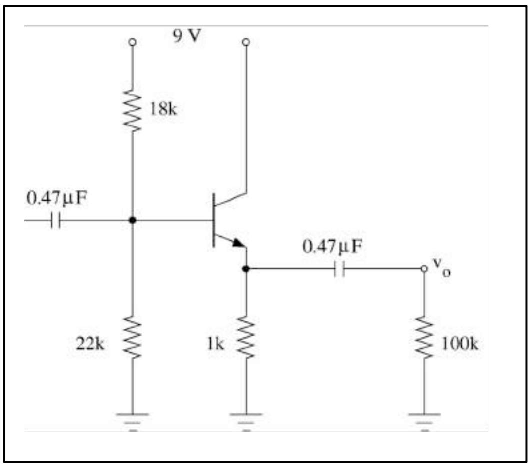


Figure 5.9 Practice Problem 2

Problem 3: Find the bias point and the DC load line of the circuit below. (Si BJT with β = 200, VA = 150 V, ignore Early effect in bias calculations). Verify the result obtained by theoretical calculations practically by simulating the circuit and carrying out suitable analysis.

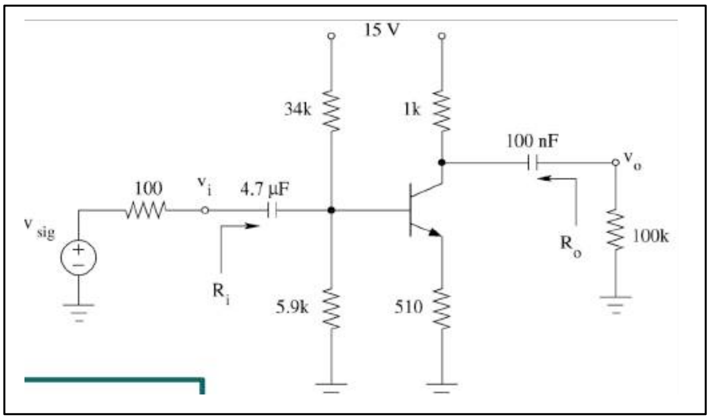


Figure 5.10 Practice Problem 3

Problem 4: The above problems were based on the Voltage divider bias circuit. The following are the other two types of BJT bias circuits.

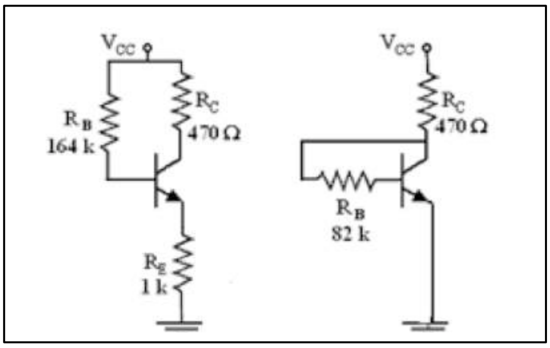


Figure 5.11 Practice Problem 4

(a) Identify the type of Bias in the two circuits.

(b) Determine the Q-point.

(c) Sketch the DC load line. What is the maximum (peak to peak) output voltage swing available in this amplifier?

(d) Verify the result obtained by theoretical calculations practically by simulating the circuit and carrying out suitable analysis.

Step 5: Provide scaffolds for solving problems

The following formulae should be used to find the Q point and DC load line for the two biasing circuits.

For Fixed Bias Circuit

- $V_C = V_{CC} – (I_C \times R_C)$
- $V_{CE} = V_C - V_E$
- $V_E = 0$ V
- $V_B = V_{BE}$
- $I_B = (V_{CC} – V_{BE}) / R_B$
- $I_C = \beta_{DC} \times I_B$
- $I_E = (I_C + I_B)$

For Collector Feedback Bias Circuit

- $V_C = V_{CC} – R_C (I_C + I_B)$
- $V_E = 0$ V
- $V_B = V_{BE}$
- $I_B = (V_C – V_B) / R_B$
- $I_C = \beta_{DC} \times I_B$
- $I_E = (I_C + I_B)$

For the BAE course most of the concepts, rules and principles can be given as Well-Structured problem solving experiments. The following are a few examples that you can give as virtual laboratory experiments.

5.7 Answering Design Question DQ1g

In this section the answer to the following design question is obtained

DQ1g: How to design an effective virtual laboratory experiment with Problem-Based instructional strategy?

Problem-based learning is becoming a popular alternative to the other three styles of laboratory instruction. Problem-based learning was also a vehicle for curricular reform in the 1960s, but to a lesser extent than discovery or inquiry-based learning. (Young,) discarded the laboratory manual in order to encourage independent thinking. His students had to create their own procedures to solve a problem and submit a written report describing the procedure, the results obtained, and the conclusions reached. Emphasis was placed on developing testable hypotheses rather than obtaining correct results.

In a problem-based learning, the methods of solving the problem are secondary to the problem itself. As in the real world, the problem comes first and serves as a vehicle for investigation and learning. In this style, students are presented with an ill-structured problem statement often lacking in crucial information.

Ill-structured problems are typically situated in and emergent from a specific context. In situated problems, one or more aspects of the problem situation are not well specified, the problem descriptions are not clear or well defined, or the information needed to solve them is not contained in the problem statement (Chi & Glaser, 1985). These are also referred to as Real World problems or Open-ended problems. They possess these characteristics:

- One or more of the problem elements are unknown or not known with any degree of confidence (Wood, 1983).
- Have vaguely defined or unclear goals and unstated constraints (Voss, 1988).
- Possess multiple solutions, solution paths, or no solutions at all (Kitchner, 1983).
- Possess multiple criteria for evaluating solutions.
- Possess less manipulable parameters

- Have no prototypic cases because case elements are differentially important in different contexts and because they interact (Spiro, Vispoel, Schmitz, Samarapungavan, & Boerger, 1987; Spiro, Coulson, Feltovich, & Anderson, 1988).
- Present uncertainty about which concepts, rules, and principles are necessary for the solution or how they are organized. Possess relationships between concepts, rules, and principles that are inconsistent between cases.
- Require learners to express personal opinions or beliefs about the problem, and are therefore uniquely human interpersonal activities (Meacham & Emont, 1989).
- Require learners to make judgments about the problem and defend them.

5.7.1 Literature Review

(David H. Jonassen, 1997) describes instructional design steps for the ill-structured problem solving. These are

Step 1: Articulate Problem Context: Because ill-structured problems are more context-dependent than well-structured problems and because it will be necessary to develop an authentic task environment (the situational context of the problem) (Voss, 1988), it is necessary first to understand the context of the problem. Therefore, a context analysis needs to be conducted.

Step 2: Introduce Problem Constraints: It is necessary to identify for the learners what requirements might reasonably constrain their solutions.

Step 3: Locate, Select, and Develop Cases for Learners: the designer must develop cases that represent probable real-world problems in the domain, that is, that are authentic. The obvious source of these cases is practitioners who can be interviewed. Anyone who has practiced in a domain for a significant length of time can identify a range of cases that involve problems to be solved. Insuring the relevance of the problem in the real world or its representativeness of the problem domain is essential to their success.

Step 4: Support Knowledge Base Construction: Another task analysis process applied to case- based learning entails identifying the alternative opinions and perspectives on the problem and instantiating those perspectives with a knowledge base of stories, accounts, reports, evidence, and information that pertains to that problem. Among the most powerful resources are stories by practitioners that relate the problem (Schank & Cleary, 1995).

Step 5: Support Argument Construction: Getting learners to make reflective judgments about what can be known and what cannot is important to support in problem-solving instruction. That support may take the form of modeling the arguments for the solution to a related problem or prompting learners to reflect on what is known.

Step 6: Assess Problem Solutions: Solutions to ill-structured problems are divergent and probabilistic. Evaluating learners' solutions must consider both process and product criteria.

5.7.2 Gaps in Guidelines Derived from Literature for Implementing Ill-Structured Problem Solving Instructional Strategy in Laboratories

- The literature gives the details of the problem solving instructional design but for the classroom content.
- There is a need for guidelines in the context of laboratory problem solving and specifically for the virtual laboratories.

- The guidelines should be comprehensive and specify the various steps for designing a virtual laboratory experiment with problem-based instructional strategy.

5.7.3 Guidelines Set VII - Designing Virtual Laboratory Experiment with Problem-Based Instructional Strategy

Throughout the history of science and engineering education, four distinct styles of laboratory instruction have been prevalent: expository, inquiry, discovery, and problem-based. These styles can be differentiated by three descriptors: outcome, approach, and procedure. Expository, discovery, and problem-based activities all have predetermined outcomes. In the problem-based instructional strategy, students are presented with a problem statement often lacking in crucial information. From this statement they redefine the problem in their own words and devise a procedure that will lead them to a solution. The problems are "open-ended". That is, they possess a clear goal, but there are many viable paths toward a solution. Use the following template to design an experiment with the problem-based instructional strategy.

Phases in the Experiment Design for Problem-Based Instructional Strategy

The laboratory experiment should be designed considering the following four important phases in the process

Formulate learning objectives

Guideline: Articulate the learning outcomes of the problem. What do you want students to know or be able to do as a result of performing the experiment? State the learning objectives of the experiment.

- Decide the broad goal of the experiment
- Formulate learning objectives

Example from BAE:

Broad Goal: Develop the skill of real world problem solving

Learning objectives of the experiment:

1. Student should be able to identify the real world applications of the PN junction diode.
2. Student should be able to analyse and design circuits for real world applications of the PN junction diode.

State the learning objectives for your experiment.

Phase 1: Problem Definition Phase

Guideline: Create the problem. Ideally, this will be a real-world situation that resembles something students may encounter in their future careers or lives. Cases are often the basis of PBL activities. Assign tasks an assessment questions so that the students will examine and define the problem. Explore what they already know about underlying issues related to it.

Example from BAE:

Identify the electronic devices in the adjacent figures. Find out the use of these devices in your day-to-day life. Identify the important specifications of the device.

Figure 5.12 Problem Definition phase

Create the problem for your experiment.

Phase 2: Research Phase

Guideline: Establish ground rules at the beginning to prepare students to work effectively in groups. Assign tasks an assessment questions so that the students will determine what they need to learn and where they can acquire the information and tools necessary to solve the problem.

Example from BAE:

Form two groups and each group will work on tasks related to Fig1 and the other on tasks related to Fig 2.

Fig 1 – Once you identify the device find out the details of the variations in the electronic circuits of the device.

Fig 2 - Once you identify the device find out the details of the variations in the electronic circuits of the device.

Design the research phase for your experiment.

Phase 3: Proposed Solution Phase

Guideline: Assign tasks an assessment questions so that the students will evaluate possible ways to solve the problem.

Example from BAE:

Fig 1 – Of the different available circuits identify which one will give the optimum output.

Fig 2 -- Of the different available circuits identify which one will give the optimum output.

Design the proposed solution phase for your experiment.

Phase 4: Implementation Phase

Guideline: Establish how you will evaluate and assess the assignment. Consider making the assessments students make of their own work and that of their peers part of the assignment grade. Assign tasks an assessment questions so that the students will solve the problem.

Example from BAE:

Fig 1 – The assessment of the circuit will be done for the correct implementation in the virtual lab and one that gives the desired output. Compare the circuit diagrams for Fig 1 and Fig 2.

Fig 1 -- Implement the circuit selected and obtain the output using the virtual lab.

Fig 2 -- Implement the circuit selected and obtain the output using the virtual lab.

List down all the components along with their specifications used in the circuit. Which of the components have you used in your course experiment?

Design the proposed solution phase for your experiment.

Phase 5: Desired results

Guideline: Assign tasks an assessment questions so that the students will report on their findings.

Example from BAE:

What output do you expect to get? Did you get the desired output? Compare the outputs for both device circuit diagrams.

Design desired results phase for your experiment.

5.8 Answering Design Question DQ1h

In this section the answer to the following design question is obtained

DQ1h: How to design authentic assessment for virtual laboratory experiment?

Assessment in the virtual lab environment is as critical as in the traditional lab setting. Performance based assessment has been demonstrated as an effective way of evaluating students' lab skills and highlights what a student knows and can actually do.

(Helena Matute 2009) provide suggestions on how to use scientific methods to assess the effectiveness of web labs. They point out that in current lab work assessment we assess is the product of learning and not the way in which it occurs. When students work with the virtual labs it is possible to measure the variables, which give the progress of learning that is, how does learning proceed from one task to another or the learning curve of the students.

The literature on implementation of virtual labs in teaching learning reveals that the assessment methods to be used are not established with well-designed experimental studies. Most of the studies use the scores of students in the semester end examinations as the criteria to indicate the effectiveness of virtual labs in students learning. The main focus is the evaluation of virtual labs rather than the assessment of students.

There are a few studies wherein the assessment is tied to the laboratory learning outcomes.

(Jing Ma and Jeffrey Nickerson 2009) have used a knowledge test with multiple-choice questions on two relevant lab topics where they try to find the if remote labs and simulations are as effective as traditional hands-on labs in promoting understanding of the specific lab topics. In their next study spread across two years again they use a knowledge test to measure students learning of concepts.

(Abdulwahed, Mahmoud Nagy, Zoltan K 2011) use a structured lab report for assessment. Marking was based on how well the report was organized in the light of the given structure, the correctness of the diagrams, the rationale of the data analysis and discussion, correctness of the figures and formatting, and the summary match with the experimental observations and conclusions alongside the report. They also administered pre and post-tests. The pre-lab tests were designed mainly to measure the students' preparation level before the lab, while the post-lab tests were designed to measure the students' learning outcome after the lab sessions. The tests were designed in correlation with the laboratory objectives and in discussion with the course lecturer.

(Dieter Müller and José M. Ferreira 2005) propose the use of Automated formative assessment methods and tools. (Armando S. Araújo and António M. Cardoso 2009) have used a lab handout to assess student performance and learning outcomes assessment. The students upload their completed file via Moodle after remote completion of the work in each experiment. Handout exposes the expected outcomes, physical circuit in remote bench, commands to use in virtual panels, waveforms to observe, and questions to be answered.

(Yvonne Tetour et.al. 2011) carried out the assessment in three phases. In the orientation phase an abstract on the experiment is presented including a short description of the experiment and the task to perform. Learning goals are described in this phase and a small pre-test evaluates the knowledge of the students before they run the exercises with online- experiments. In the next execution phase the students have to master the task by practice. In the last review phase the students give a test with open-ended question.

5.8.1 Literature Review

In summary the various assessment methods used can be categorized as follows

Based on mode of administration

1. Online
2. Offline – Paper and Pencil

Based on time of administration

1. After the end of semester – Term or Semester end - Summative
2. After the students complete the lab work – Post-test - Summative
3. While the students are carrying out the labwork – Formative

Based on Instrument used

1. Lab report – Handwritten
2. Lab report – Online
3. Tests
4. Presentations

Based on what it measures

1. Students lab skills
2. Students conceptual understanding
3. Students learning outcomes defined prior

Several researchers (Chung, et al., 2006; Van der Pol, et al., 2008; Vonderwell, et al., 2007; Wolsey, 2008) have revealed the pedagogical prospective of online formative assessment. Pachler et al. (2010, 716) used the term formative e-assessment which they defined as "the use of ICT to support the iterative process of gathering and analyzing information about student learning by teachers as well as learners and of evaluating it in relation to prior achievement and attainment of intended, as well as unintended learning outcomes".

Kigandi (2010) identified ten design principles based on critical analysis of literature. They specify that the assessment activities should have following characteristics.

The assessment activities

- Need to be authentic by being relevant and meaningful to the learner,
- Need to engage and support learners in individual construction of knowledge,
- Need to provide learners with opportunities to construct knowledge,
- Need to be accompanied with opportunities to provide formatively useful, ongoing and timely feedback,
- Need to be accompanied by analytical and transparent rubrics,
- Need to create opportunities that engage learners in meaningful reflection,
- Need to provide opportunities for ongoing documentation and monitoring of learner achievements and progress over time,
- Need to involve learners in multiple roles and
- Need to be flexible and provide room for multiple approaches and solutions.
- Teachers need to be more explicit in stimulating shared purpose and meaning of learning and assessment activities

The laboratory assessment

- Should assess the students' knowledge and laboratory skills
- Should be aligned to learning objectives
- Should assess when they are engaged in inquiry and practical work
- Should be based on a set of protocols for analyzing student laboratory activities and not just the final outcome
- Should be such that the students' learning is assessed effectively

5.8.2 Gaps in Literature for Assessment in Virtual Laboratories

In order to incorporate authentic assessment of students' labwork using virtual laboratories there is a need to define and develop the following three

a. Overall conceptual framework for laboratory work assessment
b. Defining laboratory skills
c. Strategies for implementation of assessment schemes

5.8.3 Guidelines Set VIII – Designing Authentic Assessment for Virtual Laboratory Experiment

The four important components for the assessment design are

1. Properties of assessment
2. Measurement metric
3. Method
4. Instruments used

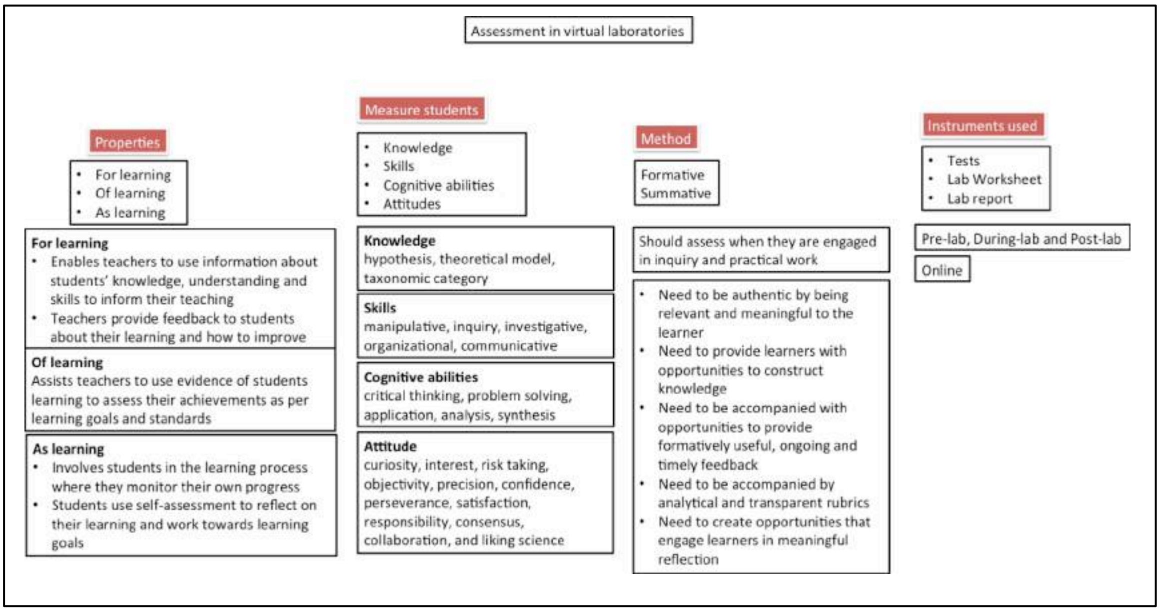


Figure 5.13 Virtual laboratory Assessment Framework

The above figure 5.13 illustrates the various components of the virtual laboratory assessment for which the guidelines are developed.

5.8.4 Properties of Assessment

Design Assessment of Learning

In majority of the cases the assessment is carried out to measure the students' learning. This type of assessment assists teachers to use evidence of students learning such as scores in the assessment questions to assess their achievements as per learning goals and standards. In this assessment the questions asked are aligned to the learning objectives of the experiment. The scores are given to the students based on a rubric for the final outcome.

In case of virtual laboratory assessment you can design the assessment as follows

1. There may be a pre test to assess the students prior knowledge of the topic
2. The students may be asked to perform certain tasks aligned to the learning objectives and questions aligned to the tasks may be asked as they perform the particular task. This way the assessment is based on what the students are learning while carrying out laboratory activities and not just on the theoretical knowledge. The following methodology may be followed for this type of assessment.

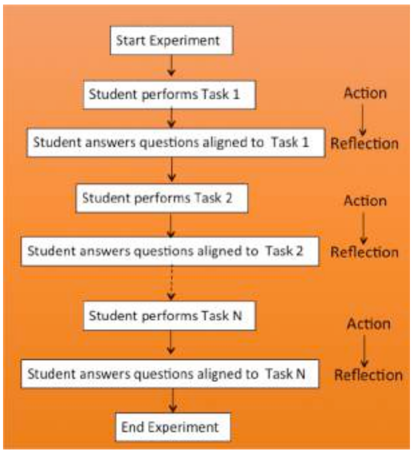


Figure 5.14 Proposed virtual laboratory assessment strategy

3. There may be posttest at the end of all the laboratory activities. The scores of this test may be used as evidence of the students learning.

Example from Basic Electronics course

Construct the circuit of Diode as a Clipper and analyse the circuit operation and output.

Action - Task1 – Select the suitable simulation settings

1. Reflection Question: What simulation settings will you select to study the operation of the circuit?
2. Reflection Question: Why did you choose these simulation settings?

Action - Task 2 - Observe the output waveform obtained

3. Reflection Question: What is the nature of the output waveform? Is it as per the desired result?

Action - Task 3 – Change the frequency of the input signal

4. Reflection Question: Will there be a change in the output if the frequency of the input signal is varied? Why?

Action - Task 4 – Change the amplitude of the signal

5. Reflection Question: Will there be a change in the output if the amplitude of the input signal is varied? Why?

6. Reflection Question: What is the range of input signal amplitude for which you get the desired output waveform?
7. Reflection Question: What is the range of input signal frequency for which you get the desired output waveform?
   Action - Task 5 – Change the resistor connected in the circuit
8. Reflection Question: Will there be a change in the output if the value of resistor is varied? Why?
   Action - Task 6 – Change the diode connected in the circuit
9. Reflection Question: Will there be a change in the output if the diode is changed? Why?
10. Reflection Question: List the diode numbers for which you get identical output waveforms.
11. Reflection Question: What would you conclude from the above?

As you can see in this example the student performs a certain task that is action, which is in the objects domain and then answers a reflection question, which is based on the previous action. This sequence of Action + Reflection solves three purposes

1. The assessment is based on what the students do while performing the experiment and hence their lab work is getting assessed. This leads to meaningful learning as they come to know the purpose behind each of the action and the results of the same. This helps them in analysis of the circuit and the various operations.
2. The students are working in the two domains of objects and concepts behind the objects. Thus they get an opportunity to link these two domains, which is a very important aspect of the labwork.
3. Such type of experiment design also helps in developing the students' skill of analysis.

Design Assessment as Learning

In this type of assessment students are involved in the learning process such that they monitor their own progress. Students use self-assessment to reflect on their learning and work towards learning goals. You can design this type of assessment by using the methodology as shown in the figure and incorporate scaffolds in the form of prompts or dialogs to assist the students understand their own learning.

This is easily possible in case of virtual laboratory experiment as the assessment can be integrated along with the experiment, which may be difficult in case of traditional laboratory activities.

Example from Basic Electronics course

Here we present the same example but with additional activity of providing help to the students in case they are not able to arrive at the desired outcomes.

Construct the circuit of Diode as a Clipper and analyse the circuit operation and output.

Questions

Action - Task1 – Select the suitable simulation settings

1. Reflection Question: What simulation settings will you select to study the operation of the circuit?

2. Reflection Question: Why did you choose these simulation settings?

Action - Task 2 - Observe the output waveform obtained

3. Reflection Question: What is the nature of the output waveform? Is it as per the desired result?

Help/Scaffold: What is the difference between the desired and the actual?

You need to change the input signal for obtaining the desired result

Action - Task 3 – Change the frequency of the input signal

4. Reflection Question: Will there be a change in the output if the frequency of the input signal is varied? Why?

Action - Task 4 – Change the amplitude of the signal

5. Reflection Question: Will there be a change in the output if the amplitude of the input signal is varied? Why?

6. Reflection Question: What is the range of input signal amplitude for which you get the desired output waveform?

7. Reflection Question: What is the range of input signal frequency for which you get the desired output waveform?

Are the two ranges as per the desired values? What is the difference?

Help/Scaffold: You need to change the value of the resistor.

Did you get the desired result by changing the value of the resistor?

Action - Task 5 – Change the resistor connected in the circuit

8. Reflection Question: Will there be a change in the output if the value of resistor is varied? Why?

Action - Task 6 – Change the diode connected in the circuit

9. Reflection Question: Will there be a change in the output if the diode is changed? Why?

10. Reflection Question: List the diode numbers for which you get identical output waveforms.

11. Reflection Question: What would you conclude from the above?

Design Assessment for Learning

This type of assessment enables teachers to use information about students' knowledge, understanding and skills to inform their teaching. The teachers provide feedback to students about their learning and how to improve. This type of assessment is not suitable for the virtual laboratory experiment.

5.8.5 Measurement Metric

The assessment can be designed to measure the following

i. Students' knowledge
ii. Students' skills
iii. Students' cognitive abilities
iv. Students' attitudes

The scope of the guidelines is limited to only the two measurement metrics of knowledge and skills. The two other metrics of cognitive abilities and attitudes is beyond the scope of this research.

Design Assessment for Measuring the Knowledge of the Students in the Virtual Laboratory Experiment

The knowledge has four dimensions – Facts, Concepts, Principles and Procedures. You can design assessment to measure the knowledge of students in each of these dimensions. The learning objectives of the experiment should be formulated according to the knowledge dimension you wish to measure. After formulating the learning objectives the assessment questions should be designed such that they are aligned to the learning objectives.

Example from Basic Electronics for assessment of each knowledge dimension

Assessment for fact

Learning objective: Student should be able to recall the circuit diagram of PN junction Diode as a Clipper.

Task: Construct the circuit diagram of PN junction Diode as a Clipper.

Assessment question: What specifications of the diode will you select?

Assessment for Concepts

Learning objective: Student should be able to understand the concept of PN junction Diode as a Clipper

Task: Apply the suitable output to the circuit and observe the output.

Assessment question: What is the nature of the output waveform? Is it as per the desired result? Why do you think the circuit behaviour is of a Clipper?

Assessment for Principles

Learning objective: Student should be able to identify the linear and non-linear regions in the V-I Characteristics plot of PN Junction Diode

Tasks: Construct the given circuit. Measure the current flowing through the diode at various values of applied DC voltage. Note down the readings for ten values. Plot the graph of current vs. voltage to obtain the V- I Characteristics of the PN junction diode. Calculate the static and dynamic resistance of the diode from the formulae given in the linear and non-linear region of the characteristics.

Assessment question: Is the slope of the V-I plots equal everywhere on the graph? What does the slope of the plot indicate?

Assessment for Procedure

Learning objective: Student should be able to carry out the procedure to find the values of gain of Common Emitter Amplifier circuit.

Tasks: A 2N2222A is connected as shown with

R1 = 6.8 kΩ, R2 = 1 kΩ, RC = 3.3 kΩ, RE = 1 kΩ and VCC = 30V. Assume VBE = 0.7V. Construct the circuit and carry out DC analysis.

Assessment question: 1. Compute VCC and IC for β = i) 100 and ii) 300.

2. Compare the theoretical and practical values obtained.

Design Assessment for Measuring the Laboratory Process Skills of the Students in the Virtual Laboratory Experiment

The students need to develop three laboratory process skills that are Manipulative skills, Investigative skills and Inquiry Skills. You can design assessment to test whether the students have developed these skills or you can develop these skills amongst the students by designing tasks that provide students opportunities to carry out these various activities. After the students perform a particular task ask assessment questions related to that task. If the student is able to answer the assessment question correctly it can be inferred that the student has developed the particular skill.

Manipulative skills – The students are said to have developed these skills if they are able to carry out the following tasks - Observations, Measurements, Manipulations, Recording results, Calculations, Explaining experimental techniques, Explaining about various decisions and Working according to the design.

Investigative skills - The students are said to have developed these skills if they are able to carry out the following tasks - Transforms results into standard form (tables), Determine relationships (could include graphs), Discuss accuracy of data, Formulate generalizations, Discuss limitations/assumptions of experiment, Explain relationships and Formulate new questions/problems.

Inquiry Skills - The students are said to have developed these skills if they are able to carry out the following tasks - Formulate question or problem to be investigated, Formulate hypothesis, Determining replications, Identifying treatments, Defining dependent variable, Defining independent variable, Design experiment, Design observation and measurement procedures, Predict results, Predict applications based on results, Formulate follow up hypotheses and Apply experimental technique to new problem.

5.8.6 Method

The two methods used for assessment are – Summative and Formative.

Design Summative Assessment

The Summative assessment is conducted after a learning phase (ranging from a single course to an entire curriculum) and serves accountability or certification purposes ('assessment of learning'). Refer the guidelines 1.1 for designing the summative assessment.

Design Formative Assessment

The formative assessment is conducted during a learning phase with the goal of promoting learning ('assessment for learning'). Learning is fostered through formative assessment when it succeeds in helping learners identify their weaker and stronger points, and in guiding them to overcome the weaker points during the learning process. This requires learners to develop an understanding of the performance criteria and standards, and helping them do so is a crucial aspect of formative assessment. That is, learners should know what aspects of performance should be assessed (criteria) and what constitutes poor, average, good or excellent performance on those aspects. Refer the guidelines 1.2 for designing the summative assessment.

5.8.7 Instruments Used

You can use various instruments for carrying out the assessment in the virtual laboratory. They are

1. Lab report – Handwritten
2. Lab report – Online
3. Tests
4. Presentations

Whatever instruments are used the assessment questions asked in each of the instrument should be aligned to the learning objectives.

Design Assessment Aligned to the Learning Objectives

Design the assessment questions such that the correct answer to the same indicates that the particular learning objective has been achieved. Also the cognitive level of the question should be same as the cognitive level of the learning objective.

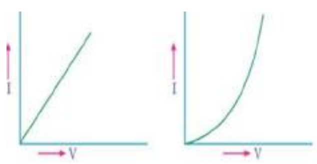
For example:

The learning objective is:

Students should be able to graphically draw the characteristics of different types of resistors.

The assessment question aligned to the above leanrning objective will be:

Which of the V-I curves could represent a Non-Ohmic resistance?



Design Assessments Based on a Set of Protocols for Analyzing Student Laboratory Activities and Not Just the Final Outcome

The weightage or marks allotted to the students for the laboratory work should be as per rubric designed taking into consideration the various aspects of the lab work. You can use the rubrics given in as part of these design guidelines in the Appendix or you can design your own rubric as per your experiment design. There are specific guidelines given on how to design a rubric for the assessment of students' laboratory work to measure the knowledge and various skills. The rubric for the scientific ability of evaluating the results is given as an example.

Table 5.22: Example Rubric for Skill assessment

Scientific ability	Missing(0)	Inadequate(1)	Needs some improvement(2)	Adequate(3)
Is able to evaluate results by means of an independent method.	No attempt is made to evaluate the consistency of the result using an independent method.	A second independent method is used to evaluate the results. However there is little or no discussion about the differences in the results due to the two methods	A second independent method is used to evaluate the results. The results of the two methods are compared. However there is little or no discussion about the reasons for the differences when the results are different.	A second independent method is used to evaluate the results. The results of the two methods are compared. There is discussion about the reasons for the differences when the results are different.

The rubrics for other laboratory skills are given in Appendix ---.

5.9 Answering Design Question DQ1i

In this section the answer to the following design question is obtained

DQ1i: How to select virtual laboratory with features aligned to the learning objectives of the experiment?

The following table gives the analysis of the literature for the features of virtual laboratories, which play important role in the achievement of various learning objectives in the labs.

Table 5.23: Features of virtual labs

Virtual lab feature	**Feature in context of selected labs**
Reality can be adapted (Ton de Jong, 2012)	Component and equipment real life images
Designers of virtual experiments can simplify learning by highlighting salient information and removing confusing details (K. C. Trundle, R. L. Bell, 2010)	Simplified models and plots
The vlab designers can modify model characteristics, such as the time scale, that make the interpretation of certain phenomena easier (D. N. Ford, 2000)	Different type of circuit analysis such as DC with and without sweep, time domain and frequency domain can be simulated and results obtained within seconds for which it takes hours just for data collection in traditional labs.
Students can conduct experiments about unobservable phenomena, such as chemical reactions, thermodynamics, or electricity (Z. C. Zacharia, 2008)	Visualizations of various phenomena and multiple representations
Students can vary the properties (Z. C. Zacharia, 2008)	Simulation values can be adjusted; Specifications of components can be adjusted/changed.
In virtual laboratories, students can also directly link unobservable processes to symbolic equations and observable phenomena, which encourages them to make abstractions over different representations (B. Kolloffel, 2011)	Visualizations of various phenomena and multiple representations
Vlabs offer efficiencies over physical experiments because they typically require less setup time and	Less time to construct circuits and

provide results of lengthy investigations instantaneously (19). This enables students to perform more experiments and thus to gather more information in the same amount of time it would take to do the physical experiment. (T. Jaakkola, 2010)	plot results
Students are not distracted by aberrations in the equipment or unanticipated consequences. (T. Jaakkola, 2010)	Correct circuits give correct results every time without error.
Measurement errors could be modeled in virtual environments, but ensuring that they are authentic would require careful research. (T. Jaakkola, 2010)	Measurement errors are modeled
Students learn how to extract valid information from a complex visualization when they draw what they observed in an experiment about bond breaking (Z. H. Zhang, 2011)	Visualizations of various phenomena and multiple representations
Computer technologies can log student interactions and use the information to diagnose random or uninformative investigations and to prompt students to revise their experimentation strategies and to reflect on their findings. (Z. H. Zhang, 2011)	Work Flow with Scaffolds for each step, Error messages
Interactive exploration of unobservable phenomena compared with physical experiments of observable phenomena. For example, university students who investigated simulated electric circuits showing moving electrons acquired more conceptual knowledge than those using physical materials. (N. D. Finkelstein et al., 2005)	Types of analysis - DC with and without sweep, Time domain, Frequency domain
Virtual experiments can enable students to use complex inquiry practices to separate variables that might be difficult to use in physical experiments. (K. W. McElhaney, M. C. Linn, 2011)	Plot of all parameters defined by equations, different type of analysis possible, simulation specifications can be varied.
Virtual experiments support the acquisition of conceptual knowledge because they produce clean data. (K. Pyatt, R. Sims, 2012)	Ideal components and plots possible
It was found that the use of virtual laboratories offered students more time to experience an experiment and to concentrate on its conceptual aspects than the corresponding physical laboratories, because the virtual laboratories allowed faster manipulation of the materials involved in the experiments. (Z. C. Zacharia, G.	Plot of all parameters defined by equation by simulation within seconds

Olympiou, M. Papaevripidou, 2008)	
It provides a set of rich tools for high levels of interactivity and networked communications. (Heidar A. Malki and Aider Matarrita, 2002)	Simulation values can be adjusted, Specifications of components can be adjusted/changed, Auto plot with selection of parameters for plotting on X-Y axes, Plot of all parameters defined by equation, Comprehensive set of components and equipment, Types of analysis - DC with and without sweep, Time domain, Frequency domain.
Massive reconfiguration is possible; extreme tasks are possible as well; a view inside the robot cover is allowed. (Potkonjak, Veljko, 2010)	Extreme tasks are possible such as plotting various parameters having different mathematical models. Power analysis within seconds.
Vlab provides the guidelines for selection of parameters and the testing of the selected values. (Vukobratovi, Miomir, 2005)	Procedure given.
All parameters may be modified, which cannot be done with the real system. (Vukobratovi, Miomir, 2005)	Simulation values can be adjusted, Specifications of components can be adjusted/changed
The component tutorials provide very basic information on how to select component values. (Pieter j. Mosterman et.al. 1994)	Video Tutorial
For the function generator and oscilloscope, the tutorial provides the name, location, and function of each control and indicator for both instruments. This method draws attention to key features of each instrument and shows how the features are used in the laboratory environment. (Pieter j. Mosterman et.al. 1994)	Video Tutorial
Detailed help can be invoked by choosing either the Demo or Problem Assistance selection. (Pieter j. Mosterman et.al. 1994)	Video Tutorial, Help section
The environment also facilitates recording measurements and plotting of data. (Pieter j. Mosterman et.al. 1994)	Auto plot with selection of parameters for plotting on X-Y axes. Plot of all parameters defined by equation
An important observation is that students felt that the VL was helpful even when using a different	Comprehensive set of components and equipment

oscilloscope model. However, we feel that the best results will be obtained when the VL is equipped with the same instruments used in the physical laboratory. Establishing a library of a variety of types of instruments can satisfy this need. ((Pieter j. Mosterman et.al. 1994)	
Considering that realism is probably the most important quality of a laboratory when it comes to student learning. (Yi Yang et.al.2010)	Component and equipment real life images
A realistic GUI is preferable in virtual lab. (Balamuralithara and Woods, 2007)	Component and equipment real life images

5.9.1 Gaps in Literature for Features of Virtual Laboratories

1. There is no mapping of the virtual lab feature with the tasks that can be performed due to the presence of the particular feature.
2. There is no mapping of the virtual lab feature with the learning objectives achievable due to the particular feature.

5.9.2 Guidelines Set IX – Selection of Virtual Laboratory Based on its Features

Objectives

- The engineering instructors should be able to understand the various features of the Circuit Simulation Virtual lab
- The engineering instructors should be able to design effective experiments utilizing these features

In these guidelines the DoCircuits Virtual lab is considered as the sample example but there are numerous such virtual labs available online. You may select any one of the labs for your experiment design. The labs available online along with their URL are

- https://www.circuitlab.com/editor/#?id=7pq5wm
- http://www.partsim.com/simulator

The landing page of the Circuit Simulation vlab is as seen in the figure 5.24.

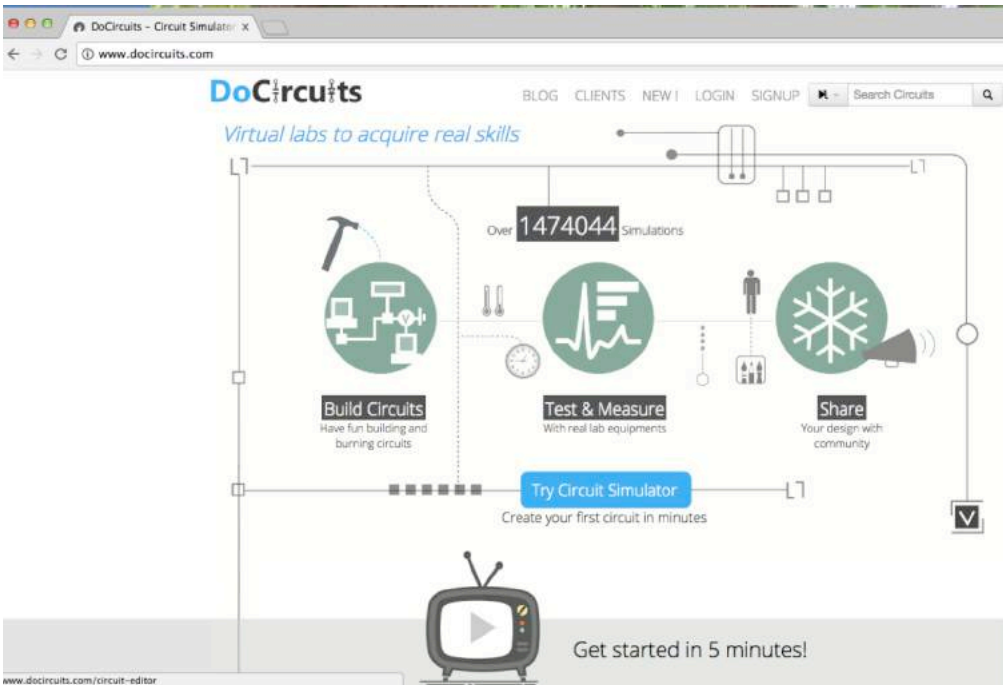


Figure5.24 Landing page of Virtual laboratory

*A*fter you select the vlab you need to register with a username and password as seen in the figure.

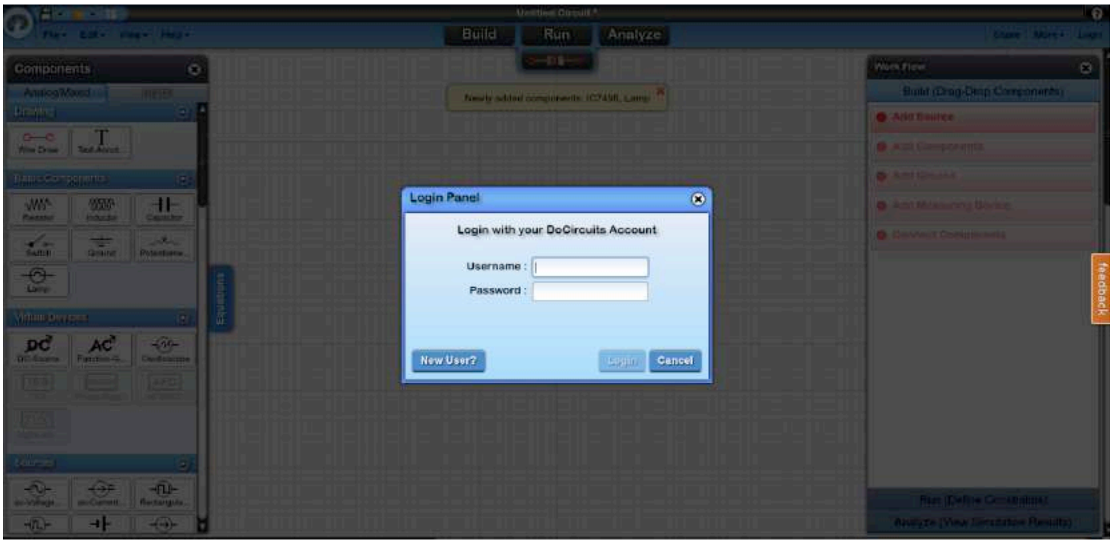


Figure5.25 Login page of virtual laboratory

The Simulators have the components as seen in the figure—

Feature 1: A library of a variety of components and types of instruments are available for the students. This provides them an opportunity to play around with them. This is one of the most important features as although there are a variety of components and equipment in physical lab too there are constraints and we do not allow the students to play around. This helps in the development of practical skills.

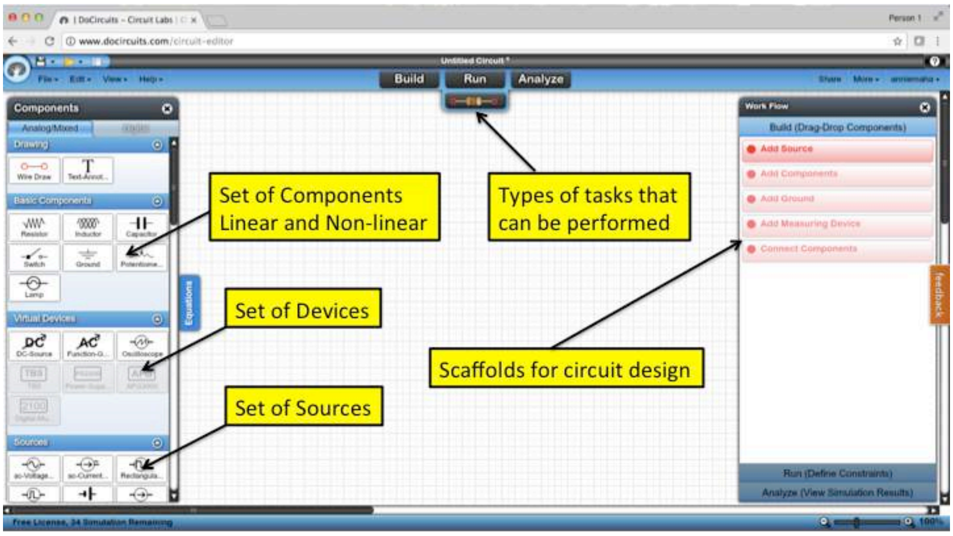


Figure 5.26 Virtual laboratory feature 1

Guideline: This feature can be used to achieve the following set of learning objectives. You can design the tasks aligned to the learning objectives and the above feature makes it possible to perform the given tasks.

Table 5.24: Guidelines for Feature 1 usage in experiment design

Vlab tasks	Learning objectives	Broad Goal achievable
Select particular components and equipment from the comprehensive set available	Student should be able to identify the components required as per the circuit diagram given	This feature is necessary to achieve all the Broad Goals of the laboratory experiment as discussed in Section…
Select particular components and equipment from the comprehensive set available	Student should be able to apply their knowledge of the components and equipment and select the most suitable for the particular experiment	
Select particular components and equipment from the comprehensive set available	Student should be able to analyze the functions of the components and equipment and select the most suitable for the particular experiment	
Select particular components and	Student should be able to evaluate the functions of the components and	

equipment from the comprehensive set available	equipment and select the most suitable for the particular experiment	

Feature 2: Students can vary the properties or specifications of all the components. In physical labs although this is possible the students are not provided the opportunity of selecting the different components due to various constraints.

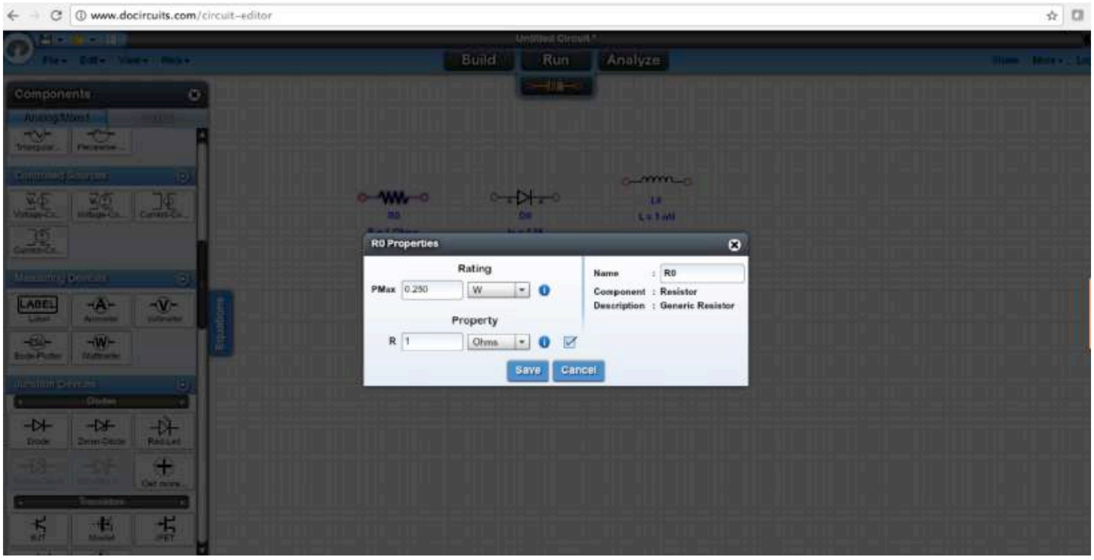


Figure 5.27 Virtual laboratory feature 2

Feature 2: As seen in the figure the students can vary the values of specifications such as temperature, junction capacitance etc. You can design experiments to enable students understand the effect of these on the V-I characteristics of the diode. This helps in the development of higher order objectives such as analysis and evaluation.

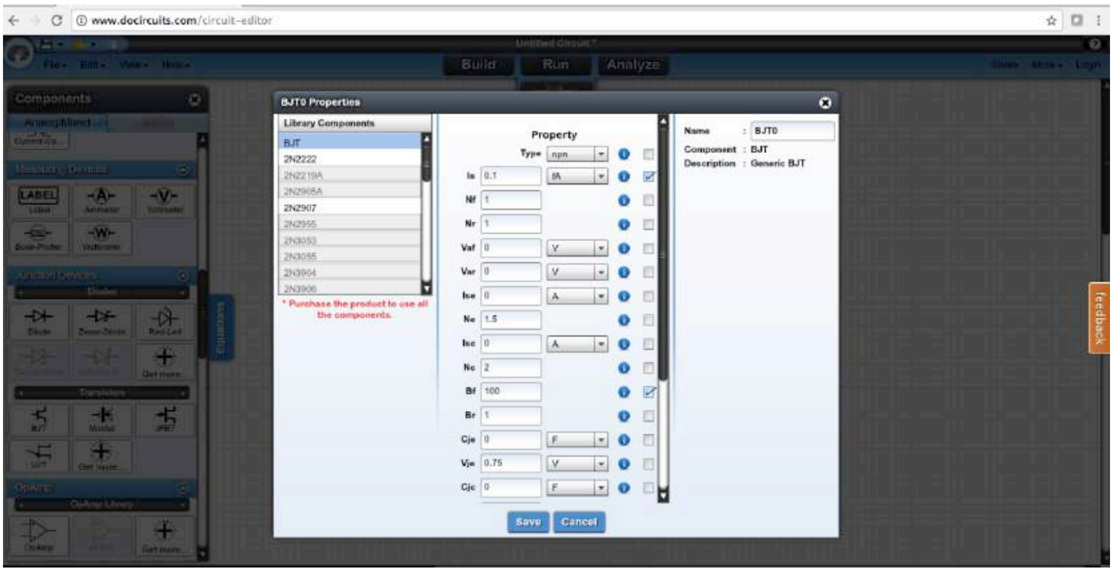


Figure 5.28 Virtual laboratory feature 2

Guideline: These features help the students in understanding the concept of specifications. You can design experiments so as to make students vary the specifications and analyse the effect on the results. This feature can be used to achieve the following set of learning objectives. You can design the tasks aligned to the learning objectives and the above feature makes it possible to perform the given tasks.

Table 5.25: Guidelines for Feature 2 usage in experiment design

Vlab Tasks	Learning Objectives	Broad Goal
Select the particular specification of the components such as value, internal parameters etc.	Student should be able to apply their knowledge of the components and equipment and select the most suitable specifications for the particular experiment	These features are necessary to achieve all the Broad goals of the laboratory experiment as discussed in section…
Select the particular specification of the equipment such as range, rating etc.	Student should be able to analyze the functions of the components and equipment and select the most suitable specifications for the particular experiment	
	Student should be able to evaluate the functions of	

	the components and equipment and select the most suitable specifications for the particular experiment	

Feature 3: As seen in the figure whenever a particular component is selected the entire specifications are visible. Also as the students selects the components one by one they can compare the specifications. You can ask questions in the experiment design related to the reasons for the selection of a particular component. This helps in the development of higher order objectives such as evaluation.

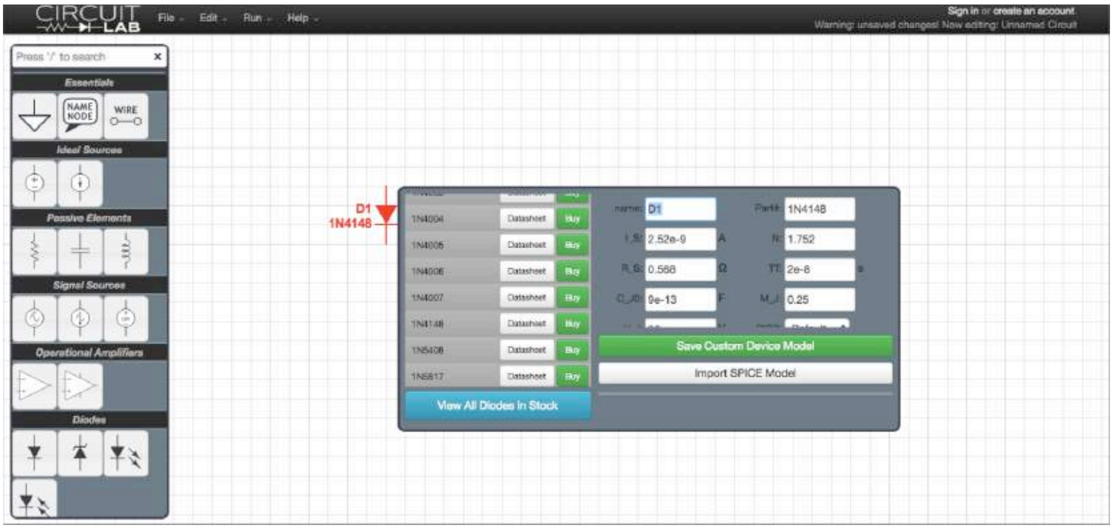


Figure 5.29 Virtual laboratory feature 3

Feature 3: As seen in the figure there is a link provided for the entire datasheet of the component. They can refer to them as and when they want. This is also provided in the physical lab but not so many copies are normally kept that each student can refer separately.

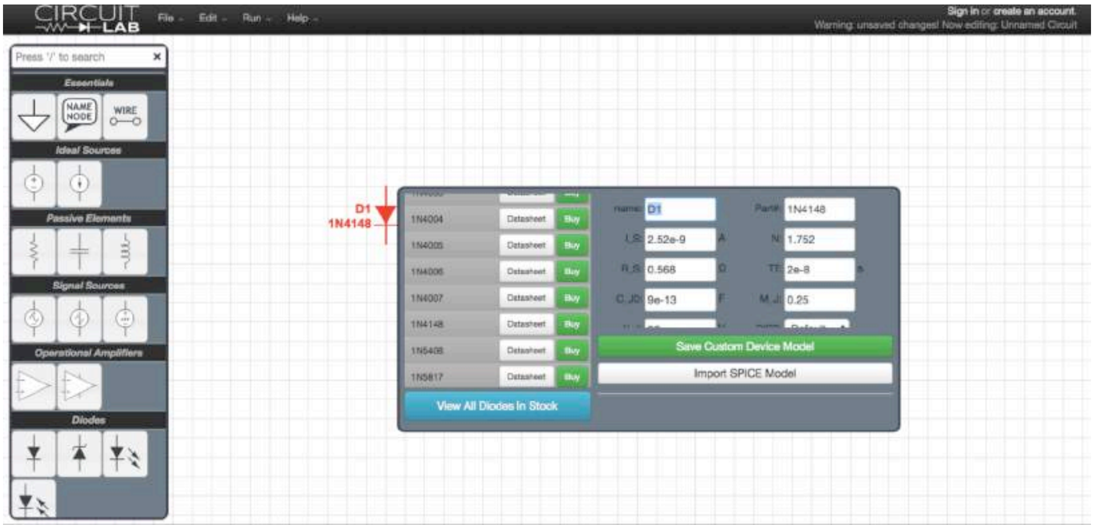


Figure 5.30 Virtual laboratory feature 3

Guideline: These features are necessary to achieve higher order learning objectives such as analysis and evaluation. For the Discovery and Problem-based Instructional Strategies these features play a very important role as the students can compare the various components according to the data sheets and solve real world problems.

Feature 4: The students can get the feel of operating real equipment as the image is real life and the various functions and adjustments are exactly same as in actual. The students are not distracted due to non-functioning of the equipment as in physical lab. You can design experiments with the objective of developing the students' practical skills such as operating equipment, taking measurements etc.

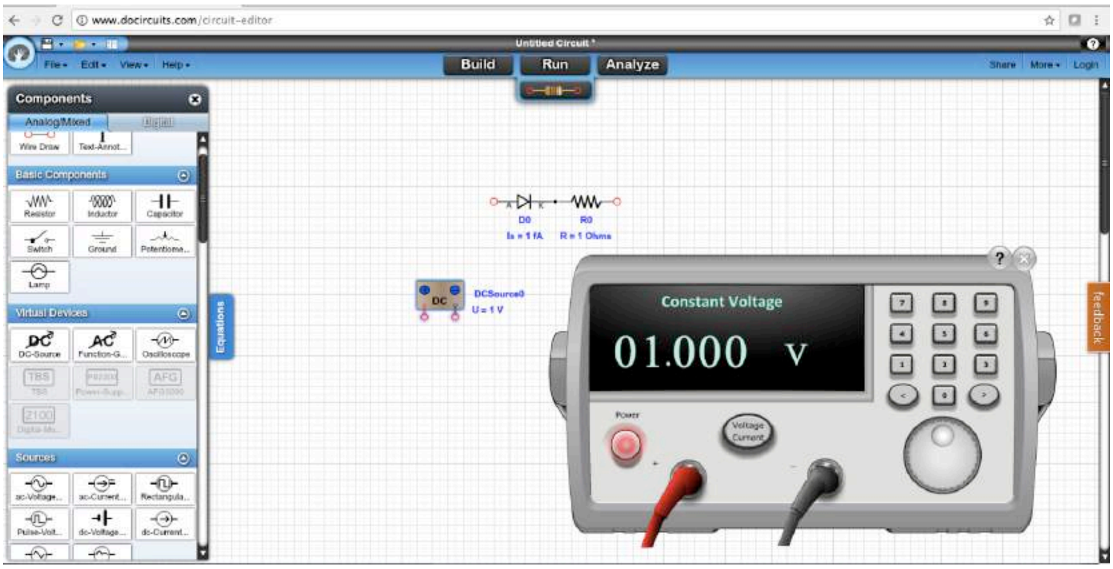


Figure 5.31 Virtual laboratory feature 4

Feature 5: The students can drag and drop any component and equipment and construct the circuits multiple times with minimum time. In case of physical labs it takes a lot of time for the students to assemble the circuit on a breadboard. You can design experiment in which the

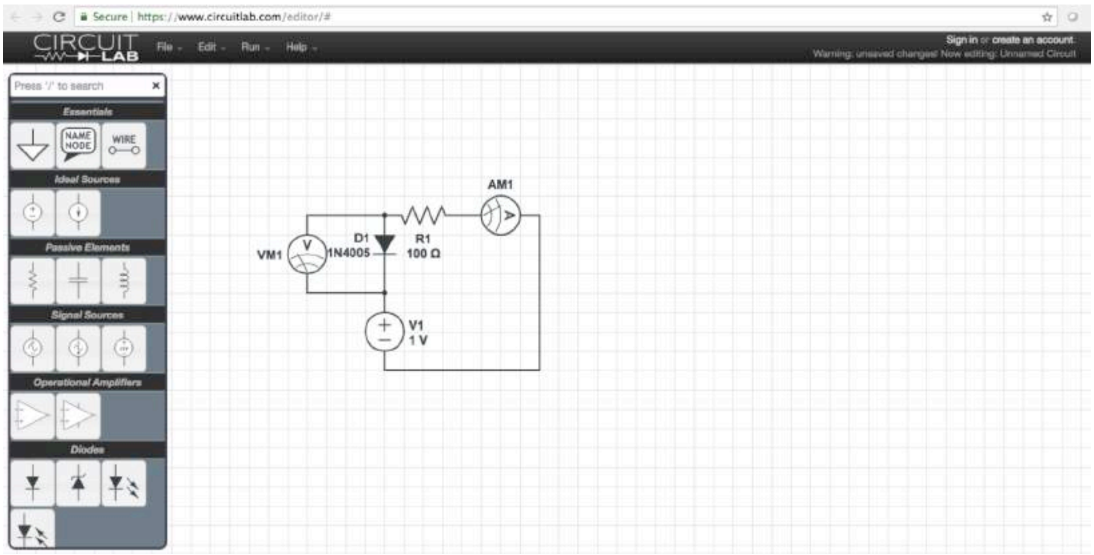


Figure 5.32 Virtual laboratory feature 5

students understand and analyse the different variations of the same circuit or compare multiple designs. This feature helps in the development of circuit design skill.

Feature 6: In some of the circuit simulators if students do not complete the circuit construction correctly, an explanation is provided in the form of a concise informative message. Scaffolds

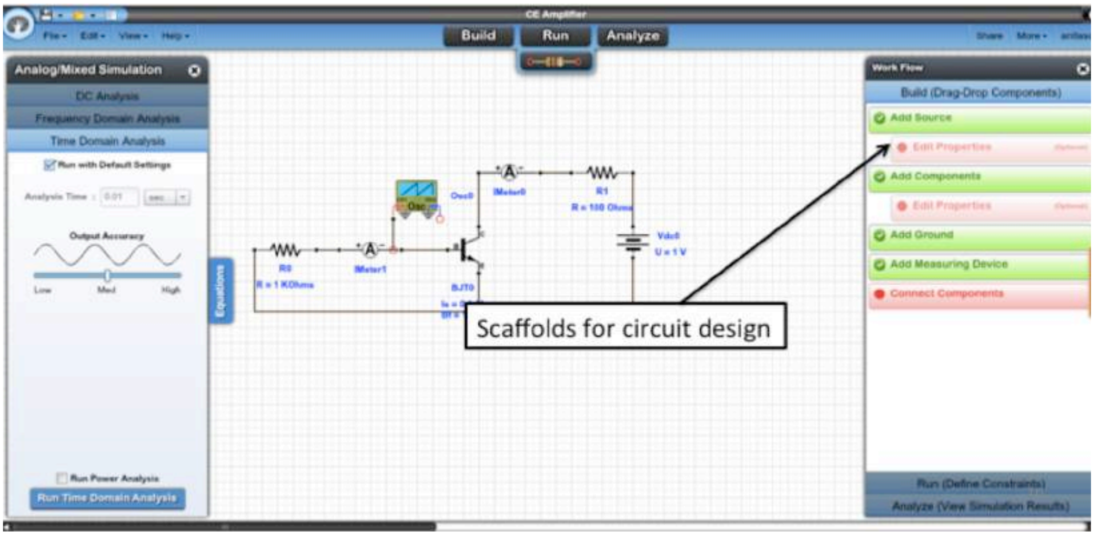


Figure 5.33 Virtual laboratory feature 6

provided for completion of circuit construction help students and keep them motivated and engaged.

Feature 7: The circuit simulator requires less setup time and Students can perform more experiments and thus gather more information in the same amount of time it would take to do the physical experiment.

Guideline: This is one of the most useful features of the virtual lab as it saves a lot of time required in physical labs for the data collection and plotting. This feature plays an important role in the achievement of higher order learning objectives such as analysis and evaluation and also in the development of skills such as manipulative skills, investigative, inquiry process skills. This is also an important feature for the cognitive ability of problem solving as the students can try different solutions and test and verify their results without spending a lot of time in data collection and plotting the results as in case of physical labs.

Feature 8: After the students construct the circuit they can carry out five types of analysis – DC without sweep, Power Analysis, DC with sweep, Time Domain and Frequency Domain. This provides results of lengthy investigations instantaneously and accurately. This helps in the development of analytical and manipulative skills.

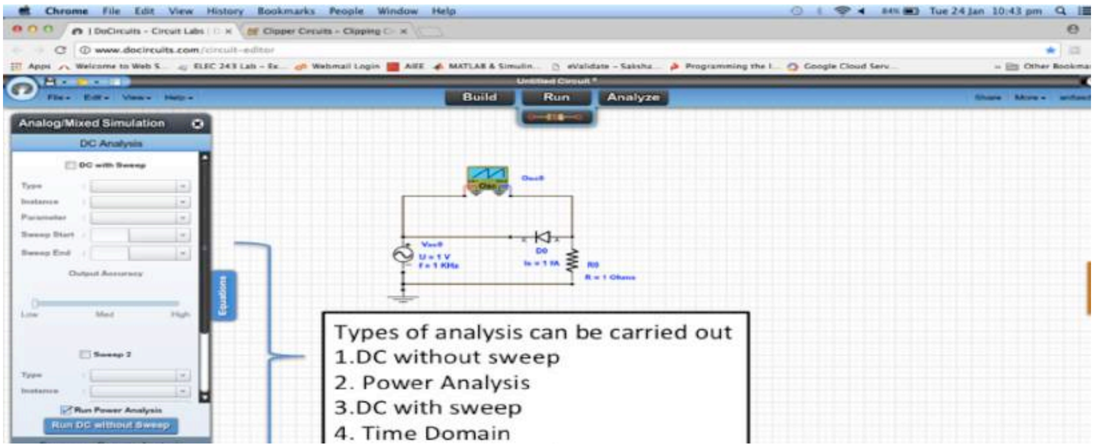


Figure 5.34 Virtual laboratory feature 8

Feature 8: After the students construct the circuit they can carry out five types of analysis – DC without sweep, Power Analysis, DC with sweep, Time Domain and Frequency Domain. You can design experiments in which students can carry out the analysis of the same circuit multiple times by changing a particular component or changing the specification of a particular component.

Feature 9: The various DC Analyses that are possible are
1. DC without sweep – This helps the students to measure the voltages at various locations in the circuit and currents through different components. You can design experiment so that the students analyse the change in these values depending on the change in the circuit components

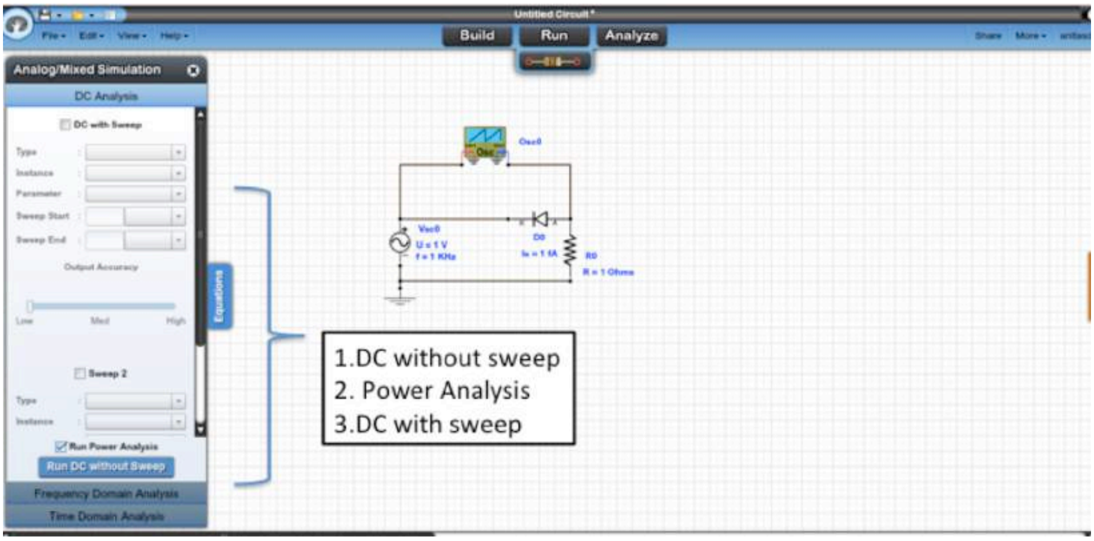


Figure 5.35 Virtual laboratory feature 9

or component specifications. This develops their analytical, manipulative and investigative skills.

2. Power Analysis – This helps the students to measure the power in the circuit. You can design experiment so that the students analyse the change in these values depending on the change in the circuit components or component specifications. This develops their analytical, manipulative and investigative skills. This is difficult in the physical labs as the equipment for power analyses are normally not available.

3. DC with sweep – This feature helps in obtaining the various plots of the continuous change in the value of a particular parameter with respect to another such as the V-I Characteristics of diode, Input Characteristics of BJT etc. The plots can be obtained instantaneously and accurately. You can design experiments in which the students

plot the graphs of the different variables and carry out analysis immediately. This is not possible in the physical labs as lot of time is required for the data collection.

Feature 10: The students can carry out Frequency Domain Analysis. The plots of the variables in the frequency domain can be obtained instantaneously and accurately. This reduces the time required as in case of the physical labs where the students initially gather the data for the plot, then plot the graph using paper and pencil and then they can analyse it. In the virtual lab as the graphs are obtained within no time you can design experiments in which the emphasis is on analyzing the graphs, improving students understanding of the relationships between the different variables.

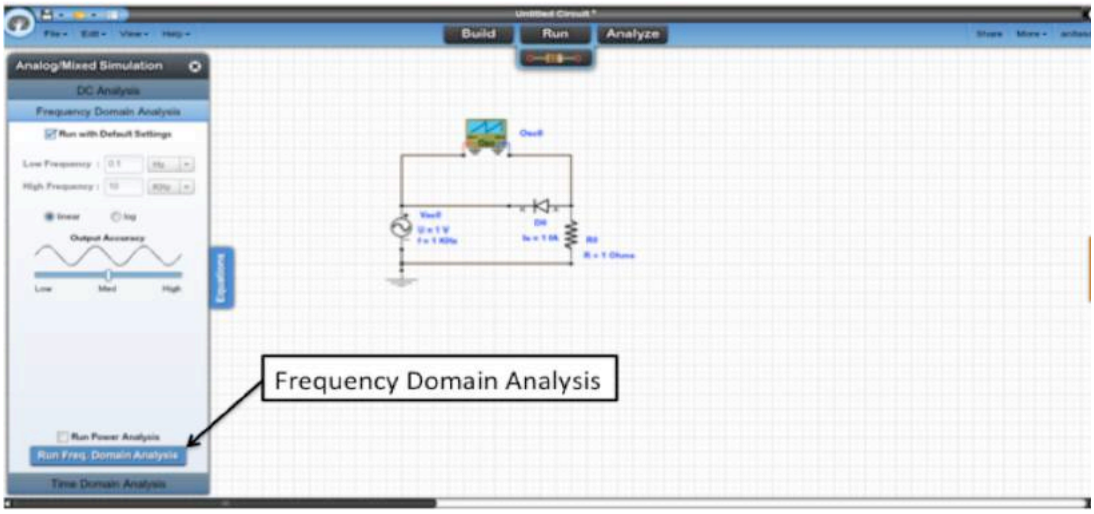


Figure 5.36 Virtual laboratory feature 10

Feature 10: The students can carry out Time Domain Analysis. The plots of the variables in the frequency domain can be obtained instantaneously and accurately. This reduces the time required as in case of the physical labs where the students initially gather the data for the plot, then plot the graph using paper and pencil and then they can analyse it. In the virtual lab as the graphs are obtained within no time you can design experiments in which the emphasis is on analyzing the graphs, improving students understanding of the relationships between the different variables.

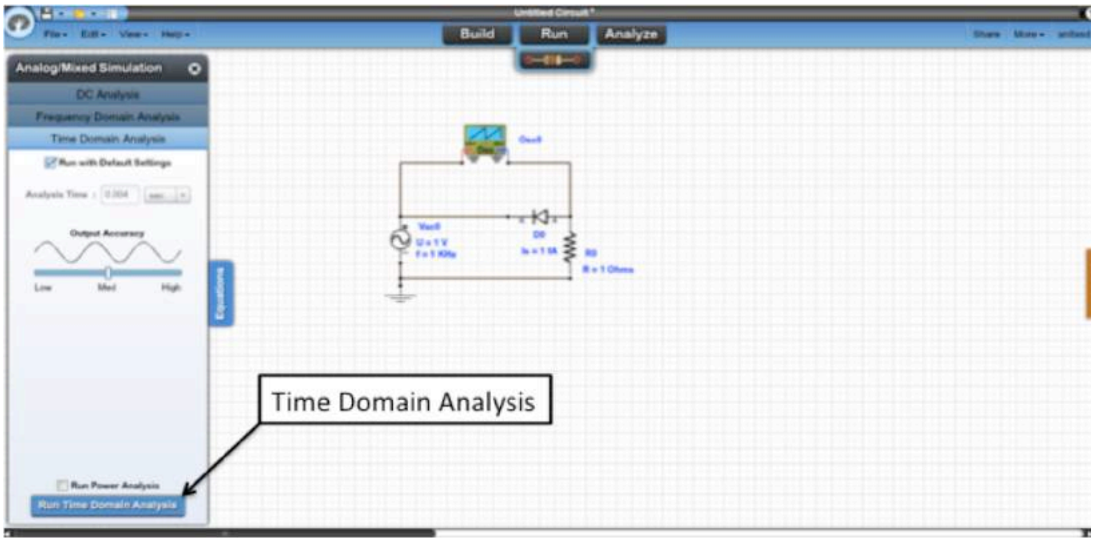


Figure 5.37 Virtual laboratory feature 10

Feature 11: Facilitates recording measurements and plotting of data (e.g., semi-log graphing of the transfer function of a low-pass filter). As can be seen from the figure the graphs of three variables can be seen simultaneously. This feature can help students understand and analyse the relationships between the different variables. You can design experiments at higher cognitive levels such as analyse and evaluate.

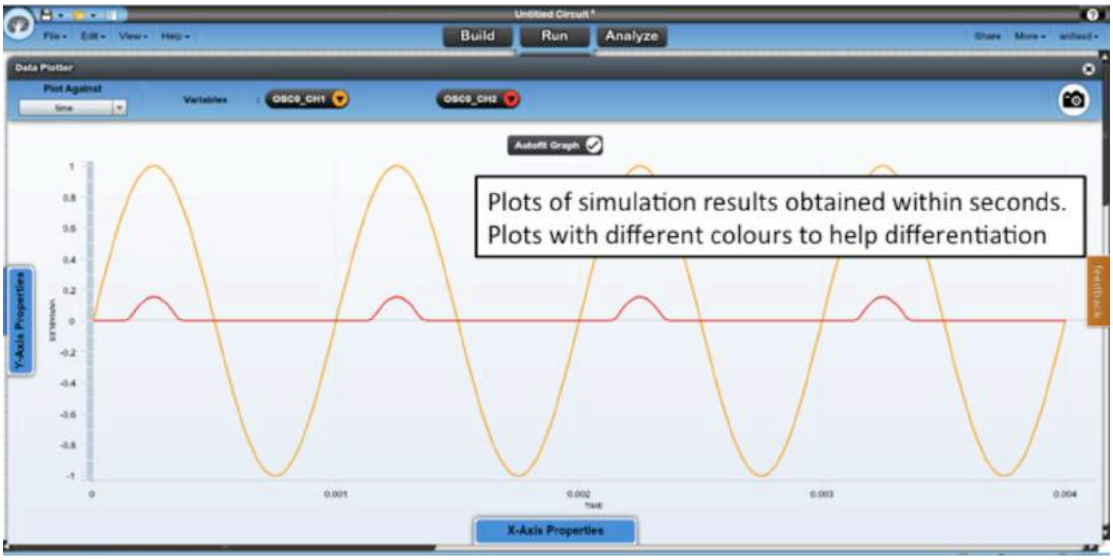


Figure 5.38 Virtual laboratory feature 11

Students can extract valid information from a complex visualization when they draw what they observed in an experiment. They can see the results of their experiments immediately. This helps in achieving the learning objectives of analysis and evaluation levels.

Feature 12: Students can also directly link unobservable processes to symbolic equations and observable phenomena, which encourage them to make abstractions over different representations. This feature allows the students to plot the graphs of equations. You can design experiments in which the students can see the relations of variables for example the Vdc, Vrms, Vac simultaneously

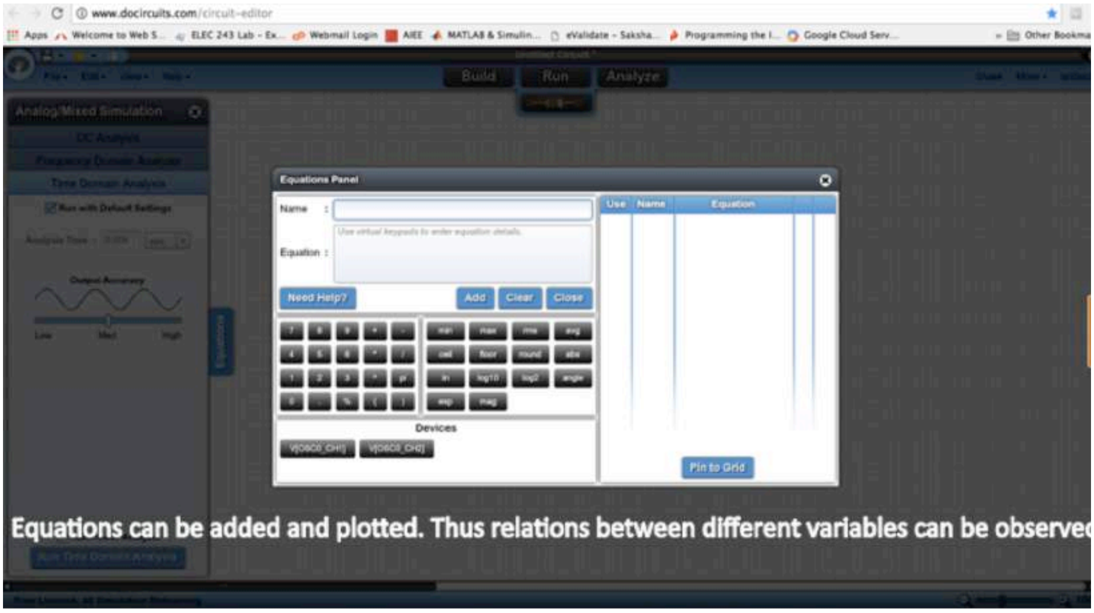


Figure 5.39 Virtual laboratory feature 12

Feature 13: A very important feature is the visual of the component burning when the current flowing through it exceeds the power rating of the component as shown in the figure. This is not allowed in physical labs as it damages the component. This is a very important part of students learning as they get to learn from failure. You can design experiments in which the students are given a circuit with higher currents and then make them adjust the values of the parameters in order to rectify the problem. This helps the students understand the concept of Thermal runaway.

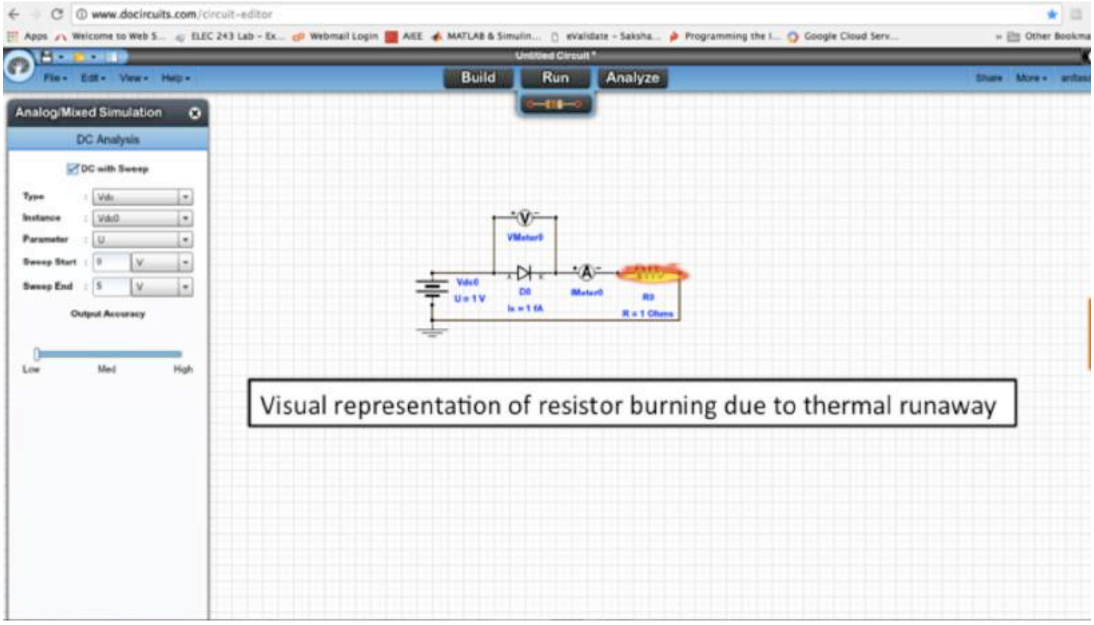


Figure 5.40 Virtual laboratory feature 13

As the Virtual laboratories have these important features you can design experiments with learning objectives at higher cognitive levels, use different instructional strategies and assign tasks with different cognitive structures.

In the next chapter the final phase of this research that is the Summative Evaluation of the virtual laboratory experiment design guidelines is presented. The evaluation is carried out for the three metrics of Usability, Usefulness and Effectiveness. The Usability and Usefulness are evaluated by means of two online survey studies with 58 engineering instructors.

Chapter 6

Summative Evaluation

During the final Evaluation phase of the research the summative evaluation of experiment design guidelines for effective use of virtual laboratories was carried out in three stages as follows.

1. Usability Study

In this SUS survey study carried out with 58 engineering instructors their perceptions regarding whether they find the experiment design guidelines usable in their design process was analysed.

2. Usefulness Study

This survey study with 58 engineering instructors was carried out to find out if they perceive the experiment design guidelines to be useful in their design process.

3. Effectiveness Study

Effectiveness of guidelines with respect to the output of experiment designs

This field test study aims to find out if the quality of the experiment designs improves after the 10 engineering instructors use the guidelines in the SDVIcE tool to design four experiments each.

Impact Study: Effectiveness with respect to impact on students' learning

The impact of the experiment design guidelines is measured by means of three quasi-experimental studies. The first study was carried out with 39 UG engineering students by the researcher. The second and third are replicate studies carried out with 142 and 150 UG and 18 PG engineering students carried out by Subject Matter Experts.

The main research question of the summative evaluation phase was:

RQ2: Are the refined guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics usable, useful to engineering instructors and effective in improving the quality of experiment designs and students laboratory learning outcomes?

6.1 Study 5: Engineering Instructors' Perceptions About the Usability of the Experiment Design Guidelines

Objective

The main objective of this survey study was to get an insight into the perceptions of the engineering instructors about the usability of the experiment design guidelines

Research Question

RQ2a: What are the perceptions of engineering instructors regarding the usability of the virtual laboratory experiment design guidelines?

Hypothesis

H1: The engineering instructors perceive that the virtual laboratory experiment design guidelines are usable.

Methodology

In order to gather the perceptions of the instructors at diploma and degree level the researcher initially gave a 10-minute presentation to the instructors describing the experiment design guidelines and then the engineering instructors were asked to use the experiment design guidelines for about an hour. This was done so that the instructors could find out the various features of the guidelines.

After they had used the guidelines a written consent was taken from the participants so that the researcher can use the data of the survey. After obtaining the consent the questionnaire was administered. They were given enough time to fill up the survey. The survey was administered in an online format.

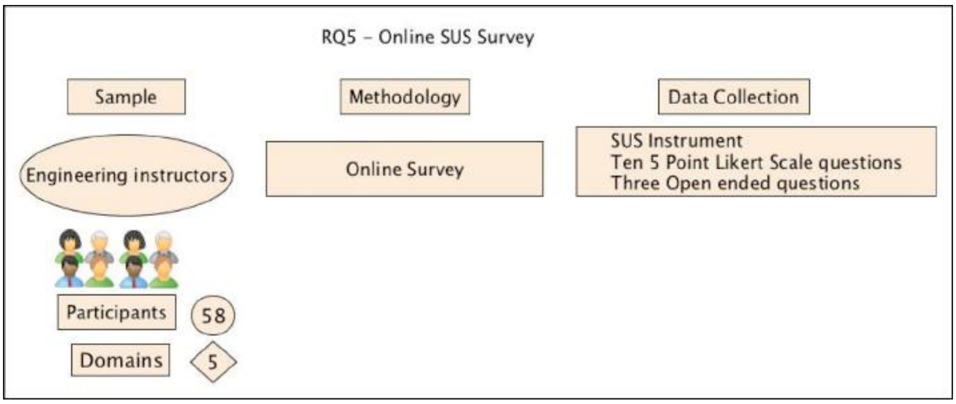


Figure 6.1 Implementation of study 5

Sample

The total number of participants who responded to the survey and gave their feedback was 58 undergraduate engineering instructors from Mumbai, Pune and Nagpur University.

Instrument

In order to evaluate the usability of the tool the SUS instrument (Brooke, 1996) with the modified statements (Bangor et al., 2015) was used. The tool was used to design the survey form administered online to instructors from engineering institutes.

The survey questionnaire consisted of twenty questions with ten questions of five point likert scale format, seven of Yes/No type and three with open-ended responses. There were two questions to find out the demographic information of the participants, seven questions to find out if the engineering instructors read the various sections that are part of the tool and ten questions to find out the perceptions of the instructors regarding the usability of the experiment design guidelines.

Table 6.1: Questions in the survey

S.No	Type of question	Question
Q1.		Your Name
Q2.		How many years of experience do you have in engineering education?
Q3.	Open-ended	What according to you are the improvements required in the experiment design guidelines?
Q4.	(Yes/No)	Did you go through the main instructions in the online tool?
Q5.	(Yes/No)	Did you go through the section - Guidelines on scientific experiment design process in the online

		tool?
Q6.	(Yes/No)	Did you go through the section - Guidelines on deciding the broad goals of the laboratories in the online tool?
Q7.	(Yes/No)	Did you go through the section - Guidelines on formulation of learning objectives of the laboratories in the online tool?
Q8.	(Yes/No)	Did you go through the section - Guidelines on selection of instructional strategy of the virtual laboratory in the online tool?
Q9.	(Yes/No)	Did you go through the section - Guidelines on design of tasks aligned to the learning objectives of the laboratories in the online tool?
Q10.	(Yes/No)	Did you go through the section - Guidelines on formulation of assessment questions aligned to the learning objectives of the laboratories in the online tool?
Q11.	(Five point Likert scale)	I think that I would like to use the experiment design guidelines frequently
Q12.	(Five point Likert scale)	I think that I would need the support of a technical person to be able to use the experiment design guidelines.
Q13.	(Five point Likert scale)	I found that the various functions in the design guidelines were well integrated.
Q14.	(Five point Likert scale)	I thought that there was too much inconsistency in the experiment design guidelines.
Q15.	(Five point Likert scale)	I would imagine that most people would learn to use the experiment design guidelines very quickly.
Q16.	(Five point Likert scale)	I found the experiment design guidelines very awkward to use.
Q17.	(Five point Likert scale)	I felt very confident using the experiment design guidelines.
Q18.	(Five point Likert scale)	I needed to learn a lot of things before I could get going with the experiment design guidelines.
Q19.	(Five point Likert scale)	I think that I would like to use the experiment design guidelines frequently.

Q20.	(Five point Likert scale)	I found the experiment design guidelines unnecessarily complex.

Data Analysis

The analysis of responses to likert scale questions was carried out by combining the responses to the two scales of strongly agree and agree and strongly disagree and disagree. All the 58 participants responded to the survey. The following table gives the summary of the findings

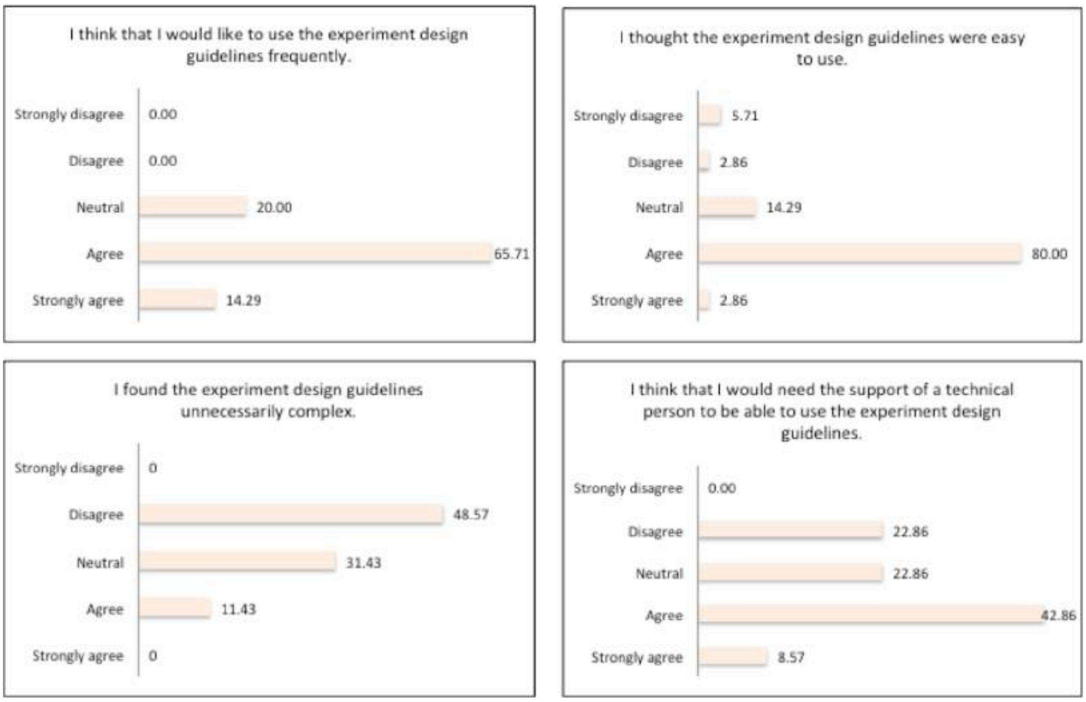
Table 6.2: Responses of participants

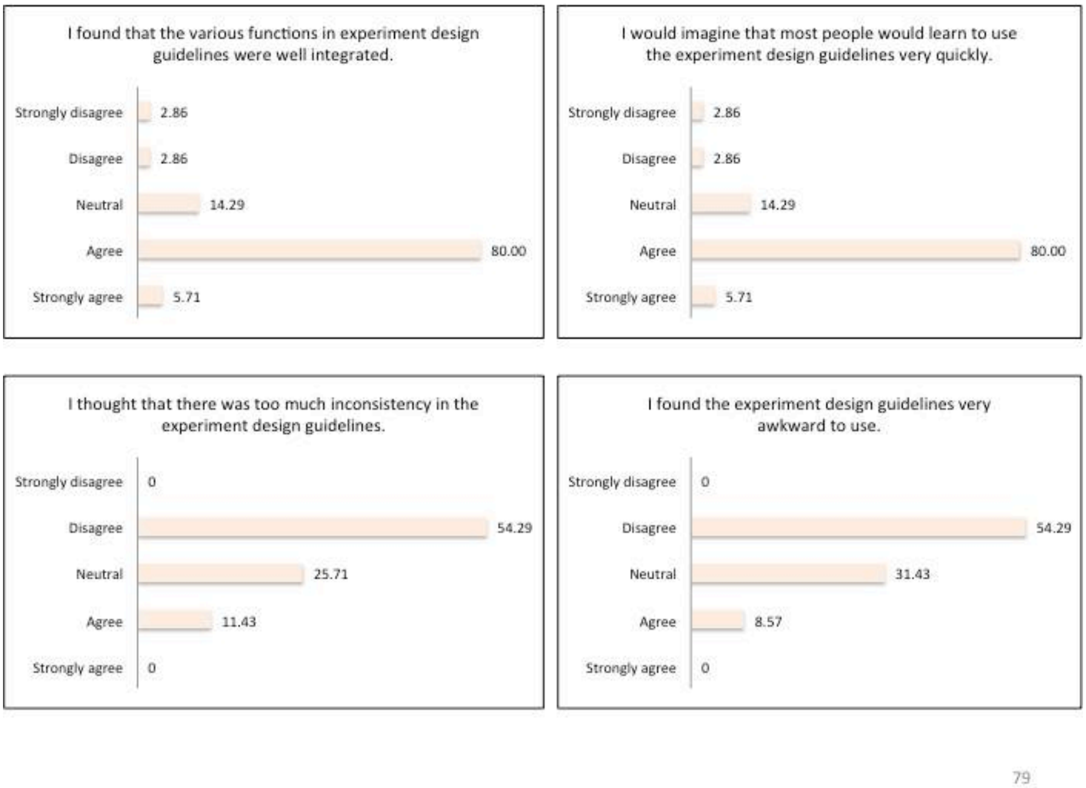
Q.No	**Percent of instructors with Yes response**	**Q.No.**	**Percent of instructors who agree**
4	82	11	80
5	88	12	51.5
6	85	13	82.9
7	85	14	11.4
8	91	15	83
9	80	16	8.6
10	62	17	77.2
Average	**82**	18	57.1
		19	77.1
		20	11.4
		SUS score	**75.3**

Results of Analysis of Likert Scale Data

The engineering instructors who responded to the survey were having teaching experience ranging from one year to fifteen years and were from the domains of Mechanical, Electrical, Civil, Chemical, Electronics, Electronics and Telecommunication, Computer Science and Information Technology.

The survey consisted of 10 items related to the usability of the tool for the engineering instructors. The Usability score was calculated as per the guidelines given by Sauro (2011).





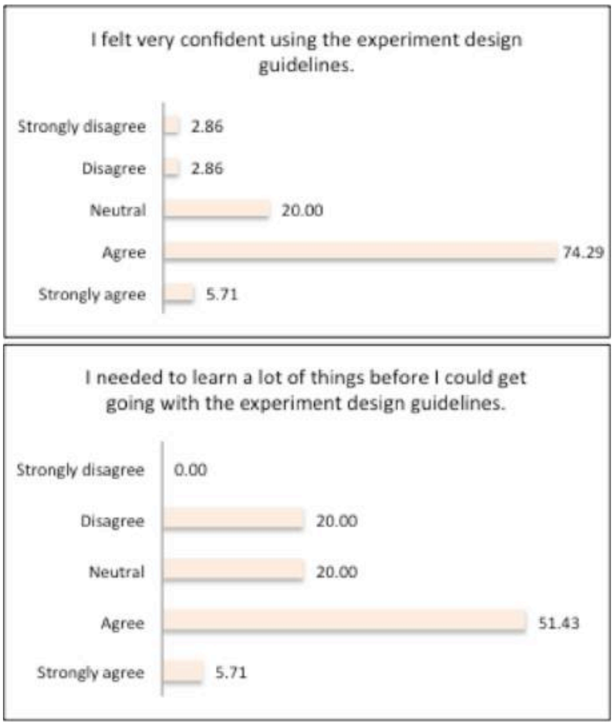


Figure 6.2 Results of responses to SUS survey questions

Scoring SUS

- For odd items: subtract one from the user response.
- For even-numbered items: subtract the user responses from 5
- This scales all values from 0 to 4 (with four being the most positive response).
- Add up the converted responses for each user and multiply that total by 2.5. This converts the range of possible values from 0 to 100 instead of from 0 to 40.

Interpreting SUS Scores

A SUS score above a 68 would be considered above average and anything below 68 is below average. For the survey with feedback from 58 instructors the SUS score is 75.3, which is considered above average. So it can be claimed that the experiment design guidelines for virtual laboratories are usable.

Results of Analysis of Open-Ended Response

The responses of the participants to the open-ended question were analysed using the thematic content analysis method. Thematic analysis is the search for and extraction of general patterns found in the data through multiple readings of the data. (Fereday and Muir-Cochrane, 2006) described thematic analysis as "a form of pattern recognition within the data, where emerging themes become the categories for analysis". The process of thematic analysis involves examination of data and identification of themes that are central to the description of the phenomenon (Daly, Kellehear, & Gliksman, 1997). Themes identified during careful reading and re-reading of the data become the categories for analysis.

In order to come up with the engineering instructor's suggestions for improvement in the experiment design guidelines two rounds of thematic analysis were carried out.

First round: In this round coding of the data was carried out. It was observed that the instructors did not just give suggestions for improvement but also pointed out the limitations of the guidelines. They also mentioned about which section in the guidelines they found most useful and which section they found difficult to understand. Thus four themes emerged from the first round of analysis as follows:

1. Shortcomings or limitations of the guidelines
2. Most useful section in the guidelines
3. Most difficult section in the guidelines
4. Suggestions for improvement

Second round: In the second round the details for each of the categories were obtained as follows.

1. Shortcomings or limitations of the guidelines
    i. 10 percent of the instructors found it difficult to design tasks aligned to the learning objectives.
    ii. 5 percent of the instructors mentioned that they need more examples for writing questions at analysis and higher cognitive levels.
    iii. 8 percent of the instructors pointed out that there should be example tasks designs aligned to the higher level learning objectives.
2. Most useful section in the guidelines

    The instructors found the following sections in the experiment design guidelines most useful

i. Experiment design templates for the various instructional strategies.
ii. Formulating learning objectives.
iii. Formulating learning objectives at higher cognititve levels of Bloom's taxonomy.

iv. Framing questions aligned to learning objectives.

v. Designing tasks aligned to learning objectives and as per the instructional strategy.

vi. Scientific design of experiments.

vii. Various examples from Basic and Advanced Electronics domain for the important aspects such as decision regarding broad goals, formulating learning objectives especially at higher cognitive levels of Bloom's taxonomy, designing tasks as per the various instructional strategies and assessment questions aligned to the learning objectives.

viii. The bank of tasks and assessment questions from Basic and Advanced Electronics domain was found very useful.

3. Most difficult section in the guidelines

   The instructors found the following sections in the experiment design guidelines most difficult to implement

i. The examples given are from Basic and Advanced Electronics so engineering instructors from other domains found it difficult to design experiments.

ii. They found the design of experiments for Discovery Instructional Strategy and Problem-based Instructional Strategy most difficult as they had never designed experiments incorporating these startegies.

4. Suggestions for improvement

   The instructors have following suggestions for improvement in the guidelines

i. They suggested that there should be examples from other domains in each and every section of the guidelines.

ii. There should be examples from other domains for every section in the experiment design templates for the various Instructional Strategies.

iii. The guidelines could be more precise with more of figures than text.

Conclusion and Discussion

The following conclusions can be drawn from the results of the quantitative and qualitative analysis of the data of the usability study

1. The engineering instructors perceive that they find the experiment design guidelines usable.
2. They find a few sections most useful while they had difficulty in a few sections.
3. They suggested a few modifications in the guidelines in order to improve the usability.

The engineering instructors from other domains found it difficult to design tasks as per the various instructional strategies compared to the instructors from Electronics domain. They found formulation of learning objectives easier and could also formulate learning objectives at higher cognitive levels. The formulation of assessment questions was also found easier but found difficulty in designing tasks especially for the instructional strategies of Discovery and Problem-based.

In order to make the guidelines more usable to the instructors from other domains examples from two other domains of computer engineering and mechanical engineering for each aspect of the experiment design were added.

6.2 Study 6: Engineering Instructors’ Perceptions About the Usefulness of the Experiment Design Guidelines

Objective

The main objective of this survey study was to get an insight into the perceptions of the engineering instructors about the usefulness of the experiment design guidelines

Research Question

RQ2b: What are the perceptions of engineering instructors regarding the usefulness of the virtual laboratory experiment design guidelines?

Hypothesis

H1: The engineering instructors perceive that the virtual laboratory experiment design guidelines are useful.

Methodology

The results of the study 1 indicate that the engineering instructors perceive that the experiment design guidelines are usable. The next part of the summative evaluation was to find out the perceptions of the instructors regarding the usefulness of the experiment design guidelines. The instructors were asked to use the experiment design guidelines for about an hour and design their experiments. This was done so that the instructors could find out if they could design experiments for their course and topic using the guidelines in the online SDVIcE tool.

After they had used the guidelines a written consent was taken from the participants so that the researcher can use the data of the survey. After obtaining the consent the questionnaire was administered. They were given enough time to fill up the survey. The survey was administered in an online format.

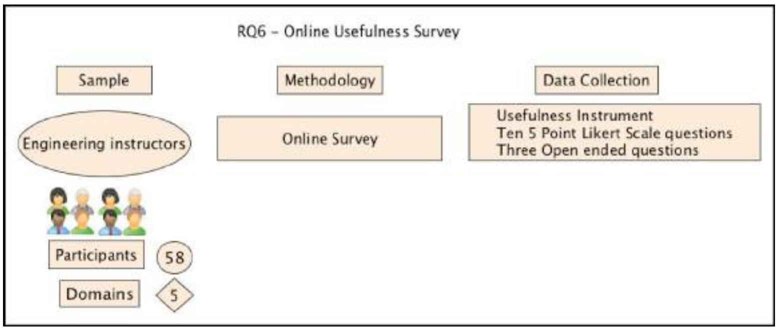


Figure 6.3 Implementation of study 6

Sample

The total number of participants who responded to the survey and gave their feedback was 58 undergraduate engineering instructors from Mumbai, Pune and Nagpur University.

Instrument

The survey questionnaire based on the TAM survey (Davis, 1989) consisted of sixteen questions with ten questions of five point likert scale format, and four with open-ended responses. There were two questions to find out the demographic information of the participants; four questions one question each to find out the limitations, most useful sections, sections that instructors find most difficult to understand and suggestions for improvement. There were ten questions to find out the perceptions of the instructors regarding the usefulness of the experiment design guidelines.

The four questions with open-ended responses were formulated taking cues from the responses of instructors in the previous study on usability. In the previous study only one open-ended question was asked and after the thematic content analysis four categories emerged. These four categories were – Limitations of the guidelines, most useful section in the guidelines, most difficult section and suggestions for improvement. Four open-ended questions based on these four categories in the survey instrument in the usefulness study were formed in order to find out if the modifications carried out after the usability study proved to be useful.

The ten Five Point Likert Scale questions helped in identifying whether guidelines are useful to the engineering instructors in the various aspects of the experiment design such as - Steps in the Experiment design process, Designing experiments at various difficulty levels, Incorporating active learning methods in the experiment designs, Decision on laboratory goals, Formulation of laboratory learning objectives, Decision regarding the most suitable instructional strategy, Designing tasks aligned to the learning objectives and instructional strategy, Designing assessment aligned to the learning objectives and tasks, Using the affordances of virtual labs to achieve the various learning objectives.

Table 6.3: Usefulness survey instrument

S.No	**Type of question**	**Question**	**Percent Agree**
Q1.		Your Name	
Q2.		How many years of experience do you have in engineering education?	
Q3.	(Five point	I was able to use the experiment design guidelines to decide the steps in the experiment	90

	Likert scale)	design process.	
Q4.	(Five point Likert scale)	I was able to use the Experiment design guidelines for selecting the broad goal for my virtual lab experiment.	91.5
Q4.	(Five point Likert scale)	I was able to use the Experiment design guidelines for selecting/formulating the learning objectives for my virtual lab experiment.	90.4
Q5.	(Five point Likert scale)	I was able to use the Experiment design guidelines for selecting the Instructional Strategy for my virtual lab experiment.	88
Q6.	(Five point Likert scale)	I was able to use the Experiment design guidelines for selecting/designing the tasks as per the instructional strategy and aligned to the learning objectives for my virtual lab experiment.	83
Q7.	(Five point Likert scale)	I was able to use the Experiment design guidelines for formulating the assessment questions for my virtual lab experiment.	90
Q8.	(Five point Likert scale)	Using the Experiment design guidelines helped me in asking questions at higher cognitive levels.	76.3
Q9.	(Five point Likert scale)	Using the Experiment design guidelines helped me in designing experiments with different difficulty levels.	65
Q10.	(Five point Likert scale)	Using the Experiment design guidelines helped me in Incorporating active learning methods in the experiment designs.	89
Q11.	(Five point Likert scale)	I was able to use the Experiment design guidelines for selecting the virtual lab as per my requirements.	87
Q12.	Open-ended	What according to you are the limitations of the experiment design guidelines?	
Q13.	Open-ended	Which section in the experiment design guidelines did you find most useful?	
Q14.	Open-ended	Which section in the experiment design guidelines did you find most difficult to understand?	
Q15.	Open-ended	What suggestions would you give to improve the experiment design guidelines?	

Data Analysis

The analysis of responses to likert scale questions was carried out by combining the responses to the two scales of strongly agree and agree and strongly disagree and disagree. All the 58 participants responded to the survey. The table gives the summary of the findings.

Results of Analysis of Likert Scale Data

The analysis of the Likert scale data indicates that on an average 85 percent of the engineering instructors find the experiment design guidelines useful for the selection, formulation and design of the various aspects of the experiment design. On an average 90 percent of the participants agreed that the guidelines for the aspects – decision regarding the steps in the design and broad goals, formulation of learning objectives and assessment questions are useful.

Similarly average 80 percent of the participants agreed that the guidelines for the aspects – selection of Instructional Strategy, designing tasks as per the Instructional Strategy and aligned to the learning objectives, incorporating active learning strategies and selecting the virtual laboratory are useful.

For the two aspects of designing experiments at various difficulty levels and formulating questions at higher cognitive levels average agreement was 71 percent.

Results of Analysis of Open-Ended Response

In order to find out the limitations of the guidelines four questions with open-ended response were asked. These sections were – limitations of the guidelines, most useful section, most difficult section and suggestions for improvements in the guidelines. The objective was to find out if the engineering instructors in this study and previous study had similar or different views about the various sections.

1. Shortcomings or limitations of the guidelines
    i. 4 percent of the instructors found it difficult to design experiments at different difficulty levels.
    ii. 2 percent of the instructors mentioned that they need more examples for writing questions at analysis and higher cognitive levels.
2. Most useful section in the guidelines

   The instructors found the following sections in the experiment design guidelines most useful

    i. Experiment design templates for the various instructional strategies.
    ii. Formulating learning objectives.
    iii. Formulating learning objectives at higher cognititve levels of Bloom's taxonomy.
    iv. Framing questions aligned to learning objectives.
    v. Designing tasks aligned to learning objectives and as per the instructional strategy.
    vi. Scientific design of experiments.
    vii. Various examples from Basic and Advanced Electronics domain for the important aspects such as decision regarding broad goals, formulating learning objectives especially at higher cognitive levels of Bloom's taxonomy, designing tasks as per the various instructional strategies and assessment questions aligned to the learning objectives.
    viii. The bank of tasks and assessment questions from Basic and Advanced Electronics domain was found very useful.
    ix. The visuals and videos describing each set of guidelines in the form of a narration.
3. Most difficult section in the guidelines

   The instructors found the following sections in the experiment design guidelines most difficult to implement

i. They found the design of experiments for Problem-based Instructional Strategy most difficult as they had never designed experiments incorporating these startegies.

4. Suggestions for improvement

The instructors have following suggestions for improvement in the guidelines

i. They suggested that there should be examples from other domains in each and every section of the guidelines.
ii. There should be examples from other domains for every section in the experiment design templates for the various Instructional Strategies.

Conclusion and Discussion

The following conclusions can be drawn from the results of the quantitative and qualitative analysis of the data of the usefulness study

1. The engineering instructors perceive that the experiment design guidelines are useful in their design process.
2. They find a few sections very useful and some sections difficult to understand.
3. There is a consensus between the participants in the usability study and usefulness study regarding most of the aspects of the experiment design guidelines.

6.3 Study 7: Effectiveness of Proposed Guidelines in Improving the Quality of Experiment Designs

Objective

The main objective of this field test study was to find out if the proposed guidelines are effective in improving the quality of the experiment designs by the engineering instructors. The effectiveness of the Experiment design guidelines was carried out after it was established that the engineering faculties find it usable and useful for designing laboratory experiments aligned to their learning objectives. The Experiment design guidelines can be considered effective if the quality of the experiments designed after using the guidelines is better than the quality of experiments without using the guidelines. In order to find out this effectiveness a field test study with 10 engineering instructors was carried out.

The leading research question for this study was:

RQ2c: What is the effectiveness of the experiment design guidelines in improving the quality of experiment designs for using existing virtual labs?

Methodology

1. Identify dimensions of quality of experiment designs.
2. Developing a rubric for assessment of the design of experiments.
3. Field-testing with ten engineering instructors.
4. Scoring the designed experiments as per the rubric
5. Analyzing the scores
6. Arriving at the results of the field testing

1. Identify dimensions of quality of experiment designs.

The experiment design guidelines were designed and developed after an iterative process and hence if they are followed and implemented by the engineering instructors it should lead to high quality experiment designs. So the basis of the guidelines was taken in order to come up with the dimensions of quality of the designs. The quality of experiment designs depends on a variety of parameters or dimensions that are as follows:

a. The experiment design follows a scientific design process
b. The experiment design incorporates the various phases in the scientific design process
c. The experiment design incorporates various instructional strategies
d. The experiment design for the various instructional strategies are as per the templates
e. If the Expository instructional strategy is used then the tasks are designed with constructivist approach
f. The experiments are designed at different difficulty levels
g. The broad goal/s of the experiment is clearly specified
h. The broad goal/s is aligned to the content type of the topic
i. The learning objectives are valid and clearly defined
j. The experiment design has learning objectives at various cognitive levels as per Revised Bloom's taxonomy
k. The virtual laboratory tasks are aligned to the learning objectives of the experiment.
l. The virtual laboratory tasks provide opportunities to the students to work in the two domains of objects and concepts
m. The virtual laboratory tasks are different for the different instructional strategies
n. The assessment questions are aligned to the learning objectives
o. The assessment questions in the design of learning are correct
p. The assessment questions in the design for learning truly help the students in their learning
q. The assessment measures the students' knowledge as per the content type
r. The assessment measures the target skills developed by the students

s. The virtual laboratory selected has affordances that allow students to perform the tasks designed in the experiment

2. Developing a rubric for assessment of the design of experiments.

After identifying the dimensions for quality of the experiment designs a rubric was developed so that the experiment designs could be assessed for their quality. The complete set of rubric is given in the Appendix A. One sample example of a rubric item is presented below.

Table 6.4: Rubric Item

Dimension	Missing(0)	Inadequate(1)	Needs some improvement(2)	Adequate(3)
9. LOs valid and specified	Not clearly specified as per the guidelines and not aligned to the BG	Not clearly specified as per the guidelines but somewhat aligned to the BG	Clearly specified as per the guidelines but not aligned to the BG	Clearly specified as per the guidelines aligned to the BG

3. Field-testing with ten engineering instructors.

The next step in the study was the field-testing in which ten engineering instructors volunteered to participate in the process. Each instructor was requested to design minimum four experiments for their course and topic before referring to the guidelines. Then they used the guidelines available online in the tool and designed the same experiments again. Thus total 40 experiment designs before and after the usage of the guidelines formed the data of the study. These artifacts were then analysed for their quality.

The experiments were designed for the courses Mobile communication, Power Electronics, Advanced Electronics, Digital Electronics, Introduction to php, Printing –

Pre-press and Optical communication. These courses belong to the domains of Electrical engineering, Information technology, Computer engineering and Electronics and Telecommunication. The quality of the designed experiments was evaluated based on the developed rubric.

4. Scoring the designed experiments as per the rubric

In order to score the experiments the designs were given to two subject experts. The scores were found to be reliable and the reliability was measured by Cronbach's alpha. The value was found to be 0.78. The experiment designs with their scores as per the rubric are given in Appendix B.

5. Analyzing the scores

After scoring the various experiments and checking for the reliability of the scores the analysis of the scores of the designs before and after the usage of guidelines per instructor was carried out. The following tables give the results of the analysis.

Table 6.5: Results of artifact analysis

Total Experiment Designs	High	Medium	Low
Before	6	8	26
After	24	3	3

As can be observed from the table the engineering instructors designed 40 experiments in total before and after using the guidelines. The number of experiments with high quality increased from 6 to 24 after using the guidelines, the number of experiments with medium quality decreased from 8 to 3 and the number of experiments with low quality reduced from 26 to only 3. So after using the guidelines there was a improvement in the quality of majority of the experiment designs. The table illustrates the instructor-wise analysis of the rubric score data.

Table 6.6: Instructor-wise Results of artefact analysis

	Quality of experiment design as per rubric							
Faculty	Before using EDG				After using EDG			
	High	Medium	Low	Total	High	Medium	Low	Total
1	1	1	2	4	2	2	0	4
2	0	1	3	4	2	1	1	4
3	1	1	2	4	2	1	1	4
4	0	1	3	4	3	1	0	4
5	1	0	3	4	3	1	0	4
6	1	0	3	4	2	2	0	4
7	1	1	2	4	3	1	0	4
8	0	1	3	4	2	2	0	4
9	1	1	2	4	3	1	0	4
10	0	1	3	4	2	0	2	4
10	6	8	26	40	24	12	4	40

Table 6.7: Quality of experiment designs

	Quality of experiment design as per rubric					
Faculty	Before	After	Before	After	Before	After
	High		Medium		Low	
Faculty 1	1	2	1	2	2	0
	High		Medium		Low	
Faculty 2	0	2	1	1	3	1
	High		Medium		Low	
Faculty 3	1	2	1	1	2	1
	High		Medium		Low	

Faculty 4	0	3	1	1	3	0
	High		Medium		Low	
Faculty 5	1	3	0	1	3	0
	High		Medium		Low	
Faculty 6	1	2	0	2	3	0
	High		Medium		Low	
Faculty 7	1	3	1	1	2	0
	High		Medium		Low	
Faculty 8	0	2	1	2	3	0
	High		Medium		Low	
Faculty 9	1	3	1	1	2	0
	High		Medium		Low	
Faculty 10	0	2	1	0	3	2

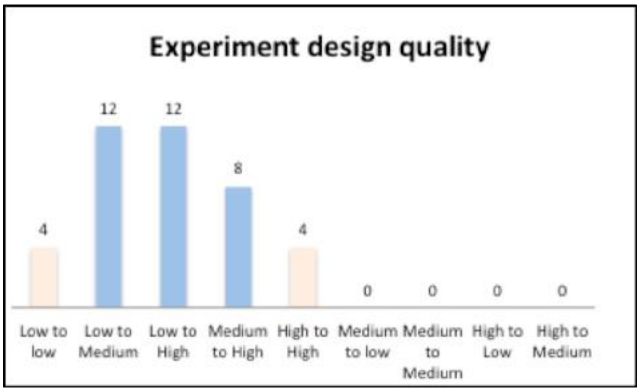


Figure 6.4 Improvement in the quality of experiment designs

The following can be inferred from the graph

i. The quality of 4 experiment designs (10%) remained at low level
ii. The quality of 12 experiment designs (30%) improved from low level to medium level
iii. The quality of 12 experiment designs (30%) improved from low level to high level

iv. The quality of 8 experiment designs (20%) improved from medium level to high level

v. There was no change in the quality of 4 (10%) experiment designs. They remained at high level.

vi. There was no negative effect of using the guidelines that is none of the experiment design quality was lowered from either high to medium or medium to low or high to medium.

vii. Arriving at the results of the field testing

The analysis of the scores of the experiment designs before and after using the guidelines indicate that there is an overall improvement in the quality of the designs. 60% of the designs had a high quality and 30% medium quality. Only 10% designs had low quality.

Conclusion and Discussion

It can be concluded from the results that the experiment design guidelines are effective in improving the quality of the experiment designs. In order to get indepth knowledge about the components of the guidelines which had greater effect on the improvement in the designs were analysed and the details are given in Appendix II. The sample experiment designs before and after using the VLEDG along with the rubric score and analysis are also given.

6.4 Study 8 Effectiveness of the Experiment Design Guidelines with Respect to Students' Learning Outcomes in Virtual Laboratory (Control Group Experimental Group CG –EG Study Carried Out by Researcher)

A longitudinal mixed method study spanning over a period of one semester was carried out in order to evaluate the impact of the lab experiments designed using the Experiment design guidelines. The sample for the study was 39 UG second year engineering students from a self-financed engineering institute affiliated to Mumbai University. The following section gives the details of the study.

Research Question

RQ2d: What is the impact of experiments designed using the experiment design guidelines for virtual laboratories on the students' laboratory learning outcomes?

Intervention

In order to measure the impact of the guidelines when students perform experiments using virtual labs following steps were carried out.

- Selection of the course
- Selection of experiments to be performed in virtual labs
- Selection of the Virtual lab
- Identification of learning objectives for the experiments as per the guidelines
- Design of tasks aligned to the learning objectives as per the guidelines

- Design of assessment questions aligned to tasks and learning objectives as per the guidelines
- Design of pre test, post test and learning outcomes test for all the experiments

The researcher in collaboration with one engineering faculty designed and developed five experiments to be performed using the virtual laboratory for the BAE course.

Scope of Work

The research study was carried out in the Electronics Engineering domain for the course Basic and Advanced Electronics. The virtual labs used for the study are for the related topics in this course available online as an open source tool. This course is a compulsory course for Electronics and Allied branches of engineering at UG level.

Research Design

The research design used to study the impact of the experiments designed using the Experiment design guidelines on the students learning was a control group experimental group mixed method study. The experimental group consisted of the students taking the virtual lab audit course with experiments designed using the Experiment design guidelines. The control group consisted of students who took the virtual lab audit course but were given the lab manual given in the traditional labs and not designed using the Experiment design guidelines. The students gave two tests – one pre-test at the beginning of the each experiment and a post-test at the end of each experiment. While performing the various experiments they also gave the learning outcome test (LOT). The entire study conducted over a period of one semester from July 2016 to December 2016 was carried out in authentic settings.

Sample

The 39 participants of the study were second year engineering students from Electronics and Electronics and Telecommunication branch from a self-financed engineering educational institute. The study was conducted in real settings where the students were undertaking the audit course on Virtual laboratories. As part of their curriculum requirements the students are required to complete two audit courses along with other credit courses. Thus the 39 students who chose to opt for the virtual laboratories course are the sample for the study with 20 students in the experimental group and 19 in control group. Hence the sampling was convenience sampling. The students were informed about the research study by the faculty and they volunteered to participate. The scores of the students in the various tests conducted as part of the study were considered for the certification of the course and not for the final grades allocated for the semester results.

Implementation Process

The experiment was conducted with the following procedure.

1. At the beginning of the lab course the students from both groups were given a pre-test based on the topics covered in the class.
2. The students from both the groups were taught the topics in the class by the faculty and they performed five experiments using the traditional lab with breadboard, components, wires and equipment spanning over a period of one semester.
3. All the students were appraised about virtual labs and the researcher gave a demo of one experiment.
4. These students worked with virtual labs for nearly two hours and performed the experiments on the same topic.
5. The control group students worked with the Basic Electronics virtual lab with the lab manual having the traditional cookbook approach.

6. The experimental group students worked with the Basic Electronics virtual lab with the experiments designed as per the guidelines.
7. All the students worked with the Basic Electronics lab for the same duration of time and answered the questions after completion of allocated tasks.
8. The entire learning process of a few students is captured using the screen capture software.
9. The same procedure is repeated for all the remaining four experiments over the complete period of one semester.
10. Once the students have completed all the five experiments they were given a Survey Questionnaire.
11. A few students belonging to each group were also interviewed.
12. After the students completed the performance of experiments along with the completion of test questions in the online material it is submitted to the instructor. In the study presented the researcher in collaboration with one faculty graded the test answers.

Data Gathered

The following data was gathered for analysis at the completion of the study.

1. The students scores in the pre-test
2. The students scores in the LOT (Learning Outcome test) for each experiment
3. The students scores in the post-test
4. The screen capture videos of a few students
5. Student responses to the Survey questionnaire
6. Responses to the open ended questions in the interviews of a few sample students

Variables for the Study

- **Independent variable**

  - Experiment designs using VLEDG

- **Dependent variables**
  - Marks in the post-test
  - Marks in learning outcome test

Confounding variables

- **Controllable**
  - Participants' prior knowledge
  - Support material
  - Experiment
  - Assessment criteria
- **Measurable**
  - Participants' preferred learning style
  - Participants' demographics
- **Uncontrollable**
  - Participants' interaction
  - Participants' awareness of the research

Instruments Used

As recommended by (Jodie Jenkinson 2009) complementary exploratory and experimental studies are necessary to characterize the learning that occurs as a result of complex interaction with educational technology. So a mixed method study was carried out where the following instruments were used

1. Experiment designs for each experiment as per the VLEDG
2. Pre-test question paper
3. Learning outcome test questions
4. Post-test question paper
5. Survey questionnaire

6. Rubrics to measure the various skills

1. Experiment designs for each experiment as per the VLEDG

The five experiments given to the experimental group were designed using the VLEDG. The topics these experiments covered were as follows:

(i) V-I Characteristics of PN Junction Diode
(ii) PN Junction Diode as Clipper
(iii) PN Junction Diode as Clamper
(iv) Common emitter characteristics of BJT
(v) CE Amplifier using BJT

The instructional strategies used for each of the experiments is as follows:

(i) Experiment 1 – Expository with various difficulty levels.
(ii) Experiment 2 – Expository with active learning methods
(iii) Experiment 3 – Discovery
(iv) Experiment 4 – Well-Structured Problem Solving
(v) Experiment 5 – Problem-based

The complete experiment designs and sample answers submitted by students are given in Appendix…

2. Pre-test question paper

The pre-test was conducted in order to find out the equivalence between the two groups control and experimental. The questions were based on the participants' prior knowledge about the particular topics in Basic Electronics on which the experiments were based.

3. Learning outcome test questions

This is an online test which the students give while they are performing the experiment and after the completion of various tasks. After the end of each task performed in the virtual lab the students reflect on their learning by answering to the questions. Each question is aligned to the task and also to the learning objectives. This has questions similar to the post-test such as

a. Multiple Choice Questions
b. Numerical Problems
c. Open Ended questions

These questions test the knowledge achieved by the students to find out if the learning objectives selected for the research are achieved. The marks obtained by the student in each task correspond to the marks obtained for the various learning objectives. So if a student scores well in a task it indicates that the student has performed well in the learning objectives targeted by the task. This test ensures that the students' assessment is authentic and the questions asked assess their knowledge and skills as per the target learning objectives. It can be inferred that the Broad Goals are achieved if the target learning objectives are met.

A few sample questions are given at the end after the reference section. Each of the questions in this test is designed by a subject expert and then validated by two other subject experts and an educational technology expert.

3 Post-test question paper

In this test all students had to perform two experiments based on the topics covered in the Basic Electronics theory course but on which they had not performed experiments using the virtual laboratories. They had to answer the questions after performing each task. The questions were similar to the learning outcome test questions aligned to the learning objectives.

4 Survey questionnaire

The Survey questionnaire is administered after the students from both the groups completed performing all the experiments in the course and appeared for the post-test. The questionnaire consisted of five point likert scale questions and two open ended questions. The following Table 6.8 gives the structure of the survey questionnaire.

Table 6.8: Structure of Survey Questionnaire

S.No	Section Title	Number of questions	Type of question	
			Four point Likert Scale	Open-ended
1	General information	4		4
2	Virtual lab helpful in improving understanding of concepts	2	1	1
3	Attractiveness	3	2	1
4	Virtual lab helpful in Data analysis	2	1	1
5	Useful Vlab features	4	4	4
6	Virtual lab helpful in developing practical skills	2	1	1
7	Virtual lab helpful in problem solving	2	1	1

The questions were related to the features of the virtual lab, which they considered useful in achieving the desired learning outcomes, and also helped them in solving problems. The analysis of the survey data is given in the next section.

5 Rubrics to measure the various skills

In the learning outcome test and the post-test there are a number of questions aligned to the learning objectives. The score of the students for a particular learning objective is calculated as the sum total of the scores obtained for the particular questions in the experiment. The learning objectives are aligned to the Broad Goals that are knowledge at different cognitive levels, various skills and cognitive ability. The attainment of the learning outcomes is measured based on the scores of students in the LOT. The attainment of the skills and cognitive ability is measured by means of rubrics. The Rubrics for the various skills and cognitive ability are given in Appendix…

Data Analysis Technique

The data analysis techniques used in the study are

1. Comparison of means of students' scores of the two groups in the pre-test.
2. Comparison of means of students' scores of the two groups in the post-test.
3. Analysis of the scores of experimental group students in the LOT.
4. Comparison of mean time spent by students in
    a. Each lab experiment to arrive at the results and answer the questions
    b. Using various features

The data obtained from the answers to open-ended questions and recorded videos when students are performing the experiment is analyzed using qualitative methods.

Comparison of Scores of Students from the Two Groups in the Pre-Test

The following table gives the statistical analysis data of the experiment. As there are two groups – control group and experimental group in the research design, initially an independent sample t test is conducted on the pre-test scores of the two groups.

Table 6.9: Results of Independent samples t-test – Pre test

Independent Samples t-test	Levene's Test for Equality of Variances		t-test for Equality of Means					
	F	Sig	t df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Equal variances assumed	11.236	0.002	1.252 28	0.221	0.23864	0.19057	-0.15174	0.62901
Equal variances not assumed			1.462 17.46	0.162	0.23864	0.16323	-0.10506	0.58233

As seen from the results the Sig values is 0.002 which is less than 0.005 and hence the equal variances are not assumed and the row number two is used to find if the two groups are different. As seen the Sig(2-tailed) value is 0.162 which is greater than 0.005 it can be concluded that the two groups are have not scored significantly different in the pre-test. This indicates that the two groups are equivalent before they used the virtual labs and perfromed the various experiemnts during the audit course.

The same test is then carried out on the post-test scores and the following Table 6.8 gives the results

Comparison of Scores of Students from the Two Groups in the Post-Test

Table 6.10: Results of independent samples t-test- Post test

Independent Samples t-test	Levene's Test for Equality of Variances		t-test for Equality of Means					
	F	Sig	t df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
							Lower	Upper
Equal variances assumed	9.728	0.002	4.533 28	0.000	0.25435	0.05612	-0.36479	0.14392
Equal variances not assumed			4.533 17.46	0.000	0.25435	0.05588	-0.36433	0.14438

From this table the Sig value is 0.002, which is much less than 0.005, and so the equal variances are not assumed. The second row values are to be used for the analysis. As seen the value of Sig (2-tailed) is 0.000, which is much less than 0.005, and hence it can be inferred that the scores of the two groups in the posttest are significantly different. This indicates that the students who carried out experiments designed using the Experiment design guidelines performed better than the students who were given the experiments similar to the traditional methods without using the Experiment design guidelines.

Table 6.11: Analysis of survey questionnaire data

S.No.	**Virtual lab helped in**	**Experimental Group N = 20**			**Control Group N = 19**		
		Percent students agree	Percent students neutral	Percent students disagree	Percent students agree	Percent students neutral	Percent students disagree
1	Improving understanding	96	4	-	73	8	19

2	Data Analysis	90	4	6	64	4	32
3	Problem solving	94	4	2	70	5	25
4	Developing practical skills	91	4	5	85	2	13
5	Attractiveness	90	7	3	89	6	5

The response of the students to the survey questionnaire was more positive from the experimental group than the control group. The response was similar for the two groups on the metric of attractiveness. All the students responded that they felt motivated and enjoyed performing experiments using virtual labs. There were a few students from the control group who perceived that the labwork did not help them in understanding concepts, data analysis, problem solving and developing practical skills. Whereas most of the students from the experimental group perceived that the virtual labs helped them in understanding concepts, data analysis, problem solving and developing practical skills.

Analysis of Qualitative Data – Recorded videos

In order to get better insights into the students learning process the activity of the students while they performed experiment was recorded using CAM studio software. Then a detailed analysis of videos from students of each group was carried out.

The videos were analyzed to find out the time spent by the student for each task and using each feature of the lab by the free and open source software named Tracker. The analysis of the video of three students randomly selected from the control group and three from experimental group who performed the experiment using virtual labs was carried out.

The following figures 6.5 and 6.6 illustrate a sample interaction of two students – one from control group and the other from experimental group.

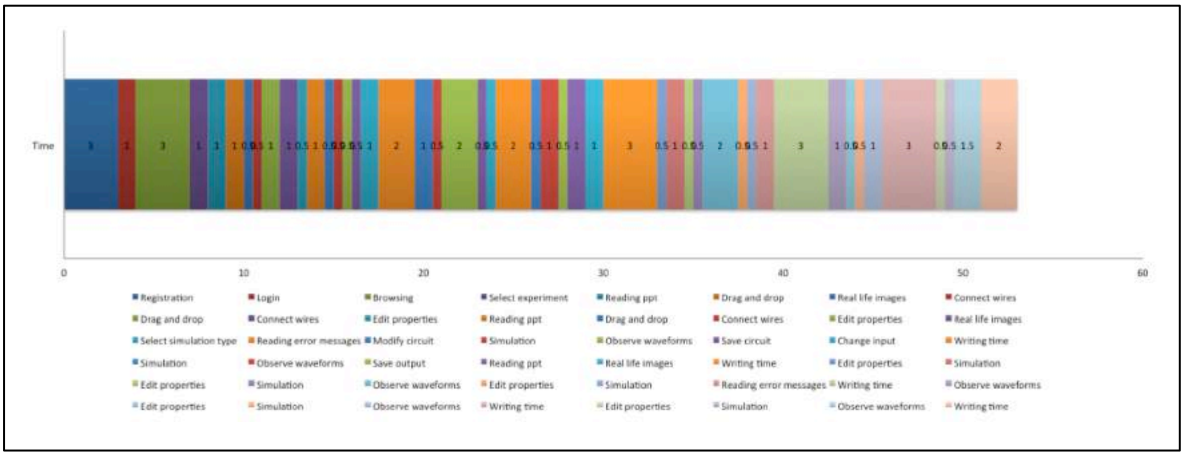


Figure 6.5 Interactivity - Experimental group

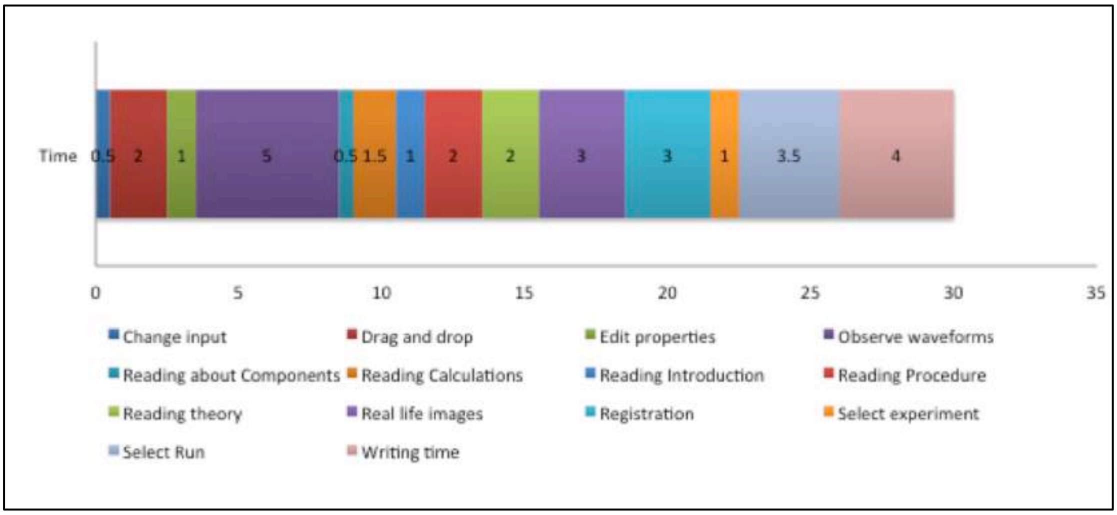


Figure 6.6 Interactivity – Control Group

The control group student completes the given experiment in 46 minutes while the student from experimental group needs 81 minutes to complete the same experiment.

The reason for this difference in the time is that the experimental group students reflect on their tasks as per the assessment questions asked after each task. The experiment design incorporates the formative assessment methodology as per the experiment design guidelines. The control group students complete all the tasks and then answer a few questions, which are as per the traditional lab experiment design. It can be observed that the students from experimental group have lot of interactions with the virtual laboratory components as these have been incorporated in the experiment design.

Analysis of Qualitative Data – Open-Ended Questions and Semi-Structured Individual Interviews

The analysis of the responses of the students to open ended questions and interview questions was carried out by content analysis method. All the answers were written verbose in a document. Then each response was given tags based on the content. The tags were then classified into different categories. These categories were related to the specific feature in the virtual lab, which the students found useful in conceptual understanding, development of technical skills, data analysis and problem solving. The following table gives the results of the analysis.

Table 6.12: Analysis of Qualitative data

Question	Student responses	Virtual lab features
Did you find virtual lab helpful in understanding concepts? Why? Which feature of virtual lab was useful?	Performance over and over again. User convenient. Easy to visualize. Concepts get cleared. We know theory but in practice don't know how it works. Bridge between practical and	Interactive exploration of unobservable phenomena Offered students more time to experience an experiment and to concentrate on its conceptual aspects than the corresponding physical laboratories, because the virtual

	theoretical concepts. Conceptual understanding improved.	laboratories allowed faster manipulation of the materials involved in the experiments.
Did you find virtual lab helpful in developing practical skills? Why? Which feature of virtual lab was useful?	Objective was met. Various parameters could be varied. Many components are present on the screen. We can click and see how it actually looks. This helped in physical lab work. We could see and use different functions in CRO without fear of damage. One varies other constant. Demo video provided made concepts clear.	A library of a variety of components and types of instruments Full function simulations of the instruments to take the measurements Students can vary the properties of components All parameters may be modified, which cannot be done with the real system
Did you find virtual lab helpful in data analysis? Why? Which feature of virtual lab was useful?	Practical knowledge more important. Virtual lab is easy to use. Put numerical values in formula and you get the output. Feature - output - entire visualization of output. Get the output immediately so we can vary values again and again and find the output. Time is not wasted in drawing graph.	Facilitates recording measurements and plotting of data Students can perform more experiments and thus gather more information in the same amount of time it would take to do the physical experiment
Did you find virtual lab helpful in problem solving? Why? Which feature of	Calculate the values. Various parameters could be	Detailed help can be invoked by choosing either the Demo or

virtual lab was useful?	varied. Help given in the form of what to do next step. Questions are asked as we proceed so it helps. Hints were given if error. Online help provided.	Problem Assistance selection Provide the guidelines for selection of parameters and the testing of the selected values. If students do not complete correctly, an explanation is provided in the form of a concise informative message.

Conclusion and Discussion

Through this study the answer to the following research question was obtained.

RQ2d: What is the impact of experiments designed using the experiment design guidelines for existing virtual laboratories on the students' laboratory learning outcomes?

In order to evaluate the students' learning Donald Kirkpatrick's Learning Evaluation was referred. Kirkpatrick's has defined 4 levels of evaluation:

- Reaction - what participants thought and felt about the training (satisfaction; "smile sheets")
- Learning - the resulting increase in knowledge and/or skills, and change in attitudes. This evaluation occurs during the training in the form of either a knowledge demonstration or test.

- Behavior - transfer of knowledge, skills, and/or attitudes from classroom to the job (change in job behavior due to training program). This evaluation occurs 3–6 months post training while the trainee is performing the job. Evaluation usually occurs through observation.
- Results - the final results that occurred because of attendance and participation in a training program (can be monetary, performance-based, etc.)

The learning of students on was measured for the two dimensions – Reaction and Learning. On both these dimensions the virtual laboratory experiment designed as per the guidelines receive a higher score than the experiment design with traditional methods.

So it can be inferred that if the guidelines are properly implemented and the experiments are designed using the virtual laboratory experiment design guidelines developed with scientific methodology the students' laboratory learning outcomes can be improved. Thus the experiments designed using the Experiment design guidelines have a positive influence on the students' laboratory learning outcomes.

Limitations

The study was conducted in authentic settings but the sample size was very small. The triangulation methods have therefore been used to ensure the reliability of the results obtained. The researcher along with a faculty member conducted the study and hence the experiment design was validated for internal and external factors. In order to establish the results with more confidence many more such studies need to be conducted by other faculties from the Electronics domain and other engineering domains implementing the experiments after careful design incorporating the guidelines and taking into account other confounding variables.

6.5 Study 9: Effectiveness of the Experiment Design Guidelines with Respect to Students' Learning Outcomes in Virtual Laboratory (Control Group Experimental Group CG –EG Study Carried Out by Subject Matter Expert)

In this section the details of the experiment carried out with 142 UG engineering students for the course Analog Electronics is discussed. The students used Virtual lab software 'Do-circuits' and the online guidelines were used to design experiments for the same. The guidelines provided by the online SDVIcE tool helped in designing two experiments for the course - one experiment on the topic of Zener Diode as Voltage Regulator and the other on BJT Common Emitter Amplifier. Both these experiments were designed with learning objectives targeting the circuit analysis and design skills.

The guidelines in the SDVIcE tool helped in designing the tasks to be assigned to the students and also the assessment questions aligned to the learning objectives. The Virtual lab software selected for the purpose of the experiment has all the necessary features required for the performance of the two experiments. After the design of the experiments all the 142 UG engineering students performed these experiments using the Virtual lab software during the allocated times of the regular laboratory sessions in the semester July to November 2017. In order to find out the perceptions of the students regarding the usefulness of the Virtual lab software in the development of analysis and design skills an online survey was designed by the instructors who taught the laboratory course along with the educational technology expert. At the end of the semester the online survey was administered to the entire batch of students. All the 142 students responded to the survey questionnaire.

1. Implementation

The first step in the implementation process was the design of experiments targeting the circuit design and analysis skills. In order to design the two experiments the guidelines provided in the online SDVIcE tool were used. The tool provides a step-by-step approach for the experiment design. The different steps carried out were formulation of learning objectives targeting circuit design and analysis skills and then designing tasks and assessment questions aligned to the learning objectives.

2. Research method

Through this study answers to the following two research questions are obtained:

RQ1: What are the practical and pedagogical advantages of using Virtual lab along with the hardware setup for analog electronics experiments such as voltage regulator and common emitter amplifier?

RQ2: What are the perceptions of students regarding the use of software Virtual lab experiments compared to hardware experiments?

3. Sample

The sample consists of 142 Second year U.G. students from Electronics and Telecommunication engineering program of the self-financed autonomous engineering college affiliated to University of Mumbai, India. The researchers are the instructors conducting the entire laboratory and theory course of Analog Electronics I for the Electronics and Telecommunication program.

6 Procedure

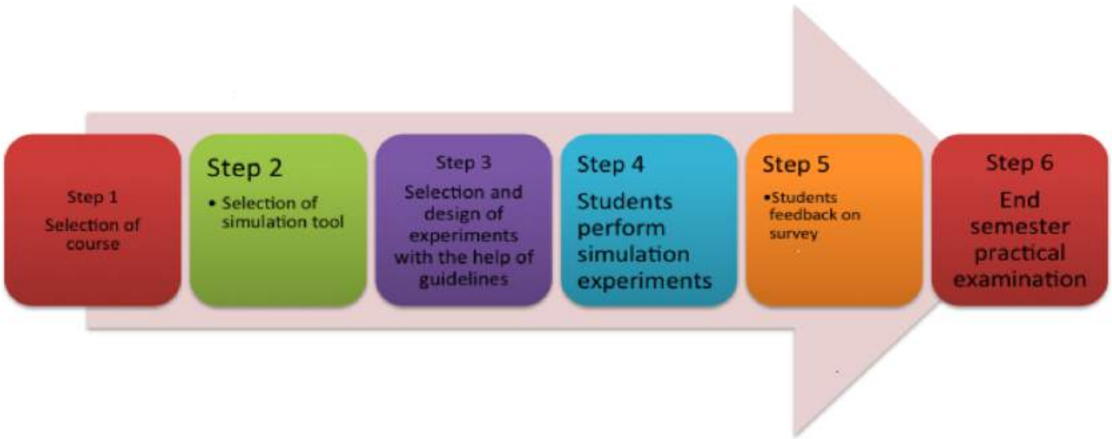


Figure 6.7 Step-wise procedure

The procedure carried out for the experiment is described in the figure 6.7. The following section describes each of the steps.

6.1 Selection of Course

Analog Electronics I is a core course for Electronics and Telecommunication engineering program. This course covers important concepts in electronics engineering and is prerequisite for higher semester courses. The course demands clarity of concepts so that one can design and analyse electronic circuit. Instructors reinforce the concepts taught in the theory class with experiments in laboratory session. Literature reveals [4] that simulation helps to improve the skills for design and analysis of electronic circuits.

6.2 Selection of Virtual Laboratory

There are various tools available for electronic circuit simulation. Due to the user friendly nature and different features provided by the 'Do-circuits' online open source Virtual lab software; a decision was made to use it for the purpose of this experiment. 'Do-circuits' is currently used in several universities for both undergraduate and graduate courses. Using 'Do-circuits' one can build, analyze and share Electronic and Electrical Circuits on the Web also. 'Do-circuits' has its own Web forum, which provides support to students and researchers all around the world, thus resulting in an almost unique example of simulation tool over the Internet.

6.3 Selection of Experiment

During July-November 2017 term 142-second year UG engineering students performed two experiments using virtual lab simulation software. These experiments cover core concepts in analog electronics course and hence these were selected for the simulation experiments. The following were the learning objectives for the two Virtual lab experiments.

1) To analyze and design voltage regulator circuit using Zener diode.
Learning Objective: Student should be able to analyze and design voltage regulator circuit using Zener diode
2) To analyze BJT amplifier for small signal application
Learning Objective: Student should be able to analyze BJT amplifier in Common Emitter configuration

6.4 Research Design

The research design used was control group experimental group with performance of students in the end semester laboratory examination and post-test as a measure of intervention followed by survey questionnaire and interviews.

6.4.1 End Semester Laboratory Examination

Students appeared for the end semester practical examination based on entire curriculum for their courses. The scores obtained by students in the end semester practical examination and post-test is considered as the dependent variable for the study.

6.4.2 Students Feedback

At the end of semester, survey questionnaire was administered through Google form. The students were given two-week duration for completion of the survey. They completed the survey individually without any bias of peer or faculty.

6.4.3 Instruments Used and Data Gathered

The instruments used for the study are: End semester laboratory examination papers, posttest paper, Survey questionnaire and Interview questions.

Table 6.13. Structure of survey

	Section Title	Number of questions	Type of question	
			Four point Likert Scale	Open ended
1.	General Information	4	-	4
2.	Helpfulness of Virtual lab experiment in understanding	1	1	-
3.	Feature of Virtual lab	2	-	2
4.	Circuit Analysis	2	2	-
5.	Circuit Design	1	1	-

The following data was gathered for analysis at the completion of the study.

- Student responses to the four point likert scale questions
- Students' responses to open ended questions in the survey questionnaire and interview.

7 Variables for the Study

Independent variable: The intervention – Using Virtual lab: do-circuits for the two experiments.

Dependent variable: Scores of students in posttest

8 Data Analysis Techniques

The data analysis techniques used in the study is the comparison of means using t-test and ANOVA for the quantitative data and content analysis for the qualitative data.

8.1 Analysis of Quantitative Data

Analysis of student's scores in end semester practical examination and posttest
Analysis of student's response to Likert scale questions in the survey

8.2 Analysis of Qualitative Data

The response of the students to open ended question was carried out by content analysis method. All the answers were written verbose in a document. Then each response was given tags based on the content. The tags were then classified into different categories. These categories were related to the specific feature in the Virtual lab, which the students found useful in conceptual understanding and helped them in circuit design and analysis.

9 Results

Results of quantitative analysis of the survey questionnaire are tabulated in tables I to VII.

Independent samples t-test was carried out on the scores of students in the end semester practical examination. The following table gives the results of the analysis.

Table 6.14: Results of end semeste examination scores

T	Std. dev.	Δf	Sig.t tailed	Effect size
4.59	1.71	307	< .00001.	0.68

The t-value is 4.58713. The p-value is < .00001. The result is significant at p < .05. There is a statistically significant difference between the two group scores.

The questions were designed considering the aspects shown in table I. Table II shows that most of the students agree that, the simulation helped them to design and analyse BJT amplifier and voltage regulator. Table III shows that, more than 90% of the students are able to identify the type of regulation correctly from the given graph. As per table IV nearly 47% of the students scored more than 75% of the marks in post-test. Features of Virtual lab software, which students felt useful are shown in Table V and VI. About 97 % of the students confirmed that Virtual lab experiments helped them in conceptual understanding.

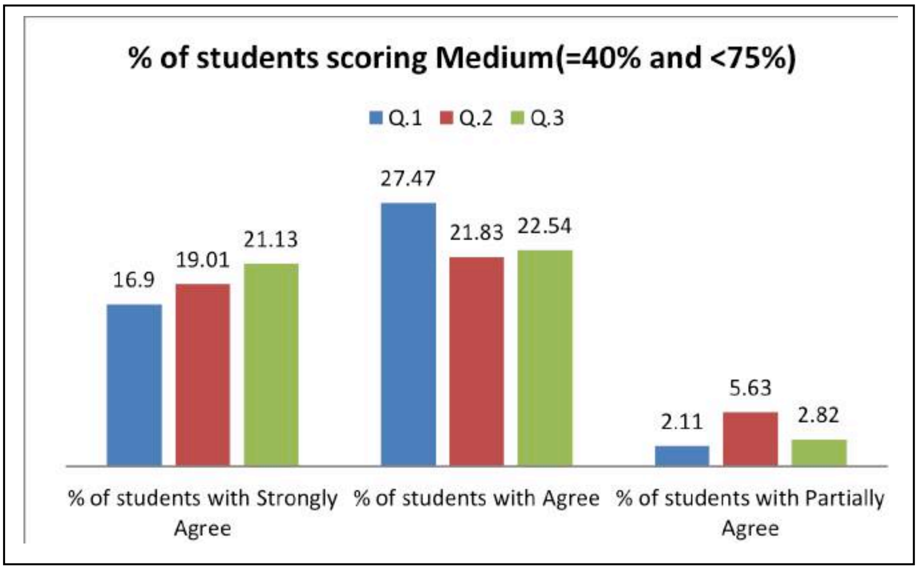
Question 1: After successful completion of Virtual lab experiments, you are able to analyze voltage regulator using Zener diode

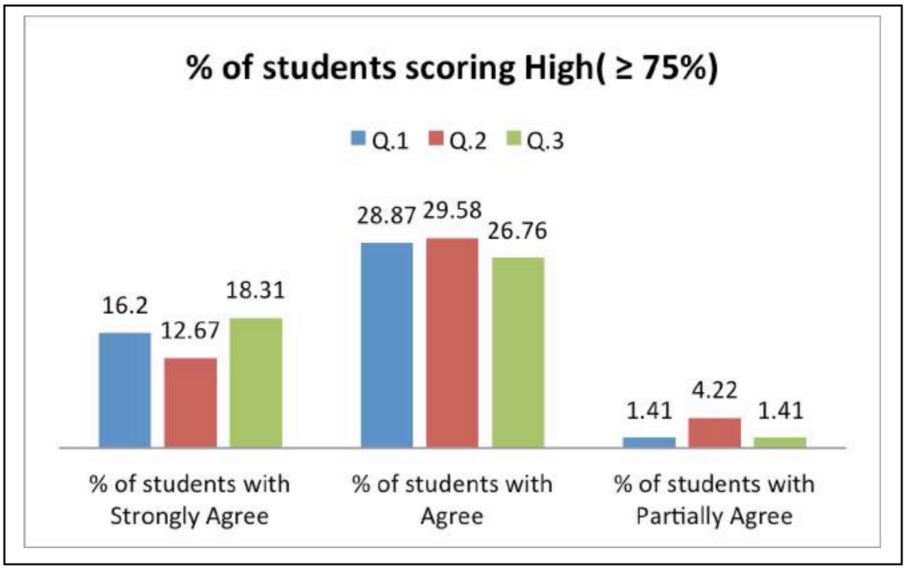
Question 2: After successful completion of Virtual lab experiments, you are able to design voltage regulator using Zener diode for particular application

Question 3: After successful completion of Virtual lab experiments, you are able to analyze BJT amplifier for small signal application.

Table 6.15: Students' Response to Questions (Q.1, 2,3)

	of students)	of students)	of students)
Strongly Agree	34.5	33.1	41.5
Agree	62	57.04	53.57





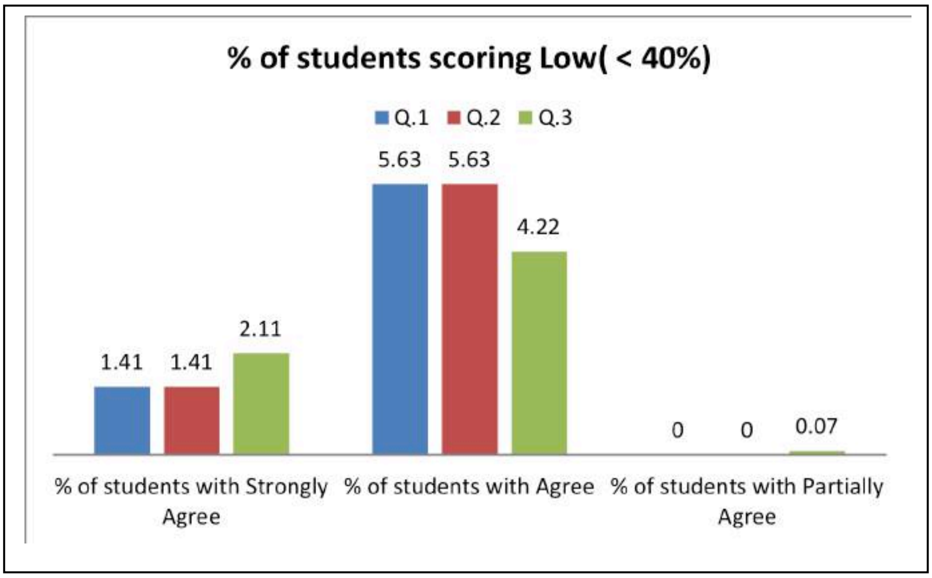


Figure 6.8 Analysis of students' responses

Question 4: From given graph, identify type of regulation.

Table 6.16: Students' Response to Question (Q.4)

Sr. No.	Feature Categories	% of students
1.	Load regulation (Correct answer)	90.14
2.	Line regulation (wrong answer)	9.86

Question 5: For the question no. 4, design the Zener diode regulator circuit. Simulate the designed circuit and obtain the regulation graph. Attach image of simulated circuit and the obtained graph.

Question 6: A. CE amplifier circuit given below. Obtain output voltage waveform. B. Simulate same circuit without bypass capacitor. Obtain output voltage waveform. C. Compare waveforms obtained in A and B.

Table 6.17: Students' Score for Question (Q.5,6)

Sr. No.	Students Score	students for Q.5	udents for Q.6
1.	5	42.25	61.97
2.	4	40.84	21.13
3.	3	2.82	4.23
4.	2	11.26	0
5.	1	2.82	9.86
6.	0	0	2.82

Q7: Which features of Virtual lab experiment helped you to analyze the voltage regulator and CE?

Table 6.18: Students' Responses to Question (Q.7)

Sr. No.	Feature	% of students
1.	Sweep	16.2
2.	Ease of construction/connection	11.27
3.	Precise output/error-free operation	15.49
4.	Ease of plotting the graph	45.77
5.	Auto variation of parameters	45.77
6.	Graph and analysis	3.52

Q8: Which features of Virtual lab experiment helped you to design the voltage regulator?

Table 6.19: Students' Responses to Question (Q.8)

	Feature	% of students
1.	Sweep	59.86
2.	Ease of use/construction/less confusion	9.86
3.	Faster completion	0.7
4.	Ease of plotting the graph	33.1
5.	Drag & drop feature/component window/easy interface	16.2
6.	Cost free	0.7
7.	Easy availability of components	2.82
8.	Ease of measurement	0.7
9.	Good analysis	2.11
10.	Simple to design	0.7
11.	No fear of damage or fault in device	2.11
12.	Easy to change parameters	7.75

Q9: Do you perceive that Virtual lab experiments (regulator & amplifier) helped you in conceptual understanding? If yes, how? If not, what changes will help you in the conceptual understanding?

Table 6.20: Student's Responses to Question (Q.9)

	Feature	% of students
1.	No	2.11
2.	More clarity in concept	1.41
3.	Yes	96.48

The performance of the experimental group students was better than the control group students. Further there was a statistically significant difference in the scores of the two groups of students. So it could be assumed that the experimental group students were weaker than the control. Moreover the simulation was also used during the lectures, which made the concepts very clear as per the interviewed students. The actual working of the circuit when certain parameters are changed was more visual and interesting for understanding the concepts. In order to get a deeper understanding of the perceptions of students regarding the usefulness of the simulation tool in the circuit design and analysis skill interviews of 20 students in groups of two or three each were conducted. Interview data was analyzed using the content analysis method. The results of this analysis are in-line with the hypothesis of the study.

10 Discussion and Conclusion

Through this study answers to the following research questions are obtained

RQ1: What are the practical and pedagogical advantages of using Virtual lab along with the hardware setup for analog electronics experiments such as voltage regulator and common emitter amplifier?

The responses of students to the questions in the survey clearly indicate that more than 90% students agree that Virtual lab help them in improving the conceptual understanding. Sweep and graph plotting feature is more helpful for analysis whereas ease of measurement, drag & drop feature is helpful for design.

RQ2: What are the perceptions of students regarding the use of software Virtual lab experiments compared to hardware experiments?

Student perceived that they could perform experiment with no risk of component damage, errors in connection and saving of time. About 97 % of the students' agreed that Virtual lab experiments were more helpful for analysis and design compared to hardware experiment.

Limitations

All hardware experiments were not simulated. Only two experiments were simulated due to time constraint of two hours laboratory session.

Breakup of marks for students examined for these experiments could not be separated from available data of practical examination Marks.

For the better understanding of research results obtained pre-test would have been additional tool. A pre-post test study is planned in the next semester as a future work.

6.6 Study 10: Effectiveness of the Experiment Design Guidelines with Respect to Students' Learning Outcomes in Virtual Laboratory (Control Group Experimental Group CG –EG Study Carried Out by Subject Matter Expert) for the Course Mobile Communication

The research study is carried out with UG and PG students in the Electronics and Telecommunication domain for the course Mobile Communications. This is a compulsory course for the curriculum of a self-financed engineering institute affiliated to University of Mumbai, India.

Research Method

Through this study answers to the following three research questions are found out.

RQ1: Do the students at UG and PG level perceive that the performance of laboratory work using virtual labs helps in improving the conceptual understanding in the course on Mobile communication?

RQ2: What are the perceptions of students at UG and PG level about the features of virtual laboratories in Mobile communications course?

RQ3: Do the UG and PG Electronics engineering students perform better in the end semester examination (ESE) after performing experiments using the virtual labs in the Mobile Communication course?

Sample

150 students of Final year UG engineering and 18 students of PG engineering of a self-financed autonomous institute affiliated to Mumbai University, India. The sampling is convenience sampling as the researchers are the faculties conducting the Mobile communications course in their institute.

Procedure

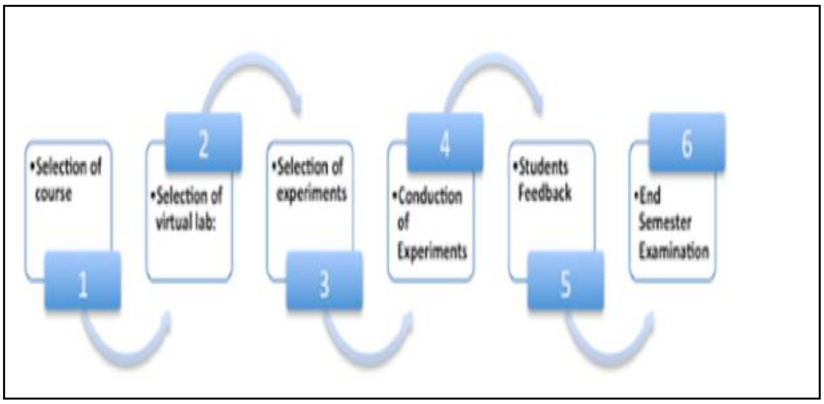


Fig 6.9 Procedure

Selection of Course

Mobile communication is a very important course for Electronics and Telecommunication engineering students. It is very important to carry out experimental work in the course as most of the concepts are abstract and students find it difficult to understand and imagine. The costs involved and availability of effective resources is always challenging. In the earlier years Matlab/ Scilab programs and presentations was the mode of conduction for mobile communication laboratory. It was observed that students struggle for concept clarity and it was reflected in their performance in ESE. It was felt that visualization of these concepts would be better mode of understanding. Use of virtual laboratory is the best choice for the same.

Selection of Virtual Lab

With reference to syllabus contents of Mobile Communication, VII semester (Electronics and Telecommunication Engineering (UG Group) and Mobile and Wireless communication of M. Tech. Semester II (PG Group) of Mumbai University two virtual labs were found relevant. The content of the Fading channel and mobile communication labs developed by IIT Kharagpur was more aligned to the prescribed curriculum than Virtual wireless lab developed by IIT Delhi. Hence three experiments from IIT Kharagpur lab were selected for this study.

Selection of Experiment

During July- November 2015 term UG Group performed total three experiments using virtual labs.

(i) To understand the cellular frequency reuse concept

Learning Objective: Mapping of the co-channel cells for a selected cell with choice of cluster size and finding the cell cluster for given cells.

(ii) To understand the concept of path loss in wireless communication

Learning Objective: Calculation of signal parameters as a function of various parameters e.g. received signal strength, carrier frequency, path loss exponent, height of antenna and distance between transmitter and receiver.

(iii) To understand the handoff mechanism

Learning Objective: To study the effect of handover threshold and margin on SNR, call drop and handoff.

The UG experimental group performed experiments 1, 2 and 3 during July – November 2015 semester whereas PG experimental group performed experiments 1 and 2 during January-May 2016 semester. In the previous year no experiment was based on above concepts and hence the learning objectives were not satisfied as per expectations. The students from the previous year i.e. academic year 2014-15 form the control group for this study. In order to find the equivalence between the control group and experimental group students, ANOVA of the UG student's scores in the semester 6 end examination before the intervention was carried out. The following table gives the results of the test. It was observed that there was a statistically significant difference between the scores of students from both the groups. The control group students performed better than the experimental group students in the semester-6-end examination. So it can be assumed that the experimental group students were weaker than the control group students. A similar test was performed for the PG students for the previous semester- end semester examination. For these students the difference in the scores was not statistically significant. So it can be assumed that the PG students from the two years, which form the control and experimental groups, were equivalent before the intervention.

Table 6.21: Results of t test- comparing end semester scores

Class	**T**	**Std. dev.**	**Mean**		**Sig.t-tailed**
			CG	**EG**	
UG	2.18	298	5.26	5.01	0.03
PG	1.28	34	3.65	3.45	0.21

Conduction of Experiments

The UG group of 150 students is subdivided in 8 batches of 18-20 students. Theoretical concepts are first introduced in theory class. The instructor explains the objective, the theory concept and procedure to be carried out in the lab. Students perform the experiment as per the procedure and submit the report. The report is graded by instructor based on rubrics that focus on interpretation of results and report submission. The PG group is of 18 students in single batch. Similar procedure is carried out for this group also.

After going through experiments available online a decision on using the Virtual Labs for the Mobile Communications available at the URL – http://203.110.240.139/ was taken as this lab had the features suitable for achieving the target learning objectives. A few important features are discussed in this section.

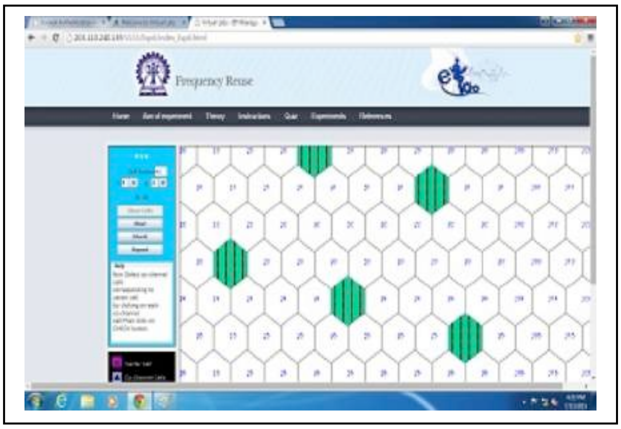


Figure 6.10 Screen display of Frequency reuse (experiment 1)

Fig.2. Illustrates simulation of experiment on Frequency reuse carried out by students. In these experiment values of cluster size N and cell radius are variable. Change in N affects location of co-channel cells. Thus the students can visualize the concept of how frequency can be reused in the cellular communications.

Figure 6.11 Screen display of finding cluster (experiment 1)

Fig3. Illustrates how a cluster can be located within a geographical area. The students selected the cell radius and N. The number of cells per cluster changed as per the selection cluster size.

REPORT				
1A: Calculation of Received Power	1B: Calculation of Pathloss Exponent	1C: Calculation of Carrier Frequency	1D: Calculation of Receiver Antenna Height	1E: Calculation of BS Antenna Height
Pr(d0): -14.44 dBm	Pr(d0): -23.53 dBm	n: 4.4	fc: 2.5 Ghz	fc: 2.9 Ghz
Dist: 616.0 m	TxPow: 50.0 dBm	TxPow: 40.0 dBm	TxPow: 40.0 dBm	TxPow: 40.0 dBm
d0: 83.0m	Dist: 616.0 m	hTx: 48.0 m	hTx: 38.0 m	n: 3.48
	Pr(d): -55.15 dBm	Dist: 616.0 m	Dist: 616.0 m	Dist: 616.0 m
	d0:71.0m	Pr(d): -52.3 dBm	Pr(d): -30.73 dBm	Pr(d): -32.5 dBm
		hRx: 7.0 m	n: 3.57	hRx: 7.0 m
Pr(Entered):-31.85 dBm	n(Entered):3.37	fc(Entered):2.22 GHz	hRx(Entered):6.67 m	hTx(Entered):27.22 m
Pr(Actual):-31.85 dBm	n(Actual):3.37	fc(Actual):2.3 GHz	hRx(Actual):7.92 m	hTx(Actual):29.32 m

Figure 6.12 Report generated for path loss (experiment 2)

Fig.4. illustrates the table, which shows the values of various parameters related to path loss in a wireless communication link. In this experiment students need to understand interdependence of path loss, path loss exponent, height of Base Station antenna, height of user terminal antenna and frequency of operation. Depending on input parameters, student calculates expected parameter value; compare the match between calculated values with actual value.

Fig.5. illustrates the table, which shows the values of various parameters related to handoff. In this experiment students need to vary input parameters such as carrier frequency, transmitted signal power, SNR etc. Students verified effect of change in these parameters on number of call drops and number of handoffs.

Input Parameters	
Reuse: 4 ,Model: Urban Micro	Pt(dBm): 41
fc(GHz): 2.5	Beam Width(deg): 70
Rotate(deg): 30	Cell Radius(m): 116
hT(m): 10	hM(m): 1.5
Sigma(dB): 4	Vertical Tilt(deg): 12
SNR(dB): 3	Band Width(MHz): 5
Noise Figure(dB): 7	Noise Power(dBm): -100.01
Pr0(dBm): -97.01	Time Slot(s): 200

Exp. Results								
SNR	No.Calldrops	No.Handoffs	Delta1	Delta2	Reading Time(ms)	Outage Time(ms)	% Outage	Alpha
5.0	0.0	13.0	3.0	3.0	200704.0	0.0	0.0	0.1
5.0	0.0	15.0	3.0	2.0	200704.0	0.0	0.0	0.1
3.0	0.0	15.0	3.0	2.0	200704.0	0.0	0.0	0.1
3.0	0.0	12.0	3.0	4.0	200704.0	0.0	0.0	0.1

Figure 6.13 Report generated for handoff (experiment 3)

Students Feedback

At the end of semester, survey questionnaire was administered through Google form. The students were given two-week duration for completion of the survey. They completed the survey individually without any bias of peer or faculty.

End Semester Examination

At the end of the semester all the students need to appear for the theory examination based on the entire curriculum for all the courses. The scores in questions related to the concepts covered in the three experiments obtained by students in the Mobile Communication course is considered as one of the dependent variable for this study.

Instruments Used

The instruments used for the study are

A. Survey questionnaire

B. The end semester examination test paper

Survey Questionnaire

After defining the research questions, scope, target audience and methodology, the survey instrument was developed in the form of a paper-based questionnaire for maximum flexibility. This was then converted to online Google form. The design process was conducted by the engineering faculties and guided and facilitated through the involvement of an educational technology expert. The questionnaire was reviewed, validated and revised before external release. Table II gives the structure of the survey questionnaire given to UG students and Table III gives the structure of the survey questionnaire given to PG students. There was a slight difference in the two as the tasks performed by UG and PG are different. These tasks are as per the corresponding curriculum for UG and PG.

Table 6.22: Survey structure and length- UG

Sr. No	**Section Title**	**Number of questions**	**Type of question**	
			Four point Likert Scale	**Open-ended**
1	General information	4	-	4
2	Helpfulness of Virtual lab in improving understanding	2	1	1

3	Attractiveness	3	2	1
4	Data analysis	1	1	-
5	Virtual lab feature	2	1	1

Table 6.23: Survey structure and length – PG

S.N	**Parameter under study for virtual lab**	**% of students agree**	**% of students partially agree**	**% of students Disagree**
1	Helpful in understanding concepts	**90**	10	0
2	Enjoyment in performance compared to traditional method	**92**	8	0
3	Ability to measure and analyse data	83	17	0
4	Usefulness of theory provided with experiment	84	16	0
5	Quality of simulation	86	14	0

End Semester Examination Test Paper

This instrument was designed by the subject experts, validated and reviewed before giving to the students. The question paper covered the complete curriculum for the Mobile communication course and 30 percent questions were targeting the conceptual understanding of the topics cellular frequency reuse, path loss in mobile communications and hand off mechanisms for both UG and PG.

Data Gathered

The following data was gathered from both UG and PG groups for analysis at the completion of the study.

The marks obtained by students of Group CG – Control Group in the end semester examination

The marks obtained by the students of Group EG – Experimental Group in the end semester examination

Student responses to the four point likert scale questions

Student's responses to open ended question

Variables for the Study

Independent variable – The intervention – Using virtual labs for three experiments

Dependent variables – Scores of students in end semester examination in questions based on these concepts

Data Analysis Techniques

The data analysis techniques used in the study are comparison of means using t-test and ANOVA for the quantitative data and content analysis for the qualitative data.

Analysis of Quantitative Data

1. Comparison of means of students scores in the end semester examination of the control and experimental groups at UG and PG level by t-test
2. ANOVA for the scores obtained in end semester examination for UG and PG groups
3. Analysis of student's response to likert scale questions in the exit survey

Analysis of Qualitative Data

The response of the students to open ended question was carried out by content analysis method. All the answers were written verbose in a document. Then each response was given tags based on the content. The tags were then classified into different categories. These categories were related to the specific feature in the virtual lab, which the students found useful in conceptual understanding and helped in the end semester theory examination.

Results

Results of Quantitative Analysis of Data

The following Table IV illustrates the scores and t-test results of the scores of CG and EG in the end semester examination for Mobile communication course.

Table 6.24: Results of t test-UG and PG

Class	**T**	**Std. dev.**	**Δf**	**Sig.t-tailed**	**Effect size**
UG	7.09	11.7	300	< 0.0001	0.52
PG	2.31	9.51	34	0.027	0.61

The primary interest was in scores of students as measured by the questions related to the concepts in the end semester examination. The table shows that there is a significant difference in the scores of students with experimental group students having higher score than the control group. This difference in the scores is statistically significant. The effect sizes are also greater than 0.5, which are considered a good effect size.

The following table V illustrates the results of ANOVA for the scores of students in the theory examination for the UG students. It is observed that there is a variation in the scores of the control group and experimental group students and this variation is statistically significant.

Table 6.25: Results of ANOVA – UG

ANOVA – UG – N (EG) =146, N (CG) =159						
	T	Df	Sig. (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
VAR00025	56.552	155	0.000	52.487	50.65	54.32
VAR00026	63.604	145	0.000	62.021	60.09	63.95

Table 6.26: Results of PG

ANOVA – PG – N=18						
	T	**df**	**Sig. (2-tailed)**	**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	**Upper**
VAR00002	16.193	18	0.000	59.684	51.94	67.43
VAR00003	13.628	18	0.000	52.737	44.61	60.87

The above table VI illustrates the results of ANOVA for the scores of students in the theory examination for the PG students. It is observed that there is a variation in the scores of the control group and experimental group students and this variation is statistically significant. The experimental group students have performed better than the control group students at both UG and PG level. In the semester-6-end examination the control group students had performed better but after the intervention the experimental group students have performed better. So it can be said that the intervention of using the virtual labs for the course on Mobile communication has been useful and effective. The control and experimental group PG students were equivalent in their Semester-1-end examination but after the intervention experimental group students performed better than control group. So the intervention has helped PG students also in scoring better than control group.

Analysis of student's response to likert scale questions in the exit survey for UG group (146 responses)

Table VI gives the results of the exit survey carried out with UG students. As it can be seen for all the parameters more than 80 percent of the students agree that they perceived carrying out experiments with virtual laboratories are better than the traditional laboratory lab work. More than 90 percent of UG students perceive that the virtual laboratories helped them in understanding core concepts related to the topics of the experiments and also they enjoyed performing experiments in these laboratories.

The results for the PG students are also very similar to the UG students. Table VIII illustrates the perceptions of PG students on the conceptual understanding of the topics of cochannel mapping, cluster formation and fading channels. It is observed that more than 90 percent of the students perceive that virtual laboratories helped them in understanding these core concepts.

Table 6.27: Analysis of student's response to likert scale questions in the exit survey for PG group (18 responses)

S.N	**Parameter under study for virtual lab**	**% of students agree**	**% of students partially agree**	**% of students Disagree**
1	Concept clarity of co channel mapping and cluster formation.	94	6	0
2	Concept clarity of fading channels	89	11	0

Results of Qualitative Analysis of Data

The following categories came up after the careful content analysis.

Table 6.28: Content analysis of data

Sr. No.	**Virtual lab feature categories**	**No. of students**
1	Multiple representations	7
2	Ease of operation	6
3	Visualization	8

4	Simulation	14
5	Interactivity	6
6	Background theory related to experiment	2
7	Demo videos	4

From the Table IX it can be inferred that if improvement in the students' conceptual understanding is desired by using the virtual laboratories then these laboratories should have specific features as listed above. These features contribute to the effectiveness of the lab work and hence attainment of the desired goals.

In order to get a deeper understanding of the perceptions of students regarding the effectiveness of virtual labs interviews of 20 students in groups of 4 each were conducted. The interview data was analyzed using the content analysis method. The results of this analysis are in-line with the hypothesis of the study.

They perceive that performing experiments using software such as Matlab is time consuming. The focus shifts from understanding the concepts to writing the code and getting the output. The virtual labs are more effective in making them understand the abstract concepts such as frequency reuse, signal strength etc. The visualizations given in the virtual labs are simple to understand and help in concept clearing. Some students pointed out that these visualizations helped them to recall the concepts when they gave the end semester theory examination. Students also mentioned that the virtual labs are easy to use and the equations given are helpful. One just needs to substitute the values and observe the results. Some students found the demo video given very useful in understanding the procedure to be followed while performing the experiment. So they could do it even without the help of the instructor whereas in case of experiment using physical equipment or software they get stuck many times and hence need instructor's help. Sometimes they are not able to complete the experiment in the stipulated time due to this problem.

The following are some of the remarks given by the students:

1. " I could perform the experiments over and over again. This helped me understand the concept of frequency reuse."

2. " I found the visualizations very useful as I could link what was taught in theory class and the practical aspect of path loss and signal fading."

3. " I was not able to complete experiment using Matlab as I am not very comfortable writing the code. In virtual labs we are not required to write the code so we can focus on the concepts and working rather on getting the output from the correct code."

4. "We should have such labs in other courses and the experiment should have more challenging tasks."

Overall students perceive that virtual labs are helpful in understanding of core concepts especially, in courses such as Mobile communication in which most of the things have to be imagined. Virtual labs are easy to use, students can perform experiments on their own and as the labs are available over the Internet they can complete the work assigned without any external help. They feel such labs should be given for other courses also and for more experiments. Students pointed out that some more challenging tasks might be given.

Conclusion and Discussion

Through this study answers to the following research questions were obtained

RQ1: Do the students at UG and PG level perceive that the performance of laboratory work using virtual labs helps in improving the conceptual understanding in the course on Mobile communication?

The responses of students in the questions in the exit survey clearly indicate that more than 90% students agree that virtual labs help them in improving the conceptual understanding. They also enjoy the experimentation with virtual labs. More than 80% students agree that the theory provided with experiment was useful to them.

Thus it can be inferred that the virtual labs help in improving the conceptual understanding in the course on Mobile communication.

RQ2: What are the perceptions of students at UG and PG level about the features of virtual laboratories in Mobile communications course?

The responses of UG and PG level students to the open ended questions indicate some of the specific features, which they found useful in the conceptual understanding. These are – Multiple representations, visualizations, interactivity, and ease of operation, Simulations, Background theory and Demo Videos.

Thus it can be concluded that for the virtual laboratory to be effective in learning process it should have these features. Also that the students should be made to explore all these features while they perform experiments in virtual labs.

RQ3: Do the UG and PG Electronics engineering students perform better in the end semester examination after performing experiments using the virtual labs in the Mobile Communication course?

The scores of students in the end semester examination of the experimental group compared to the control group clearly indicate an improvement in the performance. It can thereby be said that performing experiments using virtual labs helped students in understanding the core concepts related to the topics covered and hence they scored better at UG and PG level.

Thus it can be inferred from the findings that the intervention of using virtual labs for Mobile Communication course has worked for the experimental group of students.

6.7 Conclusions and Discussion

The summative evaluation of the virtual laboratory experiment design guidelines was carried out for the three metrics of Usability, Usefulness and Effectiveness. The Usability was measured after the survey study with 58 engineering instructors and the results indicate that the guidelines are found to be usable by them. The Usefulness was measured through a survey study with 58 engineering instructors and the results of the study point out that they find the guidelines useful in designing effective experiments for using virtual laboratories. The Effectiveness was measured on two dimensions. The first dimension was the assessment of experiments designed by 10 engineering instructors before and after using the guidelines. Each instructor designed four experiments and a rubric was used to assess the quality of the designs. The results of field-testing indicate that the quality of the experiment designs improved after using the VLEDG. The second dimension of Effectiveness was the measurement of laboratory learning outcomes of students. This was carried out by three quasi-experimental studies. The EDR carried out the first study and the later two by SMEs. The results of all the three studies indicate that the experiment designs created by using the VLEDG improved the laboratory learning outcomes of the students. Thus these five studies establish that the VLEDG are usable, useful and effective. So it can be claimed that the objective of this research has been achieved.

The next chapter 7 discusses the overview of the problem and the proposed solution, discussion on the research questions and how generalizability can be established.

Chapter 7

Results and Discussions

In the initial part of this chapter the results of the research are discussed giving the answers to the research questions. In the next part the discussion regarding how the results can be generalized is presented and in the final part the limitations of the research work are discussed.

7.1 Overview of the Problem and Proposed Solution

The engineering students are finding the current laboratory work mundane and not challenging enough. The learning outcomes are mostly at the lower cognitive levels due to the ineffective learning designs and constraints of resources in the physical laboratories. The virtual laboratories have been proven to be effective in achieving higher level learning objectives. The engineering instructors perceive that the virtual laboratories are useful and suitable for achieving the learning outcomes. At the same time they also perceive that many of the problems faced by them in physical laboratories may be resolved by using the virtual laboratories. If the engineering instructors design student-centered and effective experiments the virtual laboratories can be used to achieve learning outcomes at higher cognitive levels, practical skills and certain cognitive abilities. The engineering instructors recognize the need of comprehensive guidelines so as to be able to design quality experiments for virtual laboratories. In order to find out the type and nature of guidelines the instructors need in their design process four studies were carried out as part of the need and problem analysis phase of the research. The various aspects were identified and the specific objectives of the proposed solution were arrived at. The solution is in the form of the following ten sets of guidelines.

1. Set I - Selection of Broad Goal based on the type of topic content
2. Set II - Formulation of learning objectives at different cognitive levels as per Bloom's Revised taxonomy
3. Set III - Designing tasks at different difficulty levels for the four phases of the Expository Instructional Strategy
4. Set IV - Designing tasks incorporating active learning methods in the four phases of the Expository Instructional Strategy
5. Set V - Designing tasks for the Discovery/Guided Inquiry Instructional Strategy
6. Set VI - Designing tasks for the Well-Structured Problem Solving Instructional Strategy
7. Set VII - Designing tasks for the Real World Problem Solving Instructional Strategy
8. Set VIII - Designing authentic assessment for the metrics of Properties, Measurement metric, Method and Instrument used
9. Set IX - Using the features of virtual laboratories

The guidelines on Broad goals assist the instructors in making decision regarding the selection of Broad Goal depending on the type of content the instructor wishes to cover in the particular experiment. The guidelines for learning objectives help in formulating the learning objectives aligned to the Broad Goal. The guidelines also help in the decisions for designing tasks for each phase of the scientific experiment design process for the instructional strategies of Expository, Discovery, Well-Structured Problem-Solving and Problem-based. The guidelines specify how the instructors can design experiments at different difficulty levels by modifications in the tasks assigned to the students and asking assessment questions aligned to the tasks and learning objectives for each phase of the Expository Instructional Strategy. They also give help on how the active learning methods can be incorporated in the various phases of the Expository Instructional Strategy experiment design. The complete framework for the virtual laboratory assessment is one of the main features of these guidelines. The engineering instructors can design experiments at different difficulty levels and achieve learning objectives at higher cognitive levels that are difficult to achieve in physical laboratories by utilizing the important affordances of the virtual laboratories.

The use of these guidelines leads to effective experiment designs by engineering instructors for the course Basic and Advanced Electronics. The survey studies with engineering instructors establish the usability and usefulness of these guidelines. The effectiveness of the guidelines in improving the quality of the experiment designs is discussed in the summative evaluation Chapter 6. Similarly the effectiveness in terms of the impact of the experiment designs using the guidelines is established with the help of quasi-experimental studies carried out by the researcher and SMEs with UG engineering students.

7.2 Answering the Research Questions

The main objective of this research was to design and develop comprehensive guidelines for engineering instructors to help them in the virtual laboratory experiment design. The design and development was carried out in three phases. The first phase was the Need and Problem analysis, the second was the design and development using the S-D-I-V-E methodology and the final phase was the summative evaluation. The following figure illustrates the research questions answered in the Need and Problem analysis phase and the summative evaluation phase. The various design questions were answered in the design and development phase but no research question was considered in this phase.

7.2.1 Need and Problem Analysis Phase

The specific research question explored in this phase was

RQ1: What are the perceptions of engineering instructors regarding the guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics?

This RQ is answered by answering the following sub questions (i) RQ1a: What are the problems in the experiment designs used in the traditional laboratories? (ii) RQ1b: What are the perceptions of engineering instructors about the usefulness and effectiveness of virtual laboratories as compared to the traditional laboratories? (iii) RQ1c: How can the problems faced by engineering instructors in using virtual laboratories in their teaching be solved? (iv) RQ1d: What are the various aspects in the experiment design process using virtual laboratories for which engineering instructors need guidelines? These four sub questions were answered with the help of four studies – Study 1, Study 2, Study 3 and Study 4.

The Study 1 was Artifact analysis of 98 experiment designs used in UG engineering for the BAE course. The results of Study 1 gave insights into the problems in the experiment designs used in the current physical laboratories in the context of this research. These helped us in formulating the interview questions for the Study 3. The aspects of the experiment design, which need to be addressed in order to improve the overall quality of the experiment designs, were – broad goal of the experiment, formulating learning objectives at various cognitive levels, using different scientifically proven instructional strategies, designing tasks and assessment questions aligned to the strategies and learning objectives and using affordances of virtual laboratories to achieve the desired learning outcomes.

The Study 2 was a survey carried out to find out whether the engineering instructors perceive that virtual laboratories are useful and effective in solving the problems encountered in the physical laboratories. The results indicate that although 100 percent of the instructors perceive that virtual laboratories are useful and effective only 5 percent are using them in their regular teaching. The Study 1 and Study 2 led us to the objective of the next study 3 in which the problems faced by engineering instructors in using the virtual laboratories were identified.

The Study 3 was a semi-structured interview with 13 engineering instructors from Study 2 who were using virtual laboratories in their teaching. The results of Study 3 established the need of guidelines and also helped in identifying the various aspects of the experiment design for which these guidelines were perceived to be necessary by the engineering instructors. The sample size for the study 3 was 13 and hence the next study 4 with 95 engineering instructors was carried out. The study 4 was an online survey with six open-ended questions and nine Five Point Likert Scale Questions. The results of the Study 4 confirmed the nine aspects identified in Study 3 for which guidelines are necessary. The results of this Need and Problem Analysis phase formed the basis for the next phase of the research that is the design and development phase.

7.2.2 Summative Evaluation Phase

The specific research question explored in this phase was

RQ2: Are the refined guidelines for making effective use of virtual laboratories for the course Basic and Advanced Electronics usable, useful to engineering instructors and effective in improving the quality of experiment designs and students laboratory learning outcomes?

This RQ is answered by answering the following sub questions (i) RQ2a: What are the perceptions of engineering instructors regarding the usability of the experiment design guidelines? (ii) RQ2b: What are the perceptions of engineering instructors regarding the usefulness of the experiment design guidelines? (iii) RQ2c: What is the effectiveness of the experiment design guidelines in improving the quality of the design of experiments for using existing virtual labs? (iv) RQ2d: What is the impact of experiments designed using the experiment design guidelines for existing virtual laboratories on the students' learning?

The answer to the first sub question RQ2a was found out by carrying out a survey with 58 engineering instructors. The survey consisted of twenty questions with ten questions of five point likert scale format, seven of Yes/No type and three with open-ended responses. The analysis of the responses to the Yes/No type questions indicate that on an average 82 percent of the instructors went through all the sections of the guidelines. The feedback from the instructors on the Five point Likert Scale questions with SUS survey gave us the score of 75.3, which is considered above average. The analysis of the responses to open ended questions gave us insights into the sets of guidelines, which the instructors found to be most useful and most difficult. The limitations of the guidelines could also be identified. The instructors perceived that there should be more examples and also examples from domains other than Electronics and for more courses besides BAE. They also suggested the use of more visuals and videos in order to deliver the content. The suggestions by addition of information in the form of visuals were incorporated. The videos describing the nine sets of guidelines one video for each set were also added.

The second sub question RQ2b was also answered through an online survey administered to engineering instructors and 58 responses were received. The survey consisted of sixteen questions with ten questions of five point likert scale format, and four with open-ended responses. The analysis of the responses to the five point likert scale questions indicate that the instructors perceived that they would be able to design effective virtual laboratory experiments by using the experiment design guidelines. On an average 85 percent of the engineering instructors agreed that they found the guidelines useful in the design of the various aspects of the virtual laboratory experiment.

It was observed that the number of instructors who perceived that some of the sets to be difficult to understand reduced from 10 percent in the previous survey to 4 percent for designing tasks aligned to the learning objectives. Similarly for writing questions at analysis and higher cognitive levels the number of participants reduced from 5 percent to 2 percent. The percentage participants who found designing tasks aligned to the higher level learning objectives reduced from 8 percent to nil. This reduction in the percentage of participants finding difficulty can be attributed to the modifications made in the guidelines after the first survey such as addition of examples, illustrative visuals instead of text and narrative videos. The instructors suggested addition of more examples from other domains and this is one of the limitations of guidelines.

In order to answer the third sub question RQ2c a field-testing was conducted with ten engineering instructors with each designing four virtual laboratory experiments before and after using the guidelines. A rubric was used to evaluate the quality of the 40 experiment designs. The results of the evaluation indicate that 30 percent improved from low level to medium level, 30 percent improved from low level to high level and 20 percent improved from medium level to high level. Overall 90 percent of the experiment designs after using the guidelines were of medium and high quality and only 10 percent designs were at low level. This leads us to the claim that the guidelines developed through the S-D-I-V-E methodology and based on the LoTaAs framework are effective in improving the quality of the virtual laboratory experiment designs.

With the help of the answer to the final sub question RQ2d the effectiveness of the experiment design guidelines with respect to the impact on student's laboratory learning outcomes was found out. A quasi-experimental study was carried out with 39 UG engineering students. In this study five experiments were designed using the guidelines and administered them to the experimental group of students. The students from both the control group and experimental group gave a pre test and posttest based on the laboratory work carried out. They also gave a Learning Outcome test while performing the experiment. The five experiment designs incorporated all the developed guidelines for the Expository Instructional Strategy with experiment at higher difficulty level, Expository Instructional Strategy incorporating active learning methods, Well-Structured Problem Solving Instructional Strategy, Discovery Instructional Strategy and Problem-based Instructional Strategy. The scores of the two groups in the pre test and posttests for each of the five experiments were compared to find out the impact on the laboratory learning outcomes. The results of the comparison establish the positive influence on the students' laboratory learning outcomes. The follow up semi-structured interviews with a few students highlighted their perceptions regarding the benefits of the virtual laboratory experiments they carried out. The students' views about the features of virtual laboratories they found most useful while carrying out the experiments were also obtained.

The sample size in this study was small and the researcher herself carried out the study. In order to establish the results convincingly Subject Matter Experts replicated the study with larger sample sizes of 120 and 142 UG engineering students. In the first study the instructors implemented the guidelines for formulating learning objectives at higher cognitive levels and incorporating active learning methods in their experiment designs. The experiment design targeted the learning objectives at analyze and evaluate levels and practical skill. In the second study they targeted the learning objectives at create level and manipulative skill. The results of both the studies indicate an improvement in the laboratory learning outcomes of the students.

7.3 Generalizability

The main objective of this research was to design and develop guidelines for engineering instructors to enable them to design effective virtual laboratory experiments. The guidelines were developed within the scope of virtual laboratory settings for UG engineering instructors for the course BAE in the Electronics engineering domain. In this section the parameters across which these guidelines can be generalized were analysed. To establish generalizability of the guidelines the following parameters are considered

(i) Domain (ii) Settings (iii) Instructors. The generalizability can also be analyzed of the process or S-D-I-V-E methodology and the criteria for quality across various domains.

7.3.1 Generalizability of the Guidelines

(i) Domain: The effectiveness of the guidelines can be generalized across various domains. This can be established from the experiment designs carried out by instructors from the domains of Applied Physics, Bioscience and Biotechnology, Chemical Engineering, Computer Science Engineering, Civil Engineering, Mechanical Engineering and Microbiology. The various topics for which the engineering instructors from these domains designed virtual laboratory experiments for their course are given in the following Table. 44 experiment designs using the experiment design guidelines were analysed and evaluated based on the rubric for the quality. Of the 44 designs the quality of 28 experiments was found to be at high level, 16 was at Medium level and only 9 was at Low level. So it can be claimed that the guidelines are generizable across domains of science and engineering. The domains belonging to Arts, Commerce, Medicine etc. were not considered. The examples given for each aspect of the experiment design are domain specific but the experiment designs carried out by instructors from other domains clearly indicate that they were able to implement the guidelines. Hence it can be claimed that the guidelines are generalizable across science and engineering domains.

Table 7.1: Experiment designs from various science and engineering domains

Domain	**Course**	**Quality**
Biotechnology	Bioinformatics lab	Medium
Biotechnology	Biochemistry Virtual Lab	Medium
Chemical	Process Heat Transfer	Medium
Chemistry	Applied Chemistry Lab	Medium
Computer Science	Artificial Intelligence Searching Techniques and algorithms	Medium
Computer Science	Python Programming lab	Medium

Computer Science	Data Structures Lab	Medium
Electronics	DSP Processor and its Architecture	Medium
Electronics	Power Electronics Devices & Circuits Lab	Medium
Humanities	Language Lab	Medium
Electronics	Power Electronics Devices & Circuits Lab	Medium
Electronics	Fiber Optics Laboratory	Medium
Chemical	Fluid Flow Operations Lab	Medium
Computer Science	Computer Graphics	Medium
Microbiology	Microbiology	Medium
Biosciences	Biochemistry	High
Biotechnology	Analytical Biotechnology Lab	High
Chemical	Unit Operations Laboratory	High
Computer Science	Operating Systems	High
Computer Science	Bootstrap Lab	High
Computer Science	Data warehousing	High
Computer Science	Virtual Networking Lab	High
Computer Science	Analysis and Design of Algorithm Lab	High
Computer Science	Cyber Security	High
EE	Electric Machines design	High
EE	Switch Gear and Protection	High
Electronics	Microprocessor and Interfacing	High
Electronics	Robot Kinematics Lab	High
Electronics	System Simulation and Modeling	High

Electronics	Power Electronics	High
Mechanical	CAD	High
Computer Science	Digital Image Processing	High
Electronics	Microprocessor & Interfacing Laboratory	High
Electrical	Control Systems	High
Applied Physics	Physical Sciences	High
Biosciences	Microbiology	High
Biotechnology	Diagnostic immunology	Low
Chemical	Process Calculation (Stoichiometry) Lab	Low
Civil	Engineering Mechanics	Low
Computer Science	Design and Analysis Of Algorithm	Low
Computer Science	Business Intelligence	Low
Computer Science	PL/SQL lab	Low
Computer Science	Data Security Lab	Low
Mechanical	Welding Lab	Low

(ii) Settings: The experiment design guidelines have been designed in the specific context of virtual laboratory environment for the course BAE in the Electronics Engineering domain for nine aspects. These guidelines can be generalized for the traditional laboratory setting as well. The guidelines for the various Instructional Strategies can be implemented in physical laboratories provided the necessary resources are available at the institute. There may be problems in administering experiments that involve the repetition of certain tasks such as data gathering, plotting of results and analyzing graphs obtained due to resource constraints.

(iii) Instructors: The experiment design guidelines have been used by 261 engineering instructors with experience ranging from 1 year to 35 years. 40 experiment designs of ten instructors from Electronics domain were analysed during the field-testing and 44 instructors from other engineering domains during the external usage. The quality of the designs was majorly of medium or high level. The instructors were able to implement guidelines for all the aspects of the experiment design. There were a few experiments of quality at low level. This could be attributed to difficulty in implementation of instructional strategies other than Expository.

7.3.2 Generalizability of the Process or S-D-I-V-E Methodology

The S-D-I-V-E methodology for the design and development of the virtual laboratory experiment designs has been synthesized and implemented. This methodology can be used by anyone who wishes to design and develop guidelines for any setting, any domain and any purpose. Thus the S-D-I-V-E methodology is generalizable across domain, setting and purpose.

7.4 Limitations

In this section the limitations of the virtual laboratory experiment design guidelines with respect to the Design aspects, broad goals and learning objectives, instructional strategies and evaluation are discussed.

(i) Design aspects: The SLID Science laboratory Instructional Design Model has been used as the fundamental basis for arriving at the guidelines. The nine aspects of the scientific experiment design process were derived for the procedural approach. This model is derived from the ADDIE and the Dick and Carey models for instructional design. There may be other models, which might lead to other aspects in the experiment design for which guidelines may be developed. But in the context of this research these guidelines have proven to be effective and have a positive impact on students' laboratory learning outcomes.

(ii) Broad goals and learning objectives: The four dimensions for the Broad Goals of the laboratory learning have been considered. The guidelines have been developed only for the practical skills and considered only the cognitive abilities of Problem Solving and Inquiry. There are other Broad Goals such as those in the Affective and Psychomotor domains such as development of Ethics, Sensory awareness etc. for which the instructional strategies and tasks may be different from the ones proposed in the guidelines. The Revised Bloom's taxonomy has been considered while formulating the guidelines for the learning objectives. The other taxonomies such as SOLO etc. have not been considered. The guidelines for other Broad Goals and learning objectives for other taxonomies may be considered as future work.

(iii) Instructional Strategies: Only the four instructional strategies have been considered for developing the guidelines. There are other instructional strategies that might be implemented using the virtual laboratories such as Project-Based, pure Inquiry etc. The guidelines have been proposed for those strategies, which have been implemented in traditional laboratories and are backed by evidence from literature. The evidence regarding their effectiveness in terms of impact on students' laboratory learning outcomes could be gathered. The development of guidelines for other instructional strategies may be considered as future work.

(iv) Evaluation: The results of the field testing with ten instructors designing four experiments each have been used to establish the effectiveness of the guidelines in terms of the improvement in the quality of designs. Also the results of the three quasi-experimental studies in the Electronics Engineering domain with total 331 UG engineering students have been used to establish the effectiveness of the guidelines in terms of impact on the students' laboratory learning outcomes. Based on these results it could be claimed that the guidelines are effective in the improvement of students' laboratory learning outcomes. Many such studies with more number of instructors and more number of students from multiple domains should be carried out to emphasize the effectiveness of the guidelines.

Chapter 8

Thesis Contributions and Future Work

In this chapter the contributions of the research work are presented and the future research directions in this field is discussed.

8.1 Thesis Contributions

The contributions of this research are mainly in the context of engineering laboratory education.

(i) Guidelines for the nine aspects such that they are usable, useful and effective for virtual laboratory experiment designs.

The virtual laboratory experiment design guidelines for nine aspects were designed and developed. These guidelines will assist engineering instructors in improving the quality of the virtual laboratory experiments. This will lead to improvement in the laboratory learning outcomes.

Who can use the guidelines: The engineering instructors can use the guidelines for designing virtual laboratory experiments. These can also be used by developers of new virtual laboratory experiments as the guiding principles. These may be made a part of the experiment design. It can be used by other researchers who have similar research objectives in some other setting or other domain.

(i) Identification of criteria for assessment of quality of guidelines

The eight metrics were identified based on which the quality of guidelines can be decided. These metrics hold true not only for guidelines for designing experiments but for any set of guidelines. There exist many frameworks, guidelines and tools to help instructional designers in designing learning material for different settings and in different domains to help instructors of varied characteristics. The quality of each can be assessed based on these criteria.

Who can use the criteria: The criteria may be used by anyone who is developing guidelines for any purpose, any setting, any domain and possessing any characteristics. It can be used by other researchers who have similar research objectives in some other setting or other domain.

(ii) Synthesis of the S-D-I-V-E methodology for guidelines development

The S-D-I-V-E methodology for developing guidelines was synthesized. This methodology if followed systematically can take into consideration the quality criteria.

Who can use the methodology: This methodology may be used by anyone who is developing guidelines for any purpose, any setting, any domain and possessing any characteristics. It can be used by other researchers who have similar research objectives in some other setting or other domain.

(iii) Rubric for evaluation of quality of virtual lab experiment

The metrics that affect the quality of experiment designs were identified and the rubric for evaluating the quality of virtual laboratory experiment designs was developed.

Who can use the rubric: The rubric can be used by engineering instructors to self-assess the quality of their experiment designs. It may be used by curriculum developers as the standards for experiment designs and by developers of new virtual labs. The rubric may be used for evaluation of new virtual labs by the reviewers.

(iv) LoTaAs Framework for experiment design for virtual laboratories in engineering education

The virtual laboratory experiment design guidelines were developed with the LoTaAs framework as the basis for the development process. The framework gives the details of the nine aspects for which the guidelines are developed.

Who can use the framework: It can be used by engineering instructors as a starting point for their experiment design. It can be used by other researchers who have similar research objectives in some other setting or other domain.

(v) Virtual laboratory assessment framework

The various dimensions that form the part of authentic assessment especially in the context of laboratory teaching learning were identified. This provides an overview to the instructors and helps them in designing their assessments.

Who can use the framework: It can be used by engineering instructors, developers of new virtual laboratory experiments and any other researcher.

(vi) SDVIcE tool

In order to increase the accessibility of the guidelines were converted to online format as the SDVIcE tool. This tool is fully functional and hosted in the institute server accessible from anywhere anytime.

Who can use the tool: It can be used by engineering instructors, developers of new virtual laboratory experiments, developers of new tools for instructors and any other researcher.

(vii) Outreach contribution

As part of the research workshops for engineering instructors and students were conducted. The takeaways from the workshops can be used by other instructors who wish to carry out similar workshops. They can adopt the methodology and the survey designs. They can also use the data and results analysis techniques.

8.2 Future Work

One direction in which this research can be carried ahead in future is by addressing the limitations of this research. The other direction may be to carry the research for similar sets of problems in other settings or other domains.

(i) The limitations of this research pertain to design aspects, broad goals and learning objectives and instructional strategies. The future work may address these limitations and design guidelines based on various models, targeting broad goals and learning objectives not covered in this work. The guidelines may be developed for instructional strategies other than those covered in this work.

(ii) The developers of new virtual laboratory experiments can carry the research ahead by implementing these guidelines in the online experiment design. For example the virtual lab may be developed for one topic covering all the target goals, instructional strategies and assessments. Thus one topic may have multiple virtual laboratory experiments. The instructor then just need to select a particular experiment from the list based on the Broad Goal, learning objectives and instructional strategy.

(iii) Adding more examples from other domains may further enhance the functionality of the SDVIcE tool. The tool may be converted from SDVIcE to ADVIcE that is automatic design. Many of the steps in the experiment design may be automated by incorporating some aspect of AI in the tool. The tool may automatically suggest or prescribe certain goals, learning objectives, tasks and assessment questions based on the characteristics of the user.

(iv) The tool may be further modified as an online tutor that helps in the experiment design process with multiple scaffolds at various decisions points in the process.

(v) The tool may be further automated if template codes are made available for the developers of new virtual laboratories.

Appendix I. Details of SDVIcE tool

Converting the paper-based guidelines to online version was analogous to using technology for providing the support to faculties in their lab manual development process. Just like any other technology the objectives of developing the online version were:

1. Increasing the accessibility
2. Improving the attractiveness of the guidelines
3. Improving the efficiency
4. Providing an effective solution

1. Increasing the accessibility: The guidelines would be developed and hosted on a server and hence accessible to the participants anytime and anywhere just like the virtual laboratories. The only requirement was a Personal computer or laptop with an Internet connection.
2. Improving the attractiveness of the guidelines: An attractive user interface helps in retaining the interest of the user.
3. Improving the efficiency: Efficiency is defined as the "accomplishment of or ability to accomplish a job with a minimum expenditure of time and effort." (Dictionary.com 2006). Going by this definition the User Interface of the SDVIcE tool should help in increasing the efficiency of the experiment design process.
4. Providing an effective solution: Effectiveness refers to the completion of activities or tasks to attain desired goals. The SDVIcE tool should be able to achieve the goal of helping the engineering faculties in developing virtual laboratory experiment designs fulfilling the quality criteria.

The user interface of an e-learning platform has five specific functions.

1. Deliver content
2. Facilitate interactivity
3. Collect and process learner responses
4. Evaluate learning
5. Deliver feedback

1. Deliver content

This is the first and foremost function of the User interface. In order to facilitate the content delivery the interface must be uncluttered and allow the user to perform the various tasks and go through the instructional material.

2. Facilitate interactivity

One of the key features of an e-learning platform is the way it requires the learner to interact with the content. The learner is able to interact with the instructional material through user-controllable UI components such as buttons, icons, text boxes, and graphics.

3. Collect and process learner responses

An E-Learning application can be designed to elicit responses or to collect information from the learner. The UI may be designed to present a list from which the user will select from among several options or it may require the user to input text in answer to an assessment question. A well-designed UI will present the learner with clear instructions and unambiguous choices so as to minimize input errors.

4. Evaluate learning
5. Deliver feedback

In case of the SDVIcE Tool these last two functions are not provided by the UI. The UI allows the users to generate their final developed dynamic manuals in the form of a pdf file. This can be given to the students taking the particular experiment or may be mailed for the evaluation of the effect of using the SDVIcE tool. The experts assess the manuals as per the quality rubrics and send feedback.

Characteristics of the SDVIcE online Tool

The SDVIcE tool consists of three sections namely Introduction, Experiment design for BAE course, and Experiment design for other courses.

1. Introduction

This section takes the user through various concepts in the scientific design of virtual laboratory experiments. The figure—illustrates the landing page of the SDVIcE tool.

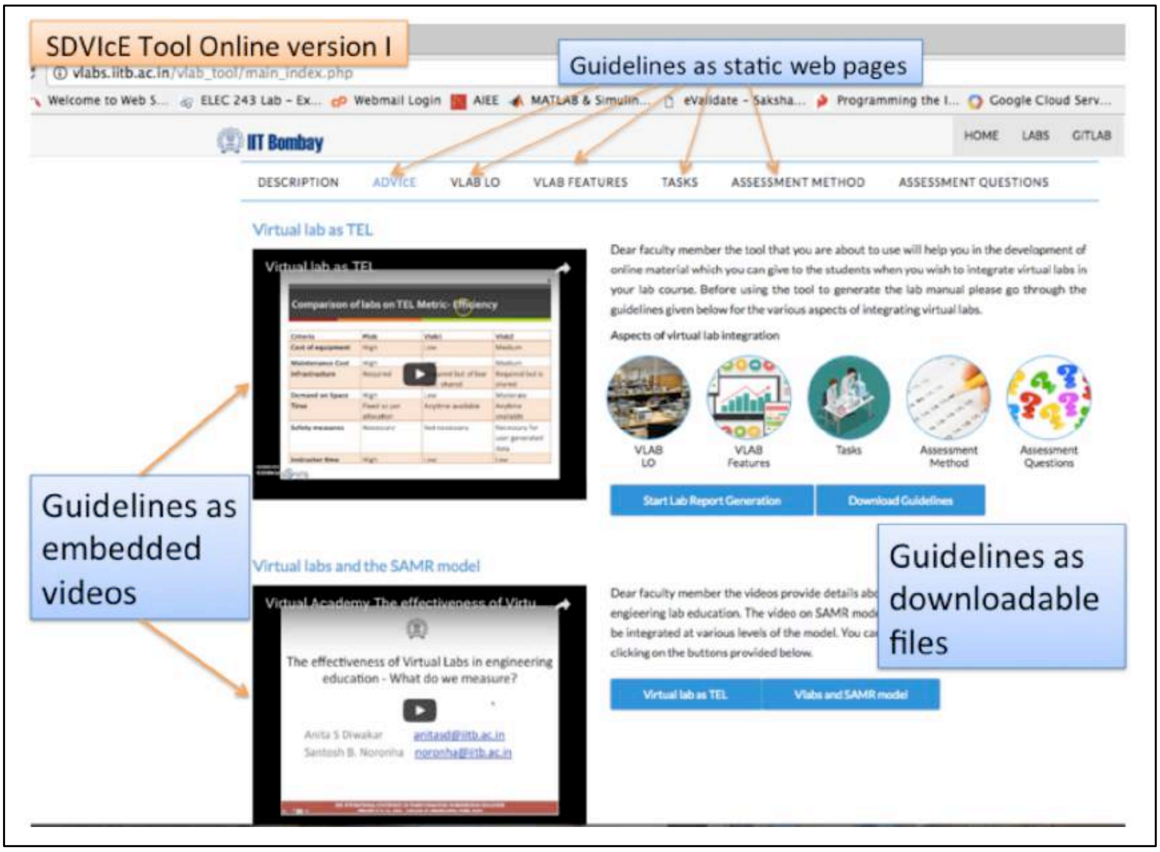


Figure I.1 Landing page of SDVIcE tool

The following concepts are covered

(i) Broad Goal of the experiment
(ii) Learning objectives of experiment
(iii) Instructional strategies
(iv) Virtual Laboratory Tasks
(v) Virtual Laboratory features
(vi) Steps in the experiment design using Expository Instructional strategy
(vii) Steps in the experiment design using Discovery Instructional strategy
(viii) Steps in the experiment design for Well-Structured Problem Solving Instructional strategy
(ix) Steps in the experiment design using Problem-Based Instructional strategy

These concepts are covered as static web pages one page per concept and also one video describing each concept. The user can browse through these pages and understand the basic concepts before starting the actual experiment design. Those who have a prior knowledge about these concepts can directly go to the experiment design. The instructors also suggested that there was more text so we added videos with visuals for each aspect of the experiment design so as to help instructors who found reading the text difficult.

2. Experiment design for BAE course

The second section of the SDVIcE tool takes the user through the various steps in the experiment design with specific examples from the BAE course. The following figure illustrates the step-wise process and the help provided to the user at each step.

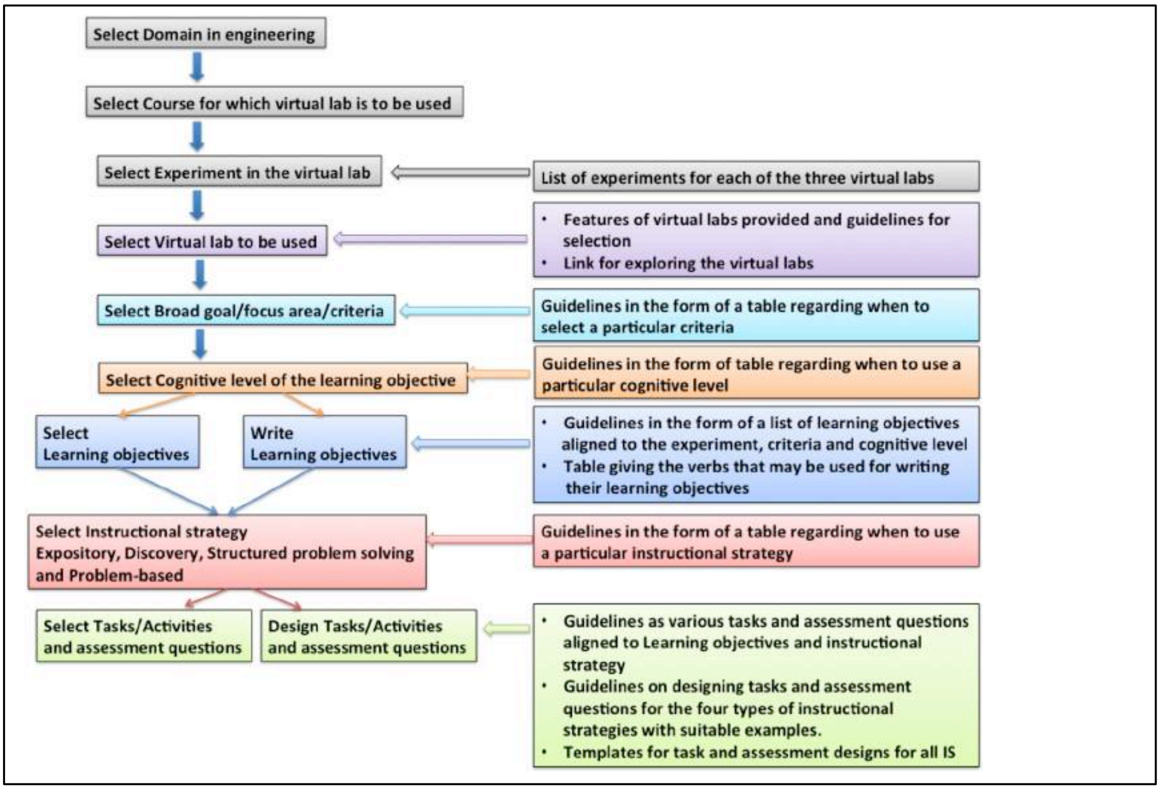


Figure I.2 Step-by-step BAE virtual laboratory experiment design process

The user can select the content provided at each step such as Broad Goals, learning objectives for a particular topic. If the user wishes to design the content for the various steps or aspects in the experiment design a text box is provided in which they can type their content for each step. The figures illustrate the screen shots of the SDVIcE tool for each step of the experiment design. After the user has completed all the steps and the experiment design is finalized they can click on the submit button and a pdf document is generated. This is the final experiment design that can be given to the students. The students can perform the experiment as per the design and submit their solution online to the instructor.

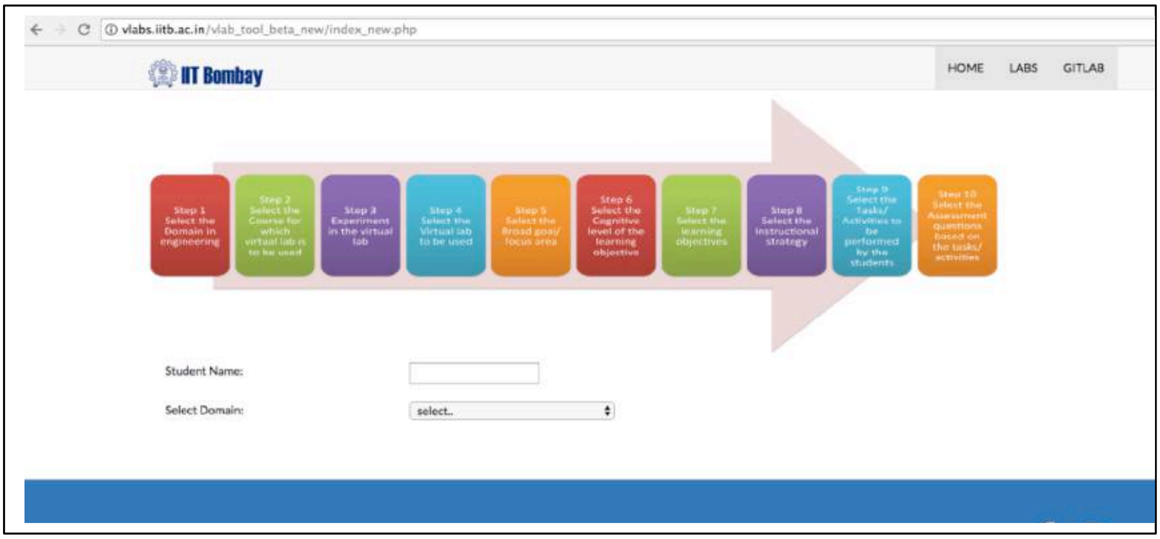


Figure I.3 Step-wise experiment design process

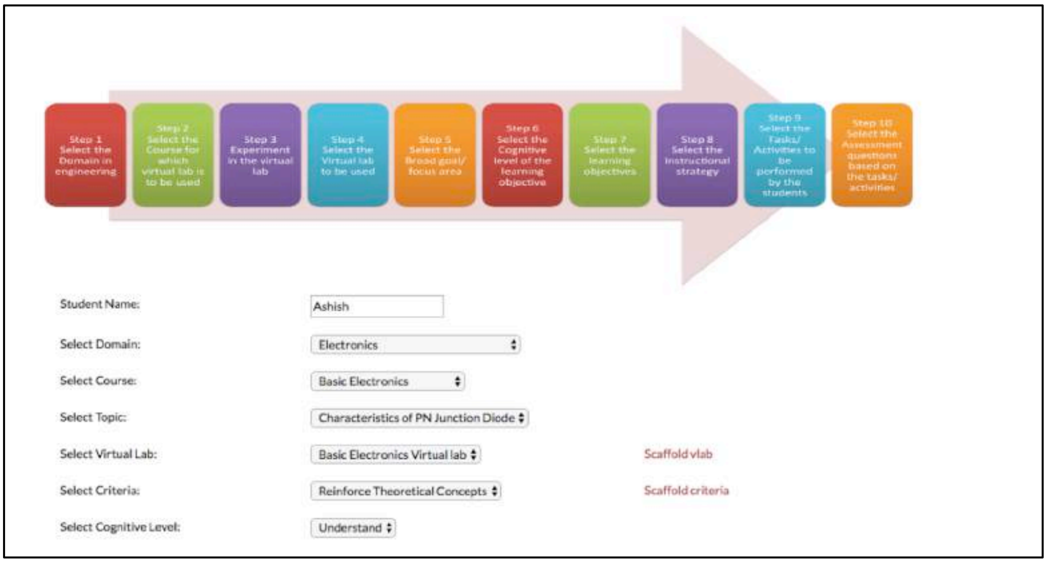


Figure I.4 Steps 1 to 7 in the experiment design process

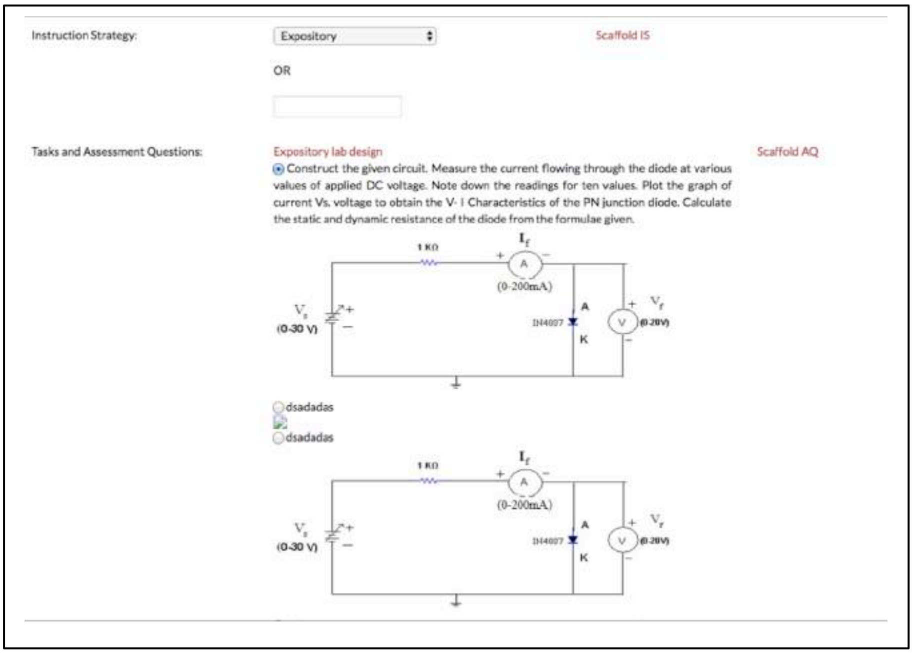
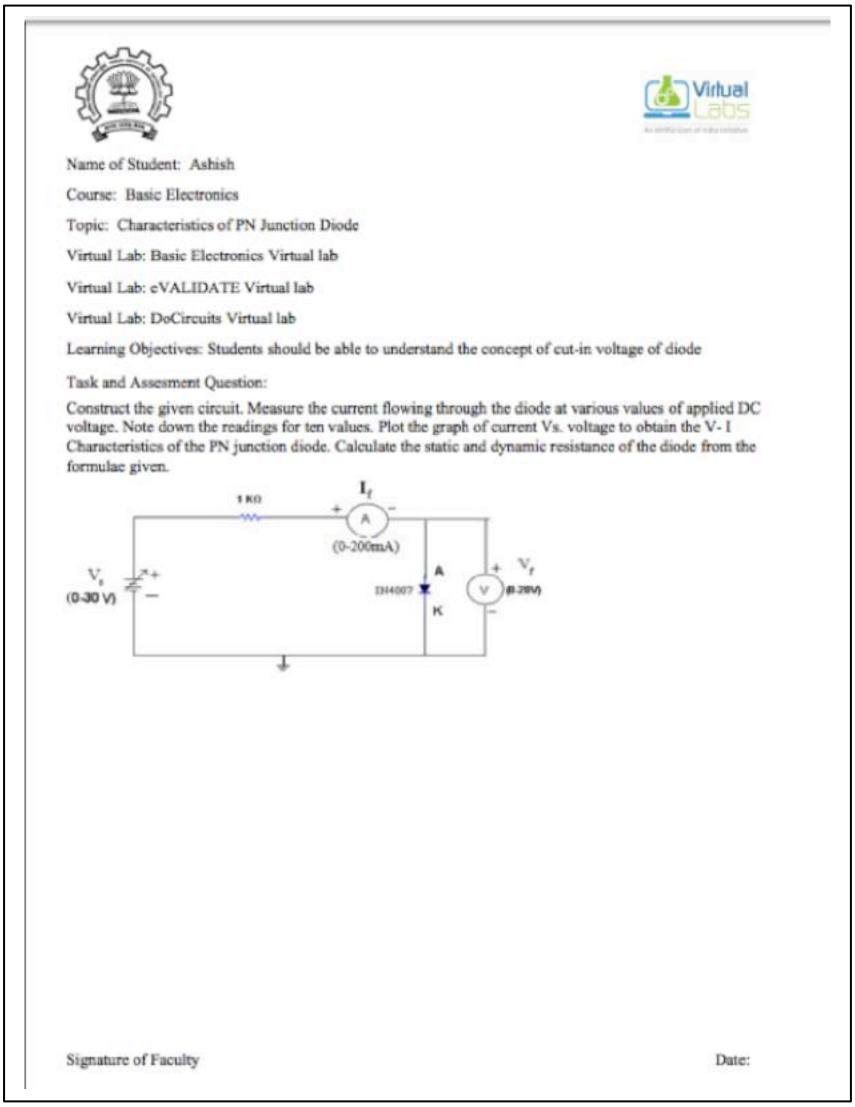


Figure I.5 Steps 8 -9 of the experiment design process



Virtual Labs

Name of Student: Ashish

Course: Basic Electronics

Topic: Characteristics of PN Junction Diode

Virtual Lab: Basic Electronics Virtual lab

Virtual Lab: eVALIDATE Virtual lab

Virtual Lab: DoCircuits Virtual lab

Learning Objectives: Students should be able to understand the concept of cut-in voltage of diode

Task and Assesment Question:

Construct the given circuit. Measure the current flowing through the diode at various values of applied DC voltage. Note down the readings for ten values. Plot the graph of current Vs. voltage to obtain the V- I Characteristics of the PN junction diode. Calculate the static and dynamic resistance of the diode from the formulae given.

Signature of Faculty

Date:

Figure I.6 Final experiment design as pdf document

3. Experiment design for other courses.

The third section of the SDVIcE tool takes the user through the various steps in the experiment design for courses other than BAE. The following figure illustrates the step-wise process and the help provided to the user at each step.

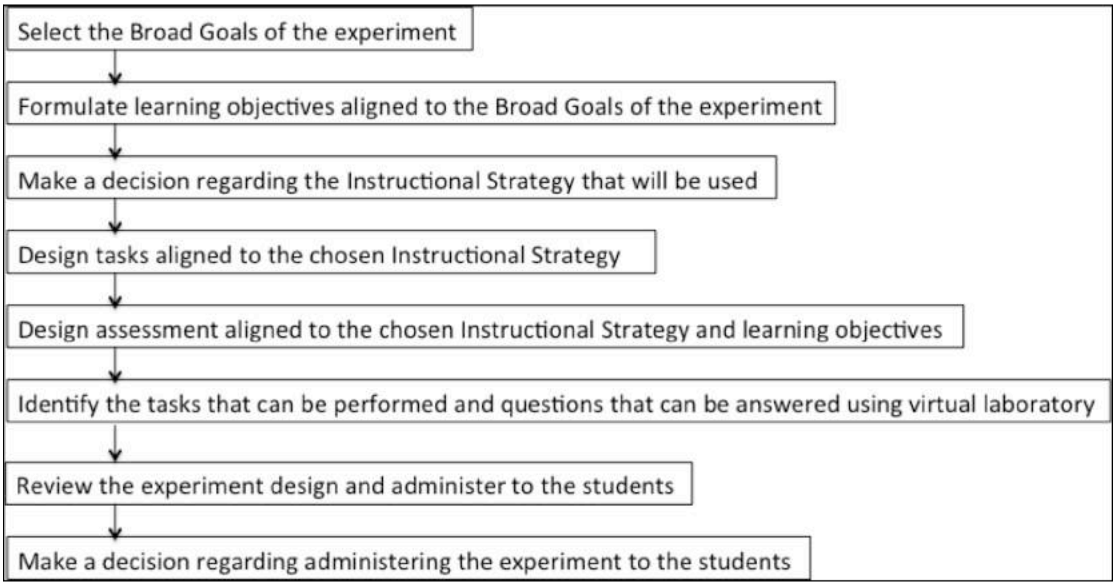


Figure I.7 Step by step experiment design process

The user is taken through the details of each and every step of the experiment design process and a text box is provided adjacent to the content in which the user can type the content for each step as follows:

1. Broad Goal of the experiment
2. Learning objectives of the experiment
3. Instructional Strategy
4. For - Expository Instructional Strategy – Design tasks for following phases
    a. Conception, planning and design of experiment
    b. Execution of experiment
    c. Analysis and interpretation
    d. Applications
5. For - Discovery Instructional Strategy – Design tasks for following phases
    a. Initiation Phase
    b. Exploration Phase
    c. Experimentation Phase
    d. Presentation Phase
6. For – Well-Structured Problem Solving Instructional Strategy – Design tasks for following phases
    a. Step 1: Review Prerequisite Component Concepts, Rules, and Principles
    b. Step 2: Present Conceptual or Causal Model of Problem Domain
    c. Step 3: Model Problem Solving
    d. Step 4: Present Practice Problems
    e. Step 5: Support the Search for Solutions

f. Step 6: Reflect on Problem State and Problem Solution

7. For – Problem-Based Instructional Strategy – Design tasks for following phases
    a. Formulate learning objectives
    b. Phase 1: Problem Definition Phase
    c. Phase 2: Research Phase
    d. Phase 3: Proposed Solution Phase
    e. Phase 4: Implementation Phase
    f. Phase 5: Desired results
8. Design assessment
    a. Properties of assessment
    b. Measurement metric
    c. Method
    d. Instruments used
9. Use features of Virtual laboratories

The figures illustrate the screen shots of the SDVIcE tool for each step of the experiment design. After the user has completed all the steps and the experiment design is finalized they can click on the submit button and a pdf document is generated. This is the final experiment design that can be given to the students. The students can perform the experiment as per the design and submit their solution online to the instructor.

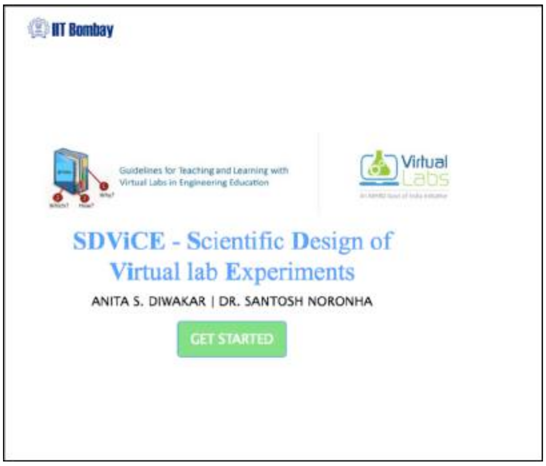


Figure I.8 Landing page of SDVIcE tool

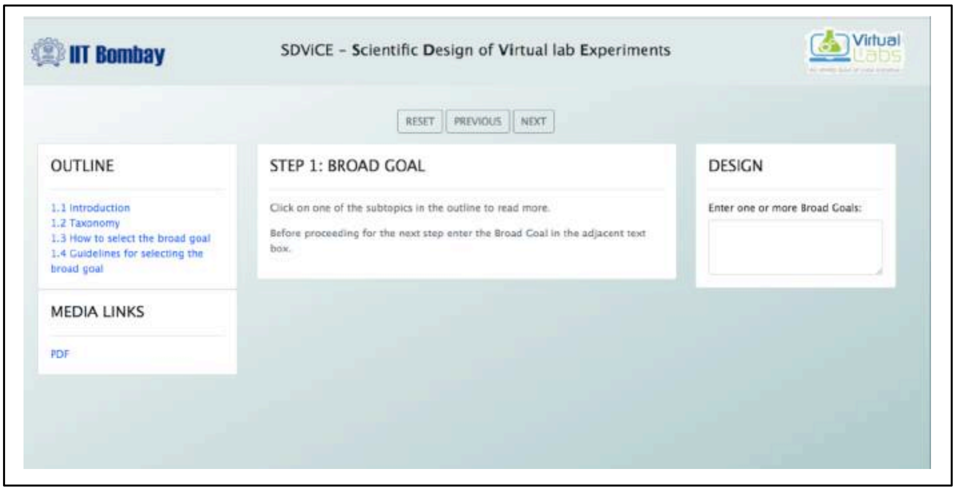


Figure I.9 Step 1 of the experiment design process – Broad Goal

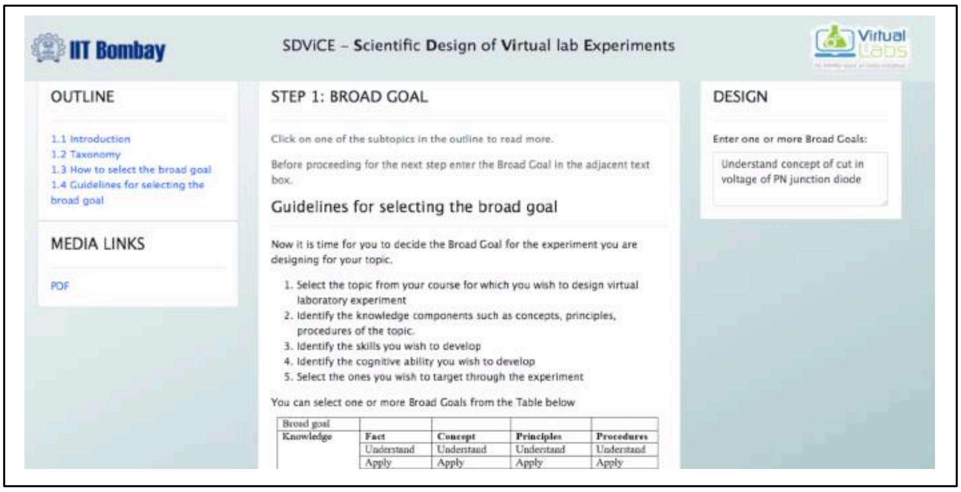


Figure I.10 Step 1 of the experiment design process – Broad Goal

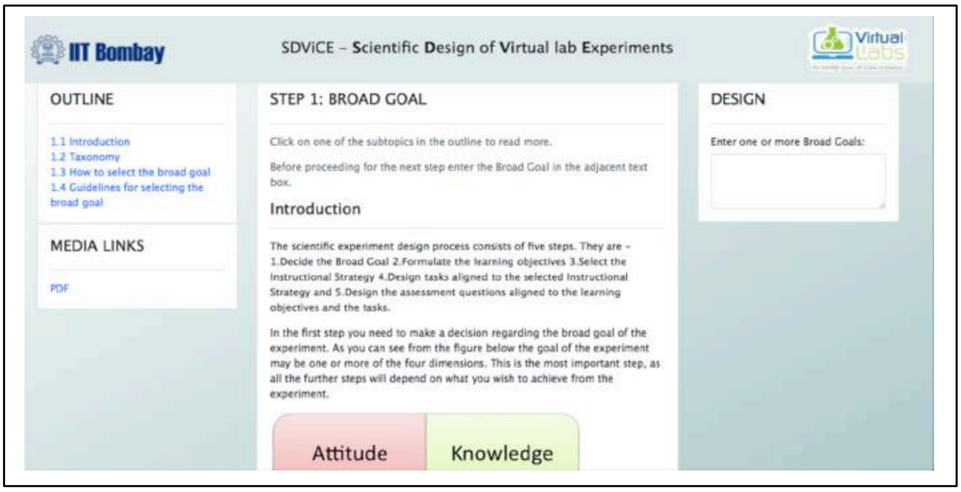


Figure I.11 Step 1 of the experiment design process – Broad Goal

Figure I.12 Step II of the experiment design process– Learning objectives

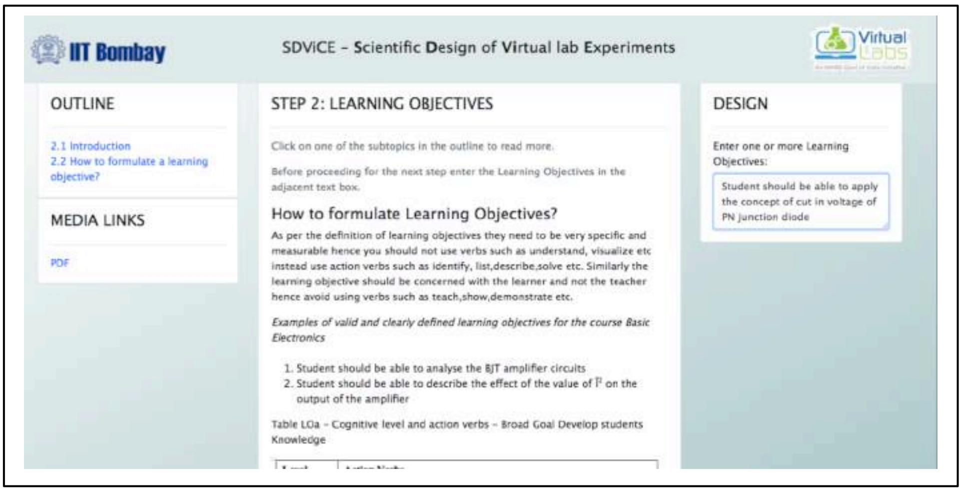


Figure I.13 Details of learning objectives

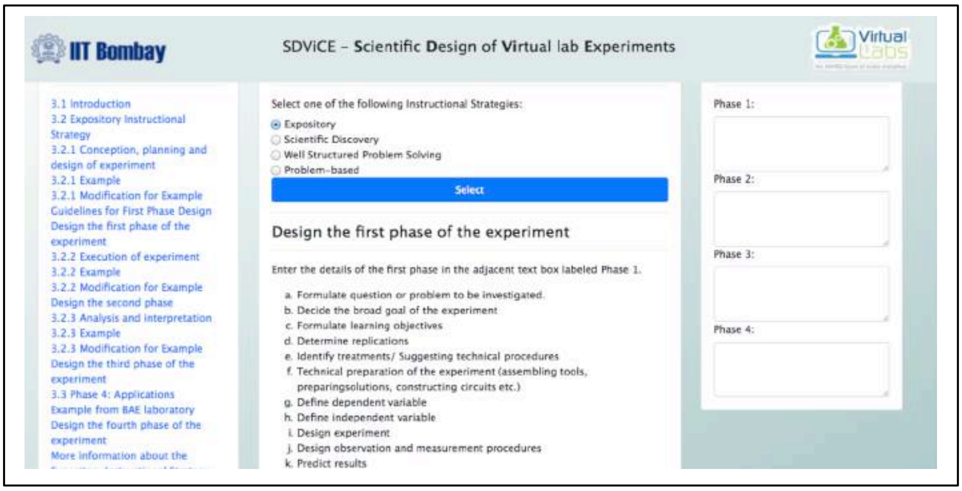


Figure I.14 Expository Instructional Strategy

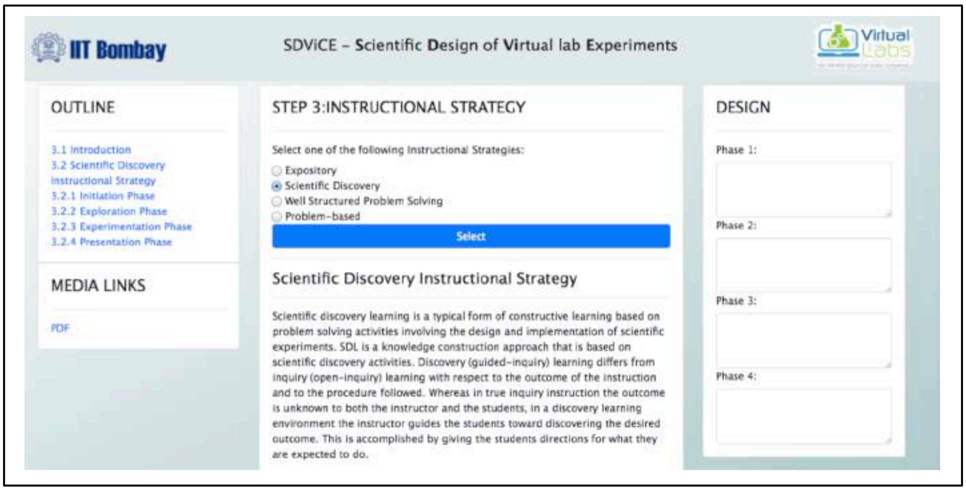


Figure I.15 Scientific Discovery Instructional Strategy

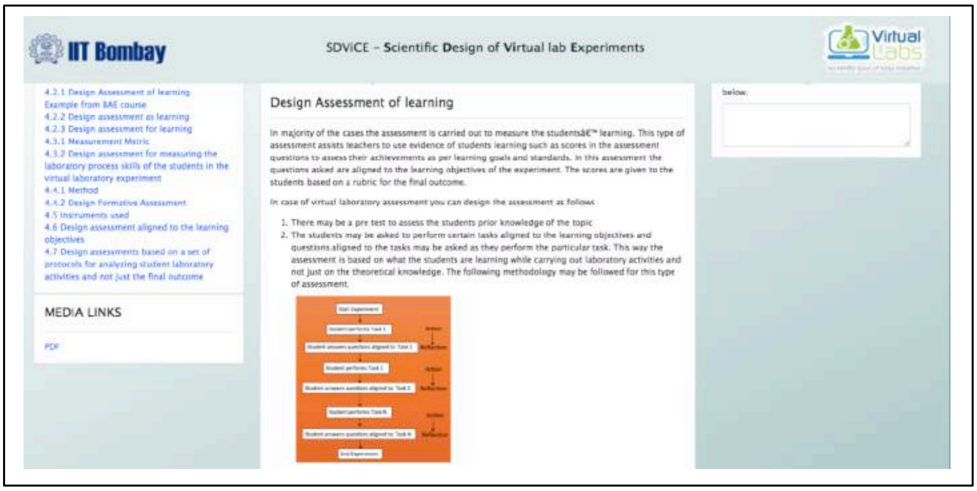


Figure I.16 Assessment design

Characteristics of the ADVIcE online Tool

4. **Content**
5. **Interactivity**
6. **User data collection and dissemination**

1. **Content:** The ADVIcE tool provides scaffolds to the engineering faculties for various stages in the dynamic lab manual development.

Guidelines as static web pages:

These guidelines are in the form of static content for the following components of the LoTaAs framework.

- Broad Goal – This gives a description of the various focus areas or criteria, which need to be achieved in engineering laboratories along with references. The guidelines assist the users in selecting Broad Goals based on the type of content to be covered by the virtual lab experiment.

- Learning objectives – This gives description of the learning objectives that need to be achieved by the students after the performance of a particular experiment. The guidelines assist the users in formulating learning objectives aligned to the Broad Goals and attainable using the virtual labs.
- Instructional Strategies - The guidelines assist the users in selection of instructional strategy suitable for the learning objectives. The instructional strategies for which guidelines are provided are Expository, Discovery, Well-Structured Problem solving and Problem-based.
- Tasks – This gives a description of the dimensions of the task profile along with example from the Basic Electronics course. The example illustrates how constructive alignment between tasks and learning objectives can be achieved by proper selection of task profiles.
- Assessment Method – The proposed assessment method is discussed on this page.
- Assessment Questions – On this page the constructive alignment between tasks, learning objectives and assessment questions is depicted with an example.

Guidelines as downloadable files

The users can download the guidelines as .doc file or .pdf file as and when they need them. The various tables have detailed guidelines for the different aspects along with examples from Basic and Advanced Electronics course. The users can also download the templates for all the four instructional strategies.

Guidelines as embedded videos

There are videos embedded in the SDVIcE tool. The videos explain the stepwise procedure of the experiment design and describe the various steps in the process as per the components of the LoTaAs framework.

2. Interactivity

The SDVIcE tool provides interactivity at two levels.

1. Virtual laboratory experiment design
2. The stepwise procedure for the generation of the Virtual laboratory experiment design is illustrated in the figure. The users are provided with options at each step of the design. They need to take decisions based on their own requirements and referring to the guidelines.

2. Addition or Modification of tasks and assessment questions

The SDVIcE tool has a bank of tasks and assessment questions aligned to the learning objectives created at the back end using the MySQL Database. The tool has a provision for addition or modification of these by the users. The users can add customized task and assessment question items if they feel the inadequacy of the existing bank.

3. User data collection and dissemination

The final Virtual laboratory experiment design is generated after the users go through the steps in the design as a .pdf file. The instructors can either disseminate the pdf file to the students or upload it for evaluation purpose.

At present the tool has been designed for the course Basic and Advanced Electronics, which is, a compulsory and fundamental course for Electronics and allied engineering UG degree. The tool has at the back end a database of the following

1. The virtual labs repository for the course Basic and Advanced Electronics
2. The type of virtual lab mapped to the goal of the experiment and instructional style
3. A repository of learning objectives for the various experiments in the course
4. The learning objectives mapped to the type of virtual lab
5. A repository of tasks/activities to be performed by the students
6. The tasks/activities mapped to the learning objectives
7. A repository of assessment questions depending on type of assessment
8. The assessment questions mapped to the learning objectives and tasks/activities

The advantages of using the SDVIcE tool are

1. The faculty can design virtual laboratory experiments in their course with minimum efforts.
2. One of the major issues in engineering lab work is plagiarism. The faculty can generate different experiments for a small group of students. So each group has a different set of tasks and assessment questions but similar. This way plagiarism can be limited to that small group.
3. The instructors can change the experiments every year.
4. Another issue in current lab practices is that most of the assessment questions are at recall level. The instructors can take care of this by increasing the cognitive level of the tasks and assessment questions from first experiment to the last.
5. The greatest advantage of the tool is the comprehensive database due to which the instructors are not required to spend too much of their time in writing the tasks and questions for BAE course. At the same time if some instructors wish to add tasks or questions there is a provision for the same and it gets added to the database. This way each year the database gets automatically updated.
6. This availability of online content for virtual laboratory experiments can lead to some level of standardization and improve the overall quality of the students' laboratory learning outcomes.

Appendix II: Artifact analysis – Experiment designs before and after using the guidelines

As part of the Summative Evaluation of the experiment design guidelines we carried out field-testing with ten engineering instructors. Each engineering instructor designed four virtual lab experiments initially without using the guidelines. After the initial design they went through the guidelines available online at the SDVIcE tool and then redesigned the same experiments for virtual laboratory. In the following sections we present the results of the analysis of the experiment designs before and after using the experiment design guidelines. Each experiment was scored on the basis of the rubric developed to assess the quality of the experiment designs.

The following is the rubric used to assign scores to the various dimensions of the experiment design.

The dimensions that form part of the rubric are

1. The experiment design follows a scientific design process – Follows SEDP
2. The experiment design incorporates the various phases in the scientific design process – Phases in SEDP incorporated
3. The experiment design incorporates instructional strategy – Incorporate IS other than Expository
4. The experiment design for the various instructional strategies are as per the templates – ED as per templates of IS
5. If the Expository instructional strategy is used then the tasks are designed with constructivist approach – CA for EIS
6. The experiments are designed at different difficulty levels – EDs at various difficulty levels
7. The broad goal/s of the experiment is clearly specified – BG specified
8. The broad goal/s is aligned to the content type of the topic – BG aligned to content type
9. The learning objectives are valid and clearly defined – LOs valid and specified
10. The experiment design has learning objectives at various cognitive levels as per Revised Bloom's taxonomy – LOs at various cognitive levels
11. The virtual laboratory tasks are aligned to the learning objectives of the experiment. – Tasks aligned to LOs
12. The virtual laboratory tasks provide opportunities to the students to work in the two domains of objects and concepts – Tasks in both domains
13. The virtual laboratory tasks are different for the different instructional strategies – Tasks aligned to IS
14. The assessment questions are aligned to the learning objectives – AQs aligned to LOs
15. The assessment questions in the design of learning are correct – AQs correct

16. The assessment questions in the design for learning truly help the students in their learning – AQs target learning
17. The assessment measures the students' knowledge as per the content type – AQs assess knowledge
18. The assessment measures the target skills developed by the students – AQs measure skills
19. The virtual laboratory selected has affordances that allow students to perform the tasks designed in the experiment – Vlab selection aligned to tasks
20. The virtual laboratory selected has affordances so that LOs can be achieved – Vlab selection aligned to LOs

Table II.1 Rubric for assessment of Experiment Design Quality

Dimension	Missing(0)	Inadequate(1)	Needs some improvement(2)	Adequate(3)
1. Follows SEDP	No attempt is made to follow the SEDP	A few steps are as per the SEDP	Many steps are as per the SEDP	Complete experiment design follows all the steps in the SEDP
2.Phases in SEDP incorporated	No attempt is made to incorporate phases in SEDP	A few phases of SEDP are incorporated	Most of the phases of SEDP are incorporated but a few are missing	All phases in SEDP are incorporated
3. Incorporate IS other than Expository	Expository IS with cook book approach	Expository IS used but not with cook book approach	Either PBIS/DIS/PIS is incorporated but	Either PBIS/DIS/PIS is incorporated
4. ED as per templates of IS	No attempt is made to design the experiment as per the template	A few steps in the template are designed	Many steps in the template are designed but a few steps are missing	The experiment design exactly as per the template
5. CA for EIS	No attempt is made to design the experiment with CA	A few tasks are as per CA	Many tasks are as per CA but a few missing	The complete experiment design follows CA
6. EDs at various difficulty levels	The experiment design is at lowest difficulty	A few tasks are at higher difficulty levels but majority at	Many tasks are at higher difficulty levels but few at lower levels	The experiment design has tasks at various

	level	lower levels		difficulty levels
7. BG specified	No attempt is made to specify BG	BG is specified but it is not valid BG	BG is specified and valid but not as per the guidelines	BG specified is as per the guidelines
8. BG aligned to content type of the topic	BG is not aligned to the content type			BG is aligned to the content type
9. LOs valid and specified	Not clearly specified as per the guidelines and not aligned to the BG	Not clearly specified as per the guidelines but somewhat aligned to the BG	Clearly specified as per the guidelines but not aligned to the BG	Clearly specified as per the guidelines aligned to the BG
10. LOs at various cognitive levels	All LOs at lower cognitive levels	All LOs at higher cognitive levels	A few cognitive levels are covered	LOs cover all of the cognitive levels
11. Tasks aligned to LOs	No attempt is made to align tasks and LOs	A few tasks aligned to LOs	Majority of the tasks aligned to the LOs but a few not aligned to the LOs	All tasks and LOs are completely aligned
12. Tasks in both domains	Tasks in objects domain only and no task in observables domain with no opportunities of linking between two domains	A few tasks in objects and few in observables domains but no opportunities of linking between two domains	A few tasks in objects and few in observables domains and opportunities of linking between two domains	Tasks in objects and observables domains with multiple opportunities of linking between two domains
13. Tasks aligned to IS	No attempt is made to align tasks and IS	A few tasks aligned to IS	Majority of the tasks aligned to the IS but a few not aligned to the IS	All tasks and IS are completely aligned
14. AQs are correct and aligned to LOs	No attempt is made to align AQs and LOs OR No AQs in the	A few AQs aligned to LOs	Majority of the AQs aligned to the LOs but a few not aligned to the LO	All AQs and LOs are completely aligned

	experiment			
15. AQs target learning	All AQs are related to theory OR No AQs in the experiment	A few AQs are related to laboratory work and many related to theory	A few AQs are related to theory and many related to laboratory work	All AQs assess the students learning in the laboratory
16. AQs assess knowledge and skills	No attempt is made to design AQs that asses students knowledge and skills OR No AQs in the experiment	A few AQs are designed that assess students knowledge but at lower cognitive levels and no AQ to assess the skills	A few AQs are designed that assess students knowledge and few AQ to assess the skills	All AQs assess the students knowledge and skills
17. Vlab selection aligned to tasks and LOs	The selected vlab does not have affordances to allow the students in the performance of the various tasks and achieve the LOs	The selected vlab has affordances to allow the students in the performance of certain tasks and achieve a few LOs	The selected vlab has affordances to allow the students in the performance of most of the tasks and achieve most of the LOs but not all LOs	The selected vlab has affordances to allow the students in the performance of all the tasks and achieve all the LOs

Faculty 1: Experiment 1: Design before using the guidelines

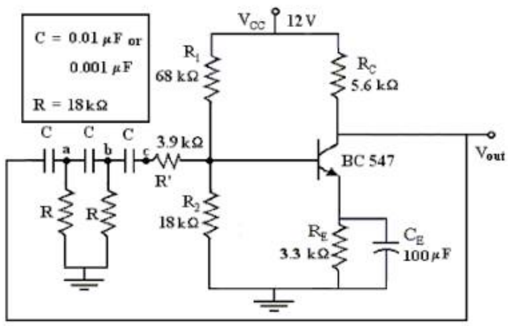
Experiment Design for Integrated Circuit Lab
Lab: Integrated Circuit
Experiment 6: To study and design oscillator using OP-AMP.

Aim: - To study the working of BJT RC Phase Shift Oscillator for different amplitude and frequency.

Apparatus: -

Sr. No.	Instrument / Component	Range / Value
1	BJT	BC 547
2	Resistors	68k, 3.3k, 18k, 5.6k, 3.9k
3	Capacitors	100µF, 0.001&0.01µF
4	Dual Power Supply	0-32 V
5	Bread Board	-----
6	Connecting wires	-----
7	CRO	-----

Circuit Diagram: -



Theory: - The BJT RC Phase shift oscillator, which uses positive feedback, is shown above. The Barkhausen's criteria for oscillation: For sustained sinusoidal oscillation the $|A\beta| = 1$ and the total phase shift from input through output and back to input should be zero or multiple of 2Π. The closer the Aβ is exactly to 1, the more nearly sinusoidal is the waveform.
Oscillator is a network, which uses positive feedback. In RC phase shift oscillator network the amplifier gives 180° phase shift and for sustained oscillations the feedback network should give additional phase shift of 180°. We are using three RC sections here because each section gives a phase shift of 60° giving a total phase shift of 180°. For RC BJT phase shift network,

$$f_o = \frac{1}{2\pi RC} \times \frac{1}{\sqrt{(6+4K)}} \text{ where } K = \frac{R_C}{R}$$

Procedure: -

1. Connect the circuit as shown in the figure. Take C = 0.01µF. Apply V_{CC} = 12V.

2. Observe the sine wave output on C.R.O. Note down its amplitude and frequency. Compare the theoretical & practical frequency.
3. Measure the Phase difference between output and input (waveforms at points a, b, & c respectively. Each point should give phase difference of 60°)
4. Take C = 0.001μF and repeat step 1 through 3.
5. Draw input and output waveforms showing Phase differences at each point a, b, and c respectively. (For C = 0.01 μF only)

Observation: -

Capacitor	Frequency		Phase Difference (observed)			Amplitude
	Theo.	Practical	a	b	c	(volts)
0.01μF						
0.001μF						

Conclusion: -

The above experiment design was scored using the rubric to assess the quality of the experiment design and the following table gives the scores.

Dimension	**Missing(0)**	**Inadequate(1)**	**Needs some improvement(2)**	**Adequate(3)**	**Score**
1. Follows SEDP		A few steps are as per the SEDP			1
2.Phases in SEDP incorporated		A few phases of SEDP are incorporated			1
3. Incorporate IS other than Expository	Expository IS with cook book approach				0
4. ED as per templates of IS	NA				0
5. CA for EIS	No attempt is made to design the experiment with CA				0
6. EDs at various difficulty levels	The experiment design is at lowest difficulty level				0
7. BG	No attempt				0

specified	is made to specify BG				
8. BG aligned to content type of the topic	BG is not aligned to the content type				0
9. LOs valid and specified	Not clearly specified				0
10. LOs at various cognitive levels			A few cognitive levels are covered		2
11. Tasks aligned to LOs		A few tasks aligned to LOs			1
12. Tasks in both domains	Tasks in objects domain only and no task in observables domain with no opportunities of linking between two domains				0
13. Tasks aligned to IS			Majority of the tasks aligned to the IS but a few not aligned to the IS		2
14. AQs are correct and aligned to LOs	No attempt is made to align AQs and LOs				0
15. AQs target learning	All AQs are related to theory OR No AQs in the experiment				0
16. AQs assess knowledge and skills	No attempt is made to design AQs that asses students knowledge and skills				0

	OR No AQs in the experiment				
17. Vlab selection aligned to tasks and LOs	(NA)				
Total Score				Low level quality	7/45

Faculty 1: Experiment 1: Design after using the guidelines

Experiment 6. To study and design oscillator using OP-AMP.
Focus area: Design and development

Learning Objective	Cognitive Level
1 Students will be able to explain the working of oscillator circuit using OP-AMP.	Understand
2. Students will be able to calculate the frequency and magnitude for RC-Phase shift and Wein Bridge oscillator using OP-AMP.	Apply
3. Students will be able to examine and interpret the graph of RC-Phase shift and Wein Bridge oscillator using OP-AMP.	Analyze
4. Students will be able to design RC phase shift and Wein Bridge oscillator form given data and compare the two circuits based on their performance.	Evaluate
5. Students will be able to design RC phase shift and Wein Bridge oscillator for different audio and radio frequency.	Create

2. Instructional Strategy: Structured Problem Solving
Assessment Method: Formative Assessment

Description:
RC Phase shift oscillator is a sinusoidal oscillator used to produce the well-shaped sinusoidal wave. The feedback network shifts the phase of the amplifier output by 180 degrees at the oscillation frequency to give positive feedback. Phase shift oscillators are often used as audio oscillators.
The Wein Bridge oscillator is an electronic oscillator and produces the sine wave. It is two stage RC circuit amplifier circuit and it uses the principle of Wheatstone Bridge. It has high quality of resonant frequency, low distortion.

3. Tasks & Assessment Questions:

Task1: Function and operation of oscillators. [LO#1]
Assessment Questions: (1 marks each)
Q.1 Which of the following feedback is used to produce oscillations?
a. Positive feedback

b. Negative feedback
c. Positive and Negative feedback
d. Non regenerative feedback

Q.2 Oscillator requires external input signal for its operation
a. True
b. False

Q.3 A circuit should satisfy …….. criterion to obtain sustained oscillations.

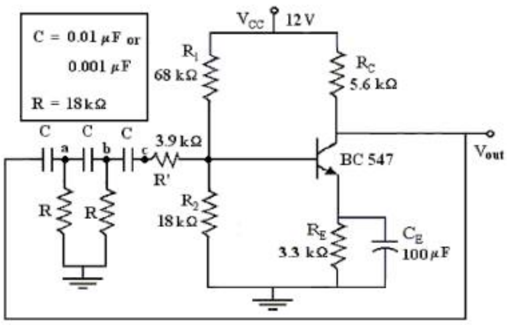
Q.4 To start oscillation, the total phase shift of an oscillator is
a. High
b. Low
c. 1
d. 0

Q.5 The voltage that starts an oscillator is caused by
a. Ripple from the power supply
b. Noise voltage in resistors
c. The input signal from a generator
d. Positive feedback

Task2: Identification of component to build circuit. [LO#1, LO#2, LO#4]
Assessment Questions: (2 marks each)
Q.1 How many resistors need to be varied to change the frequency of a Phase Shift oscillator?
a. One resistor
b. Two resistors
c. Three resistors
d. One capacitor

Q.2 How many RC ladder are used in RC Phase shift oscillator circuit
a. 1
b. 2
c. 3
d. 4

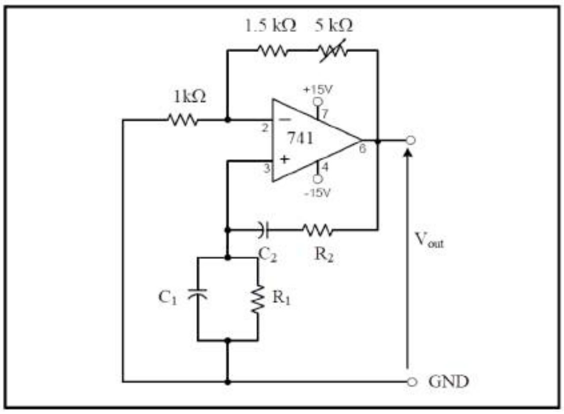
Task3: Mathematical calculation to get desired output voltage and frequency. [LO#2, LO#3, LO#4]
Assessment Questions: (3 marks each)
Observe the below RC phase shift oscillator circuit to answer the same.



Q.1 With value R1 = R2 = R3 = 1 KΩ; and C1 = C2 = C3 = 0.22 µF, by adjust the 1 MΩ; potentiometer until get the output waveform has the least amount of distortion. The output waveform supposedly sine wave waveform. State the formula for the frequency of the Oscillator. Calculate the frequency of the output from theoretical calculations and practical observations. Are the values exactly same? Give reason for the same.

Q.2 Discuss how the resistor R1=R2=R3 and C1=C2=C3 effected the frequency of the for Phase-shift oscillator. What is the change in the frequency if the resistor value is changed to 2 KΩ? What is the change in the frequency if the capacitor value is changed to 0.01 µF? Describe the relation between the values of resistor, capacitor and frequency.

Observe the below Wein bridge oscillator circuit to answer the same.



Q.3 With value R1 = R2 = 10 KΩ; and C1 = C2 = 0.22 µF, by adjust the 5 KΩ; potentiometer until get the output waveform has the least amount of distortion. The output waveform supposedly sine wave waveform. Calculate the frequency.

Q.4 Discuss how the resistor R1=R2 and C1=C2 effected the frequency response for Wien bridge oscillator. How to vary the frequency of Wien bridge oscillator?

Task 4:

Q1: Design RC phase shift and Wein bridge oscillator circuit for desired frequency. Compare the two circuits with respect to the number of components and the generated frequency range possible for both the circuits. [LO#5]
Assessment Questions: (4 marks each)

Q2: Which of the two oscillators has a higher range? Which of the two will you suggest to be used as a Signal generator circuit?

Q.3 Design a RC phase shift oscillator circuit for 250 Hz. Calculate R1, Rcomp and Rf. Take Rf ≥ 29R1, R1 ≥ 10R and Choose C = 0.1 µF.

Q.4 Design a Wein Bridge oscillator circuit for 1 kHz. Calculate R, C, Rf and Ri. Take Rf = 2Ri, C = 0.047 μF.

Dimension	Missing(0)	Inadequate(1)	Needs some improvement(2)	Adequate(3)	Score
1. Follows SEDP			Many steps are as per the SEDP		2
2.Phases in SEDP incorporated			Most of the phases of SEDP are incorporated but a few are missing		2
3. Incorporate IS other than Expository				Either PBIS/DIS/PIS is incorporated	3
4. ED as per templates of IS			Many steps in the template are designed but a few steps are missing		2
5. CA for EIS	NA				
6. EDs at various difficulty levels		A few tasks are at higher difficulty levels but majority at lower levels			1
7. BG specified				BG specified is as per the guidelines	3
8. BG aligned to content type of the topic	BG is not aligned to the content type				0
9. LOs valid and specified				Clearly specified as per the guidelines aligned to the BG	3
10. LOs at various cognitive levels			A few cognitive levels are covered		2
11. Tasks aligned to LOs			Majority of the tasks aligned to the LOs but a		2

			few not aligned to the LOs		
12. Tasks in both domains		A few tasks in objects and few in observables domains but no opportunities of linking between two domains			1
13. Tasks aligned to IS		A few tasks aligned to IS			1
14. AQs are correct and aligned to LOs			Majority of the AQs aligned to the LOs but a few not aligned to the LO		2
15. AQs target learning			A few AQs are related to theory and many related to laboratory work		2
16. AQs assess knowledge and skills		A few AQs are designed that assess students knowledge but at lower cognitive levels and no AQ to assess the skills			1
17. Vlab selection aligned to tasks and LOs			The selected vlab has affordances to allow the students in the performance of most of the tasks and achieve most of the LOs but not all LOs		2
Total score					29/48

Analysis of the experiment designs

Experiment design before using guidelines	Experiment design before using guidelines	Guideline implemented
Learning objective is the Aim and it is not valid as the verb used is "To study"	Four learning objectives are formulated and each is valid, correct and used the correct action verbs according to the cognitive level. The learning objectives are at cognitive levels of – Understand, Apply, Analyze, Evaluate and Create.	Formulating learning objectives at different cognitive levels
The instructor has specified all the details of the components and equipment to be used to perform the experiment	The instructor assigned the task of identifying the necessary components and equipment to the students	Active learning – making students participate in the phase - Technical preparation of the experiment
The instructor has specified the background theory	The instructor has specified the background theory and asked questions related to the theory so that the students recall their prior knowledge of the topic.	Active learning – making the students participate in the learning.
The instructor has specified all the details of the technical procedure to be carried out.	The instructor has assigned tasks and questions that make the students make decisions regarding the procedure to be carried out. The tasks and questions make the students work in both the objects and concepts domain. The students are made to reflect on their actions.	Active learning – Designed tasks so that students work in the two domains of objects and concepts.
The instructor has specified all the details of the observations to be taken and also given the observation table.	The instructor has not specified all the details and not given the observation table. The students are made to write the formula and find out the relation between the variables in the experiment. They are asked to find out the difference between the theoretical and practical	Active learning – The students are made to decide the observations to be taken and the calculations to be carried out.

	values obtained.	
In the last part of the experiment the students have to write the conclusion of the experiment. The phase of application is not implemented. The students do not reflect on their results. They do not change any parameters. The learning objectives achieved with such experiment design are at the understand level.	The students have to change the values of the parameters and observe the change in the output. They are made to analyse and evaluate the two circuit designs having the same function in order to achieve the learning objectives at analyze and evaluate levels.	Learning objectives and constructive alignment - The tasks and assessment questions asked are aligned to the learning objectives at all the cognitive levels.

The above is an example of an experiment design where the quality improved from low level with a rubric score of 7/45 to high level with a rubric sore of 29/45.

Faculty 1: Experiment 2: Design before using the guidelines

Voltage regulator using IC723

Aim: To set up a low voltage regulator using IC723 and plot the regulation characteristics.
Objectives: After completion of this experiment the student will be able to construct voltage regulator using IC 723 for the required voltage and know about regulation characteristics

Equipment/Components:

Sl. No.	Name and specifications	Quantity
. 1	Variable Power Supply (0- 30 V)	.. 1
. 2	Resistors, rheostat	.. 3
. 3	Capacitor	.. 2
. 4 .	IC 723	.. 1 ..
5	Volt meter (0-30V) Voltmeter (0-10V)	1 1
. 6.	Ammeter (0-10 mA)	.. 1
. 7 .	Bread board	.. 1 ..
8	Connecting Wires	As required

Principle:

Type 723 is the most versatile of the monolithic voltage regulators. It can be used to provide high and low positive regulated voltages. Current can be boosted to provide 5A or more. It has short circuit protection. The input voltage of IC723 varies from 9.5V to 40V and provides output voltage from 2V to 37V.

IC 723 regulator has two separate sections. One section provides a fixed voltage of 7.15v at the terminal Vref, other section consists of an error amplifier. These two sections are not internally connected. For constructing low voltage regulator using 723, Vref point is connected through a resistance to the non-inverting terminal and the output is feedback to the inverting terminal of the error amplifier. If the output voltage becomes low, the voltage at the inverting terminal of error amplifier also goes down. Thus make the output of the error amplifier become more positive, there by driving transistor more into conduction. This reduces the voltage across transistor and drives more current into the load, causing voltage across the load to increase. Thus the initial decrease in the load voltage is compensated. Similarly any increase in the load voltage gets regulated.

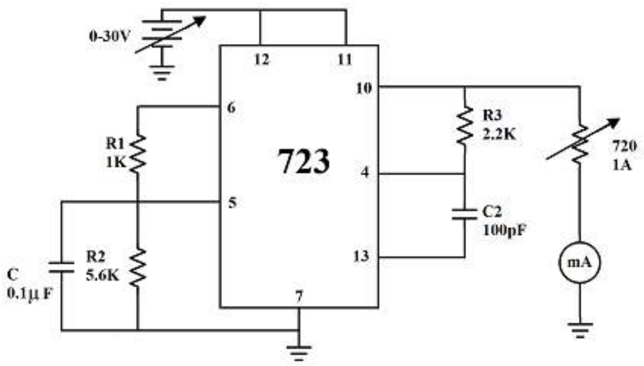
Procedure:

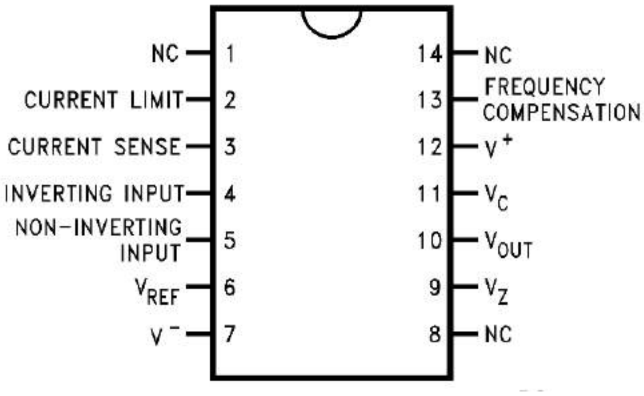
1. Check all the components
2. Set up circuit on the breadboard and check the connections
3. Switch on the power supply
4. Vary the input dc voltage and measure the input and output voltages using voltmeter
5. Vary the load resistance potentiometer and measure output voltage and current
6. Plot line regulation and load regulation characteristics on the graph
7. Calculate percentage load regulation

Result:

Inference:

Circuit Diagram:





Design:

Let the regulated output voltage Vo = Vref x { R2 / (R1+R2)} 6 = 7.15 x R2/(R1+R2) Let the current through resistor R1 and R2 I1 = 1mA Then R1 = (Vref - Vo)/I1 = (7.15 – 6) /1ma = 1.1K = 1K (std) Then R2 = 6 / 1.15 = 5.6K (std)
For room temp. Stability R3 = R1 || R2
Take R2=2.2K, choose C1=0.1µF and C2 = 100PF
IC 723 Pin details
(Optional) Vo = 6V
As per data sheet 966 Ω< R3 < 3.52K
Observations:

Sl.No	Vi (volts)	Vo (volts)

Sl.No	Vo (volts)	Io (amps)

Percentage load regulation = {(VNL-VFL)/VNL} x 100 % = ?
Graph:

Faculty 1: Experiment 2: Design after using the guidelines

Lab: Integrated Circuit
Experiment: To study and understand working and datasheet of any one voltage Regulator
Broad goal: Design Skill

Learning Objectives	Cognitive level
1 Students will be able to identify different IC's and components required in a voltage regulator.	Understand
2 Students should be able to compare theoretical and practical results and analyse the discrepancies	Analyze
3 Students should be able to evaluate magnitude of output voltage for different values of R2 resistor.	Evaluate
4 Students will be able to design voltage regulator for different Output voltages	Create

Instructional Strategy: Problem solving Laboratory Experiment
Assessment Method: Formative Assessment
Description:
A voltage regulator is an electronic circuit that provides a stable DC voltage independent of the load current, temperature and AC line voltage variations. By changing the values of reference voltage the value of constant output of desired voltage is obtained.

Task & Assessment Questions:
Task1: Read the theory and comprehend the concepts related to the experiment. [LO#1]
Assessment Questions: (1 mark each)

1 Name the different terminals of IC LM317?
Ans:

2 How many resistors are required for LM317 to obtain desired output voltage?
A. One
B. Two
C. Three
D. Four

3 What is the importance of a reference voltage?
Ans:

Task2: Implementation of the procedure [LO#1, LO#2]
Assessment Questions: (2 marks each)
1 What value of resistance did you choose for the rheostat?
Ans:

2 To which terminal of IC did you connect the rheostat?
Ans:
Task3: Observations and interpretations of readings: [LO#2, LO#3]
Assessment Questions: (2 marks each)

1 Is there any difference between theoretical and practical output voltage?
Ans:

2 If there is any difference enlist suitable reasons.
Ans:

Task 4: Evaluation of output voltages for different component specification. [LO#3]
Assessment Questions: (2 marks each)

1.If the value of resistance on rheostat R2 is increased what will be change in output voltage?
Ans:

2. If the value of the resistance of rheostat is doubled and the reference voltage is tripled of the given values, what will be the new output voltage?
Ans:

Task 5: Design and build regulator circuit using the generalized simulator. [LO#4]
Assessment Questions: (4 marks each)
1 Design a voltage regulator circuit to produce output voltage of 25V using LM317 IC.
Ans:

2 Design a voltage regulator circuit to produce an output voltage of 20V provided there is loss of 5%
Ans:

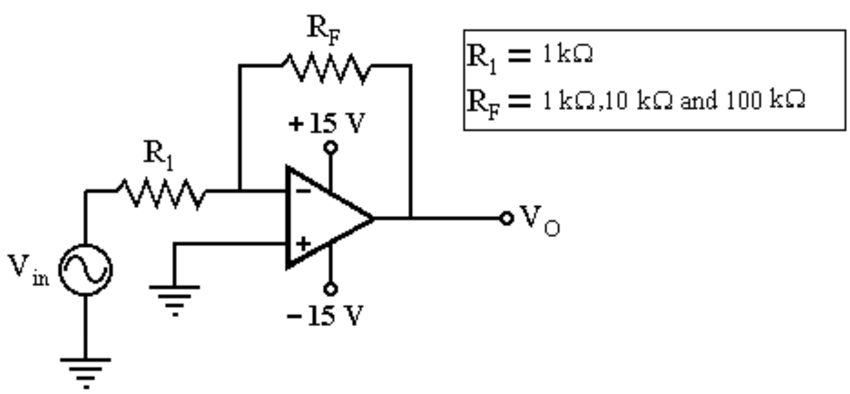
Faculty 1: Experiment 3: Design after before the guidelines

Aim: - To study the basic amplification of an Operational amplifier as Inverting as well as Non-inverting amplifier.

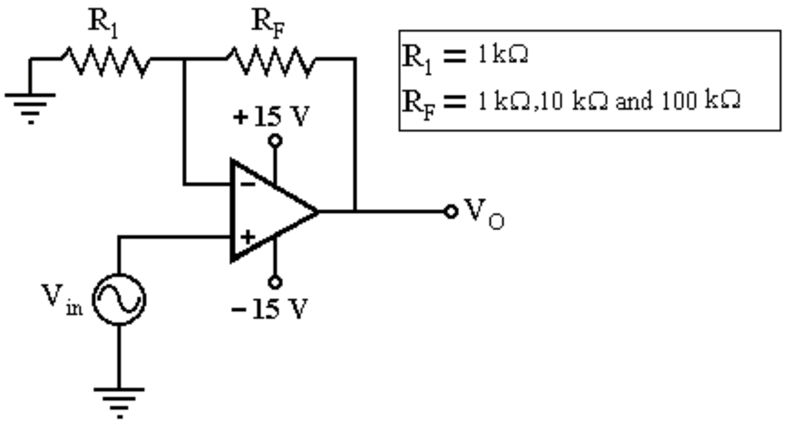
Apparatus: -

S.No.	Instrument / Component	Range / Value
1	Op-amp	741
2	Resistors	1 kΩ, 10 kΩ, 100 kΩ
3	Power supply	± 15V
4	C.R.O., Function Generator and C.R.O. probes	---
5	Bread Board & connecting wires	---

Circuit Diagram: - Inverting amplifier



Non-Inverting amplifier



Theory: -

Inverting amplifier: - A circuit that gives inverted output (i.e. the output is 180° out of phase with respect to the input) is known as the Inverting amplifier. The op-amp Inverting amplifier is shown above. Here the output is A_v times the input (inverted) where A_v is given by $A_v = - (Rf/R_1)$. The minus sign here indicates the phase inversion between input and output.

Non-Inverting amplifier: - A circuit whose output is in phase with the input is known as non-inverting amplifier. The op-amp non-inverting amplifier is shown above. Here also the output is A_v times the input (non-inverted) where A_v is given by $A_v = 1+ (Rf/R_1)$.

Procedure: -

1. Connect the circuit for Inverting amplifier as shown in the figure. Take R_F as 1 kΩ.
2. Generate input of 50 mV peak to peak at 1 kHz frequency sine wave and give this input at V_{in} shown in the figure.
3. Observe output on CRO, clearly showing amplification. Calculate output voltage and find out gain.
4. Repeat steps 2 & 3 for R_F = 10 kΩ & 100 kΩ.
5. Draw input and output waveforms for R_F = 10 kΩ only.
6. Repeat steps 2 through 5 for Non-inverting amplifier.

Observation table: - Inverting amplifier

Input (mV)	R_F (kΩ)	Output	Gain (A_V) Theo.	Pract.
	1			
	10			
	100			

Non-Inverting amplifier

Input (mV)	R_F (kΩ)	Output	Gain (A_V) Theo.	Pract.

	1			
	10			
	100			

Conclusion: -

Faculty 1: Experiment 3: Design after using the guidelines

Lab: Integrated Circuits & Applications
Experiment: Inverting and Non-Inverting configuration
Broad goal: Student will gain skills to develop Filters, Phase Shifters and Voltage Followers etc.

Learning Objectives	Cognitive Level
1. Students will be able to apply Basic Concept of Inverting and Non-Inverting OP-AMP.	Understanding
2. Students will be able to apply Concept of OP-AMP and analyze gain, output voltage and waveform.	Analyze
3. Students will be able to calculate Value of components for Applications.	Apply
4. Students will be able to design the Real-time Applications.	Create

Instructional Strategy: Guide-Inquiry Based Experiment
Assessment Method: Formative Assessment

Description:
Op-Amp and other resources will be provided to the student. They will be guided to step-by-step to make given circuit. The circuit will have 2 option, either Inverting or Non-Inverting, the student has to make a choice accordingly. Student will have an option to change the values of components and get the desired results. There will be option of creating a graph as well. Students can get the graphs according to their experiment values, which they feed, earlier in the components.

Task & Assessment Questions:
Task1: Student will observe the output based on default values provided.
Task 2: Student will vary the values in components and observe the output.
Assessment Questions: (2 marks each)

1 Write down the Equation of Gain Inverting and Non-Inverting Amplifier?

2 Calculate Output Voltage?

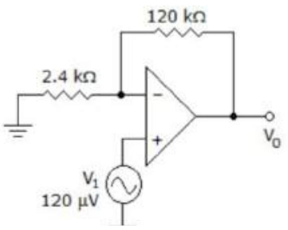


Figure 1
a) -6.00 mV
b) 6.00 mV
c) 6.12 mV
d) -6.12 mV

3 Find the Gain of the circuit in figure 1.
VIN = 5V
RIN = 10K Ω
RF = 100K Ω

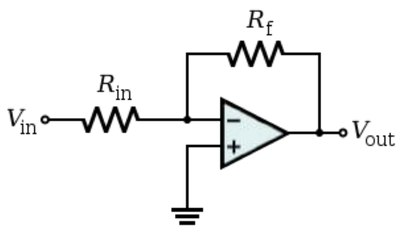


Figure 2

4 Calculate the input voltage for this circuit if Vo = –11 V.

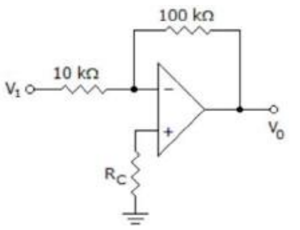


Figure 1

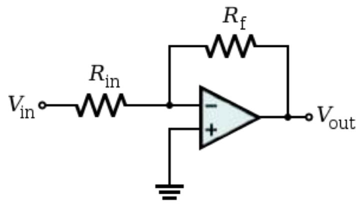
Task2: Student can provide variable input values in components and observe output waveform accordingly.
Assessment Questions: (2 marks each)

1 What change will be reflected in output voltage if we set RF at 0 and R1 at ∞?

2 If the gain of original circuit is to be increased by 40 times, find the new value of components?

3 Measure the % error in output voltage calculated in theoretical and practical results.
VIN = 6V

RIN = 1KΩ
RF = 80KΩ



4 Calculate the input voltage for this circuit if (i) Vo = –11 V. (ii) Vo = 11 V. and Give your Comment

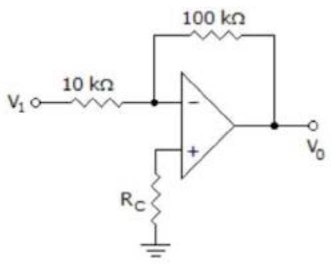


Figure 4

5 Calculate the gain for Inverting and Non Inverting amplifier?
V in = 6V, R in = 1KΩ, R f = 80KΩ and Give your Comment on Amplifier Gain.

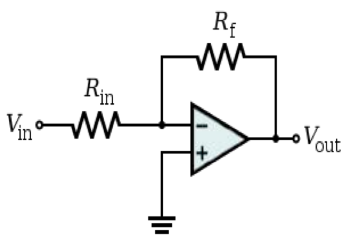
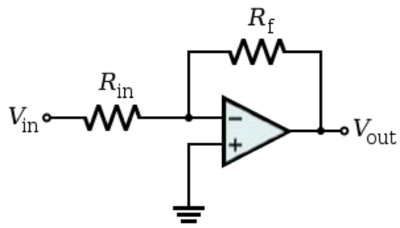


Figure 5

Task 3: Student can design the circuit based on given components.
Then, Student can provide the different inputs and get the desired result.
Assessment Questions: (2 marks each)

1 What is the smallest voltage that can be applied in the given scenario and still have Op-amp in linear phase?
IF: - VOFFSET = (-2.5,2.5)
RIN = 5Ω
RF = 25Ω



2 Design an inverting amplifier with gain 10 and input resistance range 500Ω to 1KΩ value.
3 In inverting amplifier, if input resistance and feedback resistance value are same then what should be the change in output?
4 Design 1ms Sample and Hold Circuit using Op-Amp.
5 Design Circuit for an automatic irrigation system that controls the switching operation (on and off) pump motor by sensing the soil moisture content.

Faculty 1: Experiment 4: Design after using the guidelines

Lab: Integrated Circuits
Experiment: Implementation of Op-amp as integrator as differentiator
Focus area: Exploring and Learning the different Configurations of Op-amp
1 Students will be able to calculate Output Voltage based on given values.
Apply.
2 Students will be able to derive the formula based on output.
Recall, Understand.
3 Students will be able to design the circuit based on application or usage.
Create
4 Students will be able to examine the configuration of OP-AMP
Analyze.

2. Instructional Strategy: Guide-Inquiry Based Experiment

Assessment Method: Formative Assessment
Description:
Op-amp and other resources will be provided to the student. They will be guided to step-by-step to make given circuit. The circuit will demonstrate Op-amp as integrator and as differentiator. Student will have an option to change the values of components and get the desired results.
Integrator is the circuit in which the output voltage in the integration of the input voltage. Op-amp Integrator is an operational amplifier circuit that performs the mathematical operation of Integration that is we can cause the output to respond to changes in the input voltage over time as the Op-amp integrator produces an output voltage, which is proportional to the integral of the input voltage.
Differentiator is the circuit which performs the mathematical operation of differentiation i.e. o/p voltage is derivative of i/p voltage.
There will be option of creating a graph as well. Students can get the graphs according to their experiment values, which they feed, earlier in the components.

3. Task & Assessment Questions:
Task1:
Read the theory and comprehend the concepts related to the experiment. [LO#1, LO#2, LO#3]
Assessment Questions: (1 mark each)
1 A differential amplifier
A. is a part of an Op-amp
B. has one input and one output
C. has two output
D. answer 1 and 2
2 When a differential amplifier is operated single-ended_______.
A. the output is grounded
B. one input is grounded and signal is applied to the other
C. both inputs are connected together
D. the output is not inverted
3 In differential-mode
A. opposite polarity signals are applied to the inputs
B. the gain is one
C. the outputs are of different amplitudes
D. only one supply voltage is used
4 With zero volts on both inputs, an Op-amp ideally should have an output
A. equal to the positive supply voltage
B. equal to the negative supply voltage
C. equal to zero
D. equal to CMRR

Task2:
Read and implement the procedure. [LO#1, LO#2]
Assessment Questions: (2 marks each)

What will happen if you reverse the components?
If the circuit is modified what analysis will you carry out?
State the purpose of each of the component used in the circuits?
What modification is required in the circuit to obtain the desired output?

Task3:
Answer the following questions: [LO#1, LO#2, LO#3]
Assessment Questions: (2 marks each)
1 what happen if r1 is constant in below figure? (2 marks)
a. r1 will get high
b. C will get high
c. can not be predicted

Task 4:
Applications based questions on integrator Op-amp circuitry
Determination of frequency [LO#1, LO#2]
Assessment Questions: (3 marks each)

Determine the lower frequency limit of integration for the circuit given below.
a 43.43kHz

b 4.82kHz
c 429.9kHz
d 4.6MHz

What will be the output voltage waveform for the circuit, $R1 \times CF = 1s$ and input is a step voltage. Assume that the Op-amp is initially nulled?
a) Triangular function
b) Unit step function
c) Ramp function
d) Square function

Task 5:
Design and build logical circuits using the generalized simulator. [LO#1, LO#2, LO#3, LO#4]
Assessment Question: (4 marks each)
Find the output waveform for an input of 5kHz.

Faculty 2: Experiment 1: Design after using the guidelines

Lab: Integrated Circuits & Applications
Experiment: 555 Timer As Astable & Monostable Multivibrator
Focus area: Analysis and Design of 555 Timer based circuits.
1 Students will be able to calculate or solve various Circuit parameters. Apply
2 Students will be able to contrast or evaluate based on the different circuits and applications. Analyze
3 Students will be able to draw output waveforms of given 555 Timer IC based circuits Analyze the data or ratings. Evaluate
4 Students will be able to designing of 555 Timer circuit as per given specification. Create

2. Instructional Strategy: Problem-based Laboratory Experiment Design

Assessment Method: Formative Assessment
Description:
A 555 Timer circuit will basically have the two basic operating modes of the IC- the astable and the monostable modes. The basic work of this circuit is to generate a square waveform. Ultrasonic frequency generator for making mosquito repellent circuit design the 555 Timer circuit as per given specification.

3. Task & Assessment Questions:

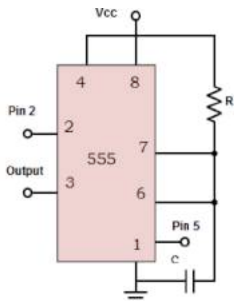
Task1:
Read the theory and comprehend the concepts related to the experiment.
Assessment Questions: (1 mark each)
1 Find monostable vibrator circuit using 555 timer.

2 Determine the time period of a monostable 555 multivibrator.

A. T = 0.33RC
B. T = 1.1RC
C. T = 3RC
D. T = RC

3 Which among the following can be used to detect the missing heart beat?
A. Monostable multivibrator
B. Astable multivibrator
C. Schmitt trigger
D. None of the mentioned

4 What will be the output, if a modulating input signal and continuous triggering signal are applied to pin5 and pin22 respectively in the following circuit?
A. Frequency modulated waveform
B. Pulse width modulated waveform
C. Both pulse and frequency modulated waveform
D. None of the mentioned



5. A 555 timer in monostable application mode can be used for?
A. Pulse position modulation
B. Frequency shift keying
C. Speed control and measurement
D. Digital phase detector

6 Load is connected between Output pin and Ground. Which type of loads is it called?
A. Partially ON
B. Normally ON
C. Normally OFF
D. Partially ON

Task2:
Read and implement the procedure.
Assessment Questions: (2 marks each)
1 What will be the equation behind Ton and Toff in Calculator for Astable Multivibrator?

2 Once you land on the Calculator simulator page what is the default Value of the RA, RB, C and Vcc and Vo?
3 What will be the output of Astable Multivibrator with RA=RB=7K and C=21uF?
4 Try to do a very keen observation.
5 conclude the experiment.

Task3:
Answer the following questions:
Assessment Questions: (2 & 4marks each)
1 How can a monostable multivibrator be modified into a linear ramp generator?
A. Connect a constant current source to trigger input
B. Connect a constant current source to trigger output
C. Replace resistor by constant current source
D. Replace capacitor by constant current source

2 Mosquito irritate by ultrasonic sound, if you asked to design mosquito repellent using 555 Timer which configuration of 555 timer you will use.
A. Astable
B. Bistable
C. Monostable
D. ALl of these

3 Your lab instructor of Digital Electronics, asked you to design a TTL test probe, which generates 1khz TTL square wave. Design the same using 555 Timer (Draw schematic output waveform and show derivation of circuit component values and test the same using simulator.)
4 Design 1 Second to 100 Second Variable timer circuit for which time period can be set to any value between 1-100 second by 180 linear rotation of potentiometer.(Draw Schematic, Output Waveform and show derivation of circuit component values and test the same using simulator)

Faculty 2: Experiment 2: Design after using the guidelines

Lab: Integrated Circuits and Logic Application
Experiment: To design and implement schmitt trigger circuit using op-amp
Focus area: Logical Analysis Skill
2. Instructional Strategy: Problem-based Laboratory Experiment Design

Assessment Method: Formative Assessment
Description:
Schmitt trigger is an electronic circuit with positive feedback, which holds the output level till the input signal to comparator is higher than the threshold. It converts a sinusoidal or any analog signal to digital signal. It exhibits hysteresis by which the output transition from high to low and low to high will occur at different thresholds.

3. Task & Assessment Questions:
Task1: Read the theory and comprehend the concepts related to the experiment. [LO#1, LO#2, LO#3]

Assessment Questions: (1 mark each)
1 A Schmitt trigger is
A. a comparator with only one trigger point.
B. a comparator with hysteresis
C. a comparator with three trigger points.
D. none of the above

2 A good example of hysteresis is a(n)
A. AM radio.
B. thermostat
C. alarm clock
D. none of the above.

3 A comparator with a Schmitt trigger has?
A. two trigger levels.
B. a fast response.
C. a slow response.
D. one trigger level.

4 How to limit the output voltage swing only to positive direction??
A. Combination of two zener diodes
B. Combination of zener and rectifier diode
C. All of the mentioned
D. Combination of two rectifier diodes

5 Schmitt Trigger Circuit uses
A. Positive feedback
B. Negative feedback
C. Compensating capacitors
D. Pull up resistor

Task2:
Read and implement the procedure. [LO#1, LO#2]
Assessment Questions: (2 marks each)
R1=100000 ohm, R2=35000 ohm
1 What kind of feedback is given in fig
2 Calculate the threshold voltage from the given parameter?
3 By changing the different inputs using function generator, analyze the outputs?

Task3:
Answer the following questions:
Assessment Questions: (2 marks each)
1In the frequency counter, what is the function of the Schmitt trigger circuit?
A. To reduce input noise
B. To condition the input signal
C. To convert non-square waveforms
D. To provide a usable signal to the display unit

2 In the digital clock project, the 60 Hz signal is sent through a Schmitt-trigger circuit to produce square pulses at the rate of ________.

(i)1 pps (ii) 60 pps(iii) 100 pps
(iv) 600 pps

3 Suppose that you have an unknown two-input gate that is either an OR gate or an AND gate. What combination of input levels should you apply to the gate's inputs to determine which type of gate it is? (4 marks)
<img height="150px" width="150px" align="right"
A. 0, 0
B. 0, 1
C. 1, 0
D. Either B or C

4 No matter how many inputs it has, an AND input gate will produce a HIGH output for only one combination of input levels.
A. TRUE
B. FALSE
C. Cannot be said
D. None of these

5 If both the inputs of an AND gate are shorted together and tied to HIGH, the output of the gate is:
A Low
B High
C Tristate
D None of these

Task 4:
Using the generalized simulator, select the appropriate gates and do connections for this experiment with following changes:
Replace motor and the wiper with green LED. [LO#1, LO#2]

Assessment Questions: (2 marks each)
Name the different gates provided on the generalized simulator.
Does the simulator allow selection of more than two input gates?
To make the connections which features on the generalized simulator did you select?
Does the simulator page prompt any messages while working on it? Do you find these messages useful?
Formulate the truth table for this application.

Task 5:
Design and build logical circuits using the generalized simulator. [LO#1, LO#2, LO#3, LO#4]
Assessment Questions: (4 marks each)
Determine the truth table for the following figure and obtain a Boolean expression for the output.
Note: The div block (Y connector) represented in the above diagram is used when a single point is to be connected to multiple point.
2 Build the logic circuit in above figure using the generalized simulator.
3 Simulate and verify the function of the circuit. 4. If inputs A1 and B1 in above diagram are swapped, does the output expression remain unchanged?

5 For the circuit given above find the simplified expression. Compare the working of given circuit with the simplified circuit. Which logic gate can replace this entire logic circuit?

Task 6:
Design a combinational logic circuit for the given problem statement and analyze and verify the circuit working using generalized simulator. [LO#1, LO#2, LO#3, LO#4]
Assessment Questions: (5 marks each)
Problem Statement: A washing machine dryer dries the clothes only if the timer is set above zero and the machine door is closed.
Consider Timer set above zero as equivalent to logic 1 and machine door closed as logic 1.
a. Formulate the truth table for the same.
b. Design and implement the circuit using generalized Simulator.
c. Verify the functionality of your design.
d. What do you observe at the output when machine door is left open?
e. Draw relevant conclusion.

Problem Statement: A burglar alarm circuit should sound an alarm only when the alarm-switch is ON and an unauthenticated person is detected (ON). Design and implement the circuit using generalized Simulator. What conclusion will you draw from the experiment?

The Boolean expressions of a half-adder circuit (a circuit that adds two single bits and produces a SUM and a CARRY output) are given as:
Carry = A1.B1 and Sum = A1 XOR B1
Implement the Carry circuit and verify.

Identify the different applications areas for AND gate using analogy.

The generalized simulator provides only two-input gates. How will you implement a four-input AND gate using two-input AND gates? Assume that the propagation delay of each AND gate is 10 ns. Compare the propagation delay of the four-input AND gate with that of two-input AND gate.

Faculty 2: Experiment 3: Design after using the guidelines

Lab: Linear Circuit Applications
Experiment: Implementation of Adder (Summing) & Subtractor using Op-Amp
Focus area: Circuit Analysis Skill
1. Learning Objectives and Cognitive Level
1 Students will be able to describe the operation of Adder & Subtractor circuit. Understand
2 Students will be able to Use the simulator Verify the functioning of adder & Subtractor using various inputs (like Pulse, Sine, Cosine etc.). Analyze
3 Students will be able to draw the output waveforms of adder & Subtractor circuits with the n number of inputs. Apply

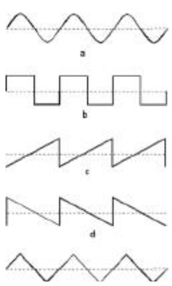
4 Students will be able to implement a circuit having function (A+B)-(C+D) where A, B, C and D are various inputs. Verify the working using given generic simulator. Create

2. Instructional Strategy: Structured Problem-based Laboratory Experiment Design
Assessment Method: Formative Assessment
Description:
A summing amplifier is given for two inputs one of the input carry voice signal or any known input source and another input carry drum beats or any known input source we have to add the signal and to verify the output using simulation. A Subtractor circuit gives the difference of input voltages in this experiment we have to apply different inputs and verify the output.

3. Task & Assessment Questions:

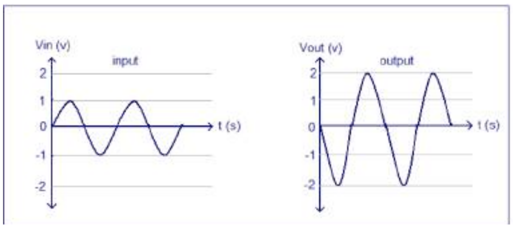
Task1:
Read the theory and comprehend the concepts related to the experiment. [LO#1, LO#2, LO#3]
Various tasks and assessment questions
1. Change the value of resistance of adder. Identify the circuit (a) adder (b) average (c) Weighted
2. Change the value of resistance of Subtractor. Find the gain
3. Change the gain of Op-Amp. Observe the output of the circuit
4. Change input voltage to DC supply (for all input). Compare the theoretical & simulated outputs results
5. Charge the input voltage to sine waveform for all inputs. Compare the theoretical & simulated outputs results.
6. Change 1 input to dc supply and other input to sine. Observe the output by charging input dc supply
7. Supply voltage is changed and input voltage remains same. Observe the different output voltage or different voltage

Assessment Questions: (1 mark each)
1 Which of the signal is saw tooth?



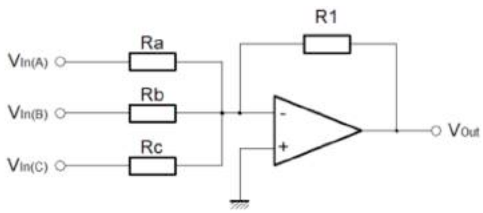
A. a
B. b
C. c
D. d

2 Find gain by analyzing input and output waveform.



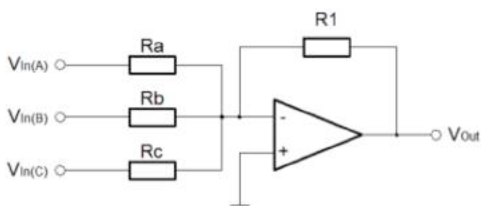
A. 2
B. -2
C. 1
D. -1

3 Identify the circuit? If R1 = Ra = Rb = Rc



A. Summing
B. Averaging
C. Weighted
D. None of These

4 Calculate the output of the circuit? If R1 = Ra = Rb = Rc =1K & Vin (a)=1v, Vin(b)=2v & Vin(c)=5v

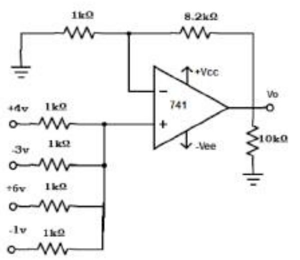


A. Summing
B. Averaging
C. Weighted
D. None of These

Task2:
Read and implement the procedure. [LO#1, LO#2]
Assessment Questions: (2 marks each)
1. Once you land on the simulator page how many options are there to select?
2. What will happen when supply voltage is not applied in operational amplifier in Summing Amplifier Option?
3. What happen if in Subtractor Option one of the inputs is set to zero? Is this kind of waveform is studied before this experiment?

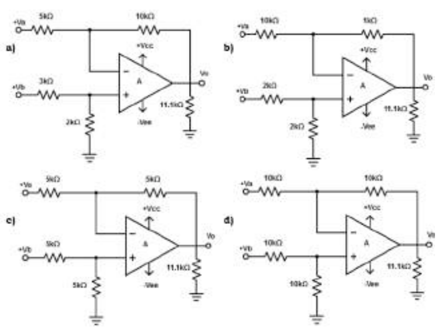
Task3:
Answer the following questions: [LO#1, LO#2, LO#3]
Assessment Questions: (2 marks each)
1. Expression for output voltage of non-inverting summing amplifier with five input voltage?
A. Vo = 5×(Va + Vb+ Vc+ Vd+ Ve)
B. Vo = [1+(Rf/R1)]× (Va + Vb+ Vc+ Vd+ Ve)
C. Vo = Va + Vb+ Vc+ Vd+ Ve
D. Vo = (Va + Vb+ Vc+ Vd+ Ve) /5

2. Find the value of V1 in the circuit shown below?



4 v
2 v
3 v
None of These

3 Find the differential amplifier configured as a Subtractor from the given circuit. (4 marks)



a
b
c
d

4 Calculate the output voltage, when a voltage of 12mv is applied to the non-inverting terminal and 7mv is applied to inverting terminal of a Subtractor.
A. 19 mV
B. 5 mV
C. 1.7 mV
D. 8.4 mV

5 In which type of amplifier, the input voltage is amplified by a scaling factor
A Summing amplifier
B Averaging amplifier
C Weighted amplifier
D Differential amplifier

Task 4:
Using the generalized simulator, select the appropriate number of inputs in summing amplifier for this experiment with following changes:
Modify the circuit with three or four inputs [LO#1, LO#2]
Assessment Questions: (2 marks each)
Name the different components provided on the generalized simulator.
Write the short cut key for placing components and wires?

Task 5:
Design adder circuit for the given problem statement and analyze and verify the circuit working using generalized simulator. [LO#1, LO#2, LO#3, LO#4]

Faculty 2: Experiment 4: Design after using the guidelines

Lab: Integrated Circuits and Applications
Experiment: To obtain frequency response of inverting and non inverting
Focus area: Circuit analysis skills
1 Students will be able to plot different frequency sin signal and plot frequency and time response of the signal. - Understand
2 Students will be able to describe the frequency response of Op-Amp. - Understand
3 Students will be able to plot graph between 1.Frequency and amplitude 2.Phase and amplitude and analyze the change in the input frequency. - Analyze
4 Students will be able to create a circuit using Op-Amp whose cut-off frequency is 20 MHz and phase difference is 45. - Create

2. Instructional Strategy: Problem-based Laboratory Experiment Design
Assessment Method: Formative Assessment

Description:
Typically op amps are used for comparatively low frequency circuits, but with the performance of these chips is improving all the time, much higher bandwidth op amps and op amp circuits are available.

So for the students, the bandwidth of the op-amp itself obviously has a bearing on the design of the op amp circuit and the frequency response or bandwidth available for the circuit.

Task1: Read the theory and comprehend the concepts related to the experiment. [LO#1, LO#2, LO#3]
Sr. No: Tasks to be performed by students: Assessment questions aligned to the task
1. Change the value of output resistance of Op-Amp. Find the cut-off frequency of the circuit

2. Change the value of input frequency. Find amplitude of output of Op-Amp
3. Change the supply voltage of circuit to DC. Compare the simulated and theoretical output result
4. Change the gain of Op-amp. Observe the output of the circuit
5. Change the supply voltage to sine waveform for all inputs. Compare the simulated & theoretical outputs results

Assessment Questions: (1 mark each)

1 A differential amplifier_____.

A. Is a part of Op-amp
B. Has one input and one output
C. Has two outputs
D. Answer (a) and (b) both

2. The Op-amp can amplify_______.
A. AC signals only
B. DC signals only
C. Both AC and DC signals
D. Neither AC nor DC signals

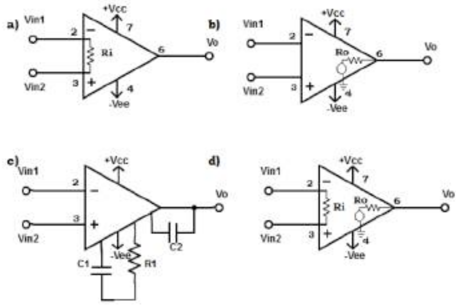
3. In the expression Vo= - AVn, A is called ________
A. Closed loop gain
B. Closed loop fault
C. Open loop gain
D. Open loop fault

4. The input applied to an Inverting amplifier is _______
A. Equal to output
B. Equal to inverted output
C. Not equal to output
D. Output is equal to input

Task2: Read and implement the procedure. [LO#1, LO#2]: Assessment Questions: (2 marks each)

1. State assumptions made for analyzing ideal op-amp.
2. What do you observe when negative feedback is present in a non-inverting op-amp?
3. Summarize: Why Op-amp is used mostly as an integrator than a differentiator?
4. Why OPAMP called direct coupled high differential circuit?

Assessment Questions: (3 marks each): Answer the following questions:
Find out the non-compensating op-amp from the given circuit



“Frequency Response and Compensating Networks”.

Variation in the operating frequency of op-amp causes
a) Variation in gain amplifier
b) Variation in gain phase angle
c) Variation in gain amplitude and its phase angle
d) None of the mentioned

Which of the following causes change in gain and phase shift?
a) Internally integrated Resistor
b) Internally integrated inductors
c) Internally integrated Capacitor
d) All of the mentioned
Lab: Integrated Circuits
Experiment: Parameters of OP-AMP
Focus area: Design and Analysis Skill
1. Learning Objectives and Cognitive Level
1 Students will be able to describe what all-different parameters like input bias current, input offset current and input offset voltage student should gain from it. Understand
2 Students will be able to conclude measure of impedance based on parameters. Analyze
3 Students will be able to design circuit diagram based on OP-AMP after performing the experiments. Analyze
4 Students will be able to calculate offset current measured in microampere. Analyze

2. Instructional Strategy: Guided enquiry Laboratory Experiment Design
Assessment Method: Formative Assessment
Description: To learn, observe and measure OP-AMP 741 parameter like open loop gain, input offset current, input offset voltage and Output offset voltage.

3. Task & Assessment Questions:
Task1: Read the theory and comprehend the concepts related to the experiment. [LO#1, LO#2, LO#3]
Assessment Questions: (1 mark each)
1. The center frequency of a band-pass filter is always equal to the
A. bandwidth
B. –3 dB frequency
C. bandwidth divided by Q
D. geometric average of the critical frequencies
2. An ideal operational amplifier has
A. infinite output impedance
B. zero input impedance
C. infinite bandwidth
D. Nibble
3. Another name for a unity gain amplifier is:
A. difference amplifier
B. comparator
C. single ended

D. voltage follower

4. Op-amps used as high- and low-pass filter circuits employ which configuration?

A. noninverting

B. comparator

C. open-loop

D. inverting

5. With negative feedback, the returning signal

A. is proportional to the output current

B. is proportional to the differential voltage gain

C. opposes the input signal

D. aids the input signal

Task2: Read and implement the procedure. [LO#1, LO#2]

Assessment Questions: (2 marks each)

1 If op-amp is a multistage on the simulator page, it will usually consist of how many amplifiers?

2 What do you observe when Input offset voltage gain parameter is passed.

3 What do you observe when offset current parameter is passed.

4 What result do you expect when the output impedence is 0?

5 Interpret and conclude the experiment.

Task3: Answer the following questions: [LO#1, LO#2, LO#3]

Assessment Questions: (2 marks each)

1 The voltage follower has a:

A. closed-loop voltage gain of unity

B. small open-loop voltage gain

C. closed-loop bandwidth of zero

D. large closed-loop output impedance

2 If the gain of a closed-loop inverting amplifier is 3.9, with an input resistor value of 1.6 kilohms, what value of feedback resistor is necessary?

A. 6240 ohms

B. 2.4 kilohms

C. 410 ohms

D. 0.62 kilohms

3 In an open-loop op-amp circuit, whenever the inverting input (–) is negative relative to the noninverting input (+), the output will:

A. swing negative

B. close the loop

C. be balanced

D. swing positive

4 If an op-amp has one input grounded and the other input has a signal feed to it, then it is operating as what?

A. Common-mode

B. Single-Ended

C. Double-Ended

D. Noninverting mode

5 When a capacitor is used in place of a resistor in an op-amp network, its placement determines:
A. open- or closed-loop gain
B. integration or differentiation
C. saturation or cutoff
D. addition or subtraction

Task 4:
• Using the generalized simulator, select the appropriate gates and do connections for this experiment with following changes:
• By varying resistance and volatge. [LO#1, LO#2]

Assessment Questions: (2 marks each)
1. Name the different parameters provided on op - amp.
2. Does the simulator allow selection of more than two input gates?
3. To make the connections which features on the generalized simulator did you select?
4. Does the simulator page prompt any messages while working on it? Do you find these message useful?
5. Formulate the reading table for this application.

Task 5: Design and build logical circuits using the generalized simulator. [LO#2]
Assessment Questions: (4 marks each)
Build the logic circuit for input offset voltage, output offset voltage in OP-AMP, input offset current and offset null OP-AMP using the generalized simulator.
Simulate and verify the function of the circuit. What happen if we choice two values of current? Does the output expression remain unchanged? Compare the working of given circuit with OP-AMP 709.

Task 6: Design an Integrated Circuit using OP-AMP and analyze and verify the circuit. [LO#1, LO#2, LO#3, LO#4]
Assessment Questions: (5 marks each)
Problem Statement: A Person in the mall is giving speech about the problem happening with everyone.
The person standing at last is not able to hear his speech.
What will the person giving speech will do so that last person can also hear his Speech. Use OP-AMP(741)
a. Design and implement the circuit using OP-AMP(741)
b. Implement OP-AMP using different parameters.
c. Draw relevant conclusion.

Faculty 3: Experiment 1: Design after using the guidelines
Lab: Integrated circuit
Experiment: Study and implementation of Op-Amp
Focus area: Operational Amplifiers
1. Learning Objectives and Cognitive Level
1 Students will be able to compare frequency response of low and high pass filter using Op-Amp. Recall & Understand
2 Students will be able to design high pass filter for low cut off frequency using On-Amp rule. Create

3 Students will be able to design low pass filter for high cut off frequency using On-Amp rule. Create

2. Instructional Strategy: Problem-based Laboratory Experiment Design
Assessment Method: Formative Assessment
Description:
An operational amplifier (often op-amp or opamp) is a DC-coupled high-gain electronic voltage amplifier with a differential input and, usually, a single-ended output. Op-amps are among the most widely used electronic devices today, being used in a vast array of consumer, industrial, and scientific devices. A Low pass filter can pass the Low frequency and suppress all other and high pass filter can pass the high frequency and suppress all other.

3. Task & Assessment Questions:
Task1: Read the theory and comprehend the concepts related to the experiment. [LO#1, LO#2, LO#3]
Assessment Questions: (1 mark each)
1 When a differential amplifier is operated single-ended
A. the output is grounded
B. one input is grounded and signal is applied to the other
C. both inputs are connected together
D. the output is not inverted
2 For an Op-amp with negative feedback, the output is
A. equal to the input
B. increased
C. fed back to the inverting input
D. fed back to the noninverting input
3 The use of negative feedback is to
A. reduces the voltage gain of an Op-amp
B. makes the Op-amp oscillate
C. makes linear operation possible
D. answers (1) and (2)
4 With zero volts on both inputs, an OP-amp ideally should have an output
A. equal to the positive supply voltage
B. equal to the negative supply voltage
C. equal to zero
D. equal to CMRR
5 A certain OP-amp has bias currents of 50 μA. The input offset current is
A. 700 nA
B. 99.3 μA
C. 49.7 μA
D. none of these

Task2: Observe frequency response and implement [LO#1, LO#2]
Assessment Questions: (2 marks each)
1 What is an op-amp?
2 List the four basic building blocks of an op-amp.
3 What is frequency response?
4 What is the difference between monolithic and hybrid ICs?

Task3: Answer the following questions: [LO#1, LO#2, LO#3]
Assessment Questions: (2 marks each)
1. Explain the effect of negative feedback on frequency response.
2. Define break frequency
3. Define bandwidth
4 Define input offset voltage and explain why it exists in all op-amps?

Task 4: Using Op-Amp design a low pass filter with cut off frequency 1kHz by choosing your own components.
Assessment Questions: (2 marks each)
1.Define a filter. How are filters classified?
2. List the most commonly used filters?

Task 5: Detect the audio frequency [LO#1, LO#2, LO#3]
Assessment Questions: (4 marks each)
1 Determine the High frequency and low frequency of audio.
2 Build the bass & Treble circuit.

Task 6: Using Op-Amp design a high pass filter with cut off frequency 1MHz by choosing your own components.

Appendix III. Design experiment with Expository instructional strategy
Experiment Design for learning objective at Evaluate level

This is the most popular instructional strategy used in the traditional laboratories. The following template should be used in order to design experiment for this instructional strategy. This strategy is criticized to be having a cookbook nature and has no activities require students to operate at any of the three higher cognition levels, analysis, evaluation or creation. But by simple modifications in the design of the various phases this can become an effective design incorporating a constructivist approach. The guidelines provide the details of the changes during various phases to convert the traditional expository design to a more effective design.

Step 1: Phases in the experiment design

You can design your laboratory experiment considering the following four important phases in the process

1. Conception, planning and design of experiment
2. Execution of experiment
3. Analysis and interpretation
4. Applications

Phase 1: Conception, planning and design of experiment

During this phase the following activities need to be carried out.

- Formulate question or problem to be investigated.
- Decide the broad goal of the experiment
- Formulate learning objectives
- Determine replications
- Identify treatments/ Suggesting technical procedures
- Technical preparation of the experiment (assembling tools, preparing solutions, constructing circuits etc.)
- Define dependent variable
- Define independent variable
- Design experiment
- Design observation and measurement procedures
- Predict results

You can design these activities yourself or make the student carry out these. Here is one example from the course Basic Electronics for the expository instructional strategy with tips on how active learning can be incorporated in each phase of the design.

1. **Conception, planning and design of experiment**

- **Formulate question or problem to be investigated.**
  Example from BAE: Of the given two diodes which one is more suitable for the purpose of rectification?

Decide the broad goal of the experiment
Example from BAE: Reinforce the theoretical concept of diode as a rectifier

- **Formulate learning objectives**
Example from BAE: 1.Student should be able to plot the graph of voltage vs. current in a PN junction diode
2.Student should be able to analyse the graph
3.Student should be able to identify the various regions in the graph
4.Student should be able to evaluate the characteristics of the two diodes and identify the one suitable for rectification

- **Determine replications**
Example from BAE: The plot can be obtained for multiple diodes having different specifications

- **Identify treatments/ Suggesting technical procedures**
Example from BAE: Circuit diagram of the experiment and DC analysis
Guideline 1: Instead of giving the circuit diagram ask the students to construct their own circuit.
Task: Construct the circuit on paper necessary to carry out the given experiment.

- **Technical preparation of the experiment (assembling tools, preparing solutions, constructing circuits etc.)**
Example from BAE: 1.In order to carry out the experiment use the Virtual lab available at the URL – www.docircuits.com
2. You will have to register for using the lab
3. After registration login and start the Circuit Simulator.
4. Construct the circuit by dragging and dropping the necessary components and equipment
Guideline 2: Instead of specifying the details of how to come up with the circuit ask the students to explore and identify the simulator available online in order to carry out the experiment. Let them explore the simulator and come up with the circuit on their own. In this step of technical preparation of the experiment the student may be given different circuits and asked to evaluate

them and identify the most suitable circuit design for the particular experiment.

Tasks: Explore the various online virtual labs available and identify the one most suitable to carry out the given experiment. Construct the appropriate circuit using the selected simulator.

- **Define dependent variable**
  Example from BAE: Current flowing through the diode (Id)
  Guideline 3: Ask the students to identify the dependent variable.
  Task: What parameter of the PN junction diode will you measure for the given experiment? How will you carry out the measurement?

- **Define independent variable**
  Example from BAE: Voltage across the diode (Vd)
  Guideline 4: Ask the students to identify the independent variable.
  Task: What parameter of the PN junction diode will you vary for the given experiment? How will you vary the parameter?

- **Design experiment**
  Example from BAE: 1. You can carry out the DC analysis of the circuit by selection of proper simulation settings.
  2. After constructing the circuit, click on the simulation tab and select the DC analysis
  3. Select the suitable settings for the DC analysis as per the necessary plot
  4. After the selection of settings is done click on the run button to obtain the graph of voltage vs. current.

  Guideline 5: Ask he students to explore the various types of analysis that can be carried out with the selected virtual lab and select the type of analysis suitable for the given experiment. Ask the students to select the most suitable settings and carry out the necessary action to obtain the results.
  Task: Explore the various types of analysis that can be carried out with the virtual lab you have selected. Decide the type of analysis you will carry out for finding out the V-I plot of the PN junction diode. Select the suitable settings and obtain the plot.

- **Design observation and measurement procedures**
  Example from BAE:
  1 Measure the range of values of voltage and current for which the graph is linear.
  2 Repeat the steps for the other diode
  3 Of the two diodes identify which diode has a larger range of linear relation
  Guideline 6: Do not specify each and every step but ask the students to identify the linear and non-linear regions in the graph, recall the formula for the static and dynamic resistance and measure them.
  Task: Identify the linear and non-linear regions in the graph. What will you measure in order to find out the suitability of the diode for the purpose of rectification?

- **Predict results**
  Example from BAE: 1. You should obtain a graph as per the figure given.
  Guideline 7: Do not specify the type of graph the students should get but ask them to predict the result.
  Task: Did you get the graph as per the desired results? If not what modifications will you carry out in order to get the necessary graph? Carry out the modifications and obtain the graph.

Checklist1: Did you carry out the following activities or have assigned to the students?

Table III.1 Checklist for Phase I

Activities	Given	Make students do
a. Formulate question or problem to be investigated		
b. Decide the broad goal of the experiment		
c. Formulate learning objectives		
d. Determine replications		
e. Identify treatments/ Suggesting technical procedures		
f. Technical preparation of the experiment		
g. Define dependent variable		
h. Define independent variable		
i. Design experiment		
j. Design observation and measurement procedures		
k. Predict results		

Phase 2: Execution of experiment

During this phase the following activities need to be carried out.

- Specify Observations to be taken or data to be gathered
- Specify the Measurements to be carried out
- Describe the Manipulations possible
- Explain the methods for Recording the results
- Specify the various Calculations to be carried out
- Specify the ways of Explaining experimental techniques
- Describe methods for Explaining about various decisions
- Working according to the design

- Specify Observations to be taken or data to be gathered
  Example from BAE: Observe the graph of voltage across diode and current flowing through the diode obtained.
  Guideline 8: Do not specify the parameters but ask the students to identify them.
  Task: Which variables will you plot on the graph? Select the two axes for the variables? Select the suitable settings for the two axes.

- Specify the measurements to be carried out
  Example from BAE: Measure the linear range for both the diodes.

  Guideline 9: Ask the students to identify the measurements they need to carry out.

Task: What observations you will carry out? What measurements will you carry out? What parameters will you measure from the graph obtained? Carry out the necessary measurements.

- Describe the manipulations possible

Example from BAE:

- Explain the methods for recording the results
- Specify the various calculations to be carried out

Example from BAE:

1. Calculate the value of slope of the diode 1 in the linear region.
2. Calculate the value of slope of the diode 2 in the linear region.
3. Identify which of the two diodes has a greater value of slope.

Guideline 10: Do not specify the complete details but ask the students to carry out the necessary steps to arrive at the result. In this step design observation and measurement procedures the students may be asked to evaluate the various ways of carrying out measurements and identify the most suitable procedure. These are the steps in which the students may be asked to carry out multiple observations, measurements and calculations. These steps are also most suitable for developing the investigative, manipulative and analysis skills.

Task: Now change the diode in the circuit and obtain the desired graph. Select the necessary settings and the suitable variables for the plot. Repeat the procedure for the second diode selected. Measure the parameter to find which of the two diodes will you prefer for rectification.

Checklist2: Did you carry out the following activities or have assigned to the students?

Table III.2 Checklist for Phase II

Activities	**Given**	**Make students do**
a. Specify the measurements to be carried out		
b. Describe the manipulations possible		
c. Explain the methods for recording the results		
d. Specify the various calculations to be carried out		

Phase 3: Analysis and interpretation

During this phase the following activities need to be carried out.

- Transform results into standard form (tables).
- Determine relationships (could include graphs)
- Discuss accuracy of data.
- Report about procedures and results
- Interpretation of results
- Statistical analysis of results
- Formulate generalizations.
- Discuss limitations/assumptions of experiment.
- Explain relationships.
- Formulate new questions/problems.

You can design these activities and make the student carry out various tasks depending on the instructional strategy you wish to incorporate, target knowledge and skills and the difficulty level of the experiment you wish to set. In order to assess whether the students are carrying out the tasks/activities various assessment questions may be asked or prompts may be designed to provide opportunities for students to reflect on the results of the tasks/activities.

- Transform results into standard form (tables)
  Example from BAE: Complete the following Table for the values of Vd and Id.

	Diode 1				Diode 2			
S.No.	Forward Bias		Reverse Bias		Forward Bias		Reverse Bias	
	Vd (volts)	Id (mA)	Vd (volts)	Id (μA)	Vd (volts)	Id (mA)	Vd (volts)	Id (μA)

Guideline 11: Do not give the detailed data table but ask the students to form their own table. Make them write the headings of the rows and the columns.

Task: Tabulate the data you measure from the graphs obtained. Specify the headings of the rows and columns along with the units of each variable.

- Determine relationships (could include graphs). Discuss accuracy of data. Report about procedures and results

  Example from BAE: Obtain the graph as given in the figure. The graph has a linear region and non-linear region. The cut-in voltage of the PN junction diode should be 0.7 Volts. The graph should be linear after this voltage and later becomes non-linear. The slope of the graph changes after the cut-in voltage.

  Guideline 12: Do not specify the results the student should get from the experiment instead ask the students to find out whether they get the desired results.
  Task: Observe the graph you have obtained after running the simulation and describe the nature of the plot. Is the nature of the graph as per desired? If not what modifications are required in order to obtain the necessary graph? What type of analysis did you carry out? Why? What simulation setting did you choose? Why?

- Interpretation of results
  Example from BAE: What can you infer from the graph obtained?

Checklist3: Did you carry out the following activities or have assigned to the students?

Table III.3 Checklist for Phase III

Activities	**Given**	**Make students do**
a. Transform results into standard form (tables).		
b. Determine relationships (could include graphs)		
c. Discuss accuracy of data.		
d. Report about procedures and results		
e. Interpretation of results		

Phase 4: Applications

During this phase the following activities need to be carried out.

- Predict applications based on results
- Formulate follow up hypotheses
- Apply experimental technique to new problem
- Summing up of acquired knowledge

- Predict applications based on results

  Example from BAE: The PN junction diode is used for the following applications – As a Rectifier, Clipper, Clamper and Switch.

  Guideline 13: Do not specify the applications to the students but ask them to explore and find out the applications themselves.

  Task: What are the various applications where PN junction diode can be used?

- Formulate follow up hypotheses
- Apply experimental technique to new problem
- Summing up of acquired knowledge

  Guideline 14: Based on the results of the experiment ask the students to come up with a new concept to be verified. The concept may be related to the same device or some other similar device. Ask them to set up the complete experiment to verify the new concept.

  Task: Identify another concept from the same topic of PN junction diode or characteristics of other types of diodes such as Zener Didoe, Light Emitting Diode etc. Set up and perform all the tasks to verify the selected concept. OR Identify similar concept for the BJT and perfrom the complete experiment to verify the nature of Input or Output characteristics.

Checklist4: Did you carry out the following activities or have assigned to the students?

Table III.4 Checklist for Phase IV

Activities	**Given**	**Make students do**
a. Predict applications based on results		
b. Formulate follow up hypotheses		
c. Apply experimental technique to new problem		
d. Summing up of acquired knowledge		

Additional Guidelines

Guideline 15: Have students suggest sources of error in the lab and modifications to eliminate these sources of error, and raise questions about the lab. Comparisons of data between groups in class and between classes may raise questions about sources of variation. Students can produce questions by substituting, eliminating, or increasing or decreasing a variable.

Guideline 16: Have students make predictions and explain them before the lab. Having students make predictions creates interest in the outcome. In addition, have students explain the basis for their predictions using their present ideas. Challenge students to come up with alternative hypotheses.

Guideline 17: Give the students an opportunity to discuss their predictions, explanations, procedures, and data table before doing the lab, and give them an opportunity to present their results after the lab. The process of formulating an opinion to express and share with a group promotes reflection.

Guideline 18: Give students opportunity to demonstrate applications after the lab. Students need opportunities to use new ideas in a wide range of contexts.

Guideline 19: In order to achieve the learning objectives at higher cognitive levels the students may be asked to plot multiple graphs and measure various parameters for each of the graph. They may be asked to calculate the values of parameters with the theoretical values and then compare the values obtained from calculations and obtained practically. Based on the results they may be asked to draw inferences from the results obtained.

Guideline 20: Ask the students to carry out the experiment in the virtual lab before they perform the same experiment in the physical lab. Make them compare the results obtained in virtual lab with those in the physical lab. Ask them to identify the reasons for the difference in the results obtained in the two formats of the lab.

Guideline 21: Ask the students to carry out the experiment in the virtual lab after they perform the same experiment in the physical lab as a practice. Many times the students are not able to complete the experiment in the physical lab. The virtual lab can help the students as a practice.

Guideline 22: The virtual lab experiment may be used for the purpose of assessment. The students may perform the experiment in physical lab and virtual lab. The final assessment may be given as a virtual lab experiment. The assessment activities can be designed to target the higher cognitive levels.

Guideline 23: Each student may be given a different experiment for the same topic and also the same level by varying the values of certain parameters. This can reduce the plagiarism practices. If the students share their results with the peers this can also help students understand the variations in the results obtained.

BAE example – PN junction diode

Ask the students to plot the graph of V-I characteristics for different diode specifications. Ask the students to adjust one specification for example the internal resistance of the diode Rs to different values and plot the V-I characteristics. Make the students analyse the change in the nature of the graph for the different values. This can be repeated for each of the specification on which the nature of the graph depends. These tasks are helpful in developing the higher level learning objectives of analysis and evaluation.

BAE Example

The example from BAE course and topic PN junction diode is given below

Activities	Example from course Basic Electronics
Predict applications based on results	What are the various applications where PN junction diode can be used?
Formulate follow up hypotheses	Justify with the help of an experiment that the PN junction diode is suitable for the purpose of rectification.
Apply experimental technique to new problem	Design the experiment for the above purpose.
Summing up of acquired knowledge	Write a summary of your learnings from the two experiments.

Guideline 24 – LO at create level
In the technical preparation of the experiment the student may be asked to design his or her own circuits.
In the step design observation and measurement procedures the students may be asked to come up with their own observations and procedures.
To achieve the learning objective at create level the students may be asked to design their own observations, measurements and calculations.

Appendix IV. Sample Learning Outcome test Questions and Sample students answers

Student Name: CHINMAY KRISHNAKUMAR BHAGWAT Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- first we set base current to 2mA as a dc source 1 as a constant current source.then we wanted to change collector to emmiter voltage that is dcsource2 from 0 to 5 volts. thats why we used advanced analysis from simulation properties in order to sweep collector to emmiter voltage from 0 to 5 volts.we selected dcsource2 to specify the sweep values.sweep start and end values are respectively 0 to 5 volts.number of points 100 is selected.after that we run simulation and got result.after that we swept the base current source.for that we selected advance analysis in simulation property. we selected sweep analysis 2. we selected dcsource1 as instance.sweep start and end values are respectively from 0 to 0.002 A. number of points 5 is selected. after running the simulation we got plot of collector to emmiter voltage against collector current. 2. What message did you get when you run the Simulation. Ans- simulation done successfully.
3. What steps did you take if there was error in the Simulation run? Ans- first we check the equipment, components and circuit connections.after that we will check the simulation properties .in that we will check sweep start and end values of parameters .this steps we will follow. 4. Did the Simulation run properly after the steps taken by you? Ans- yes. 5. Plot the characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- done successfully. 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: done successfully. Parameter on Y-axis: done successfully. 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- yes. What changes did you make in the settings? Ans- there is a small difference in the setting because beta of two transistor not always same .so base currents value should be change .accordingly changes will take place in the setting.
8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- no. What change do you observe? Ans- there is no change.only values are slightly different What is the reason for the same? Ans- Because for all practical purpose dc current gain and ac current gain are consider to be equal
9. Write the conclusion you draw from the experiment. Ans- beta indicates that collector current is 100 times that of base current.for all practical purpose dc current gain and ac current gain are consider to be equal

α
Ω
Student Name: Harshal Sanjay Pulekar Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- step 1:- click on simulation properties step 2:- select ' Advanced analysis ' from drop down step 3:- select dc source1 to specify the sweep value as shown sweep start :- 00.000 v sweep end :- 05.000 v step 4 :-run simulation. 2. What message did you get when you run the Simulation. Ans- "The simulation is successful " this message you will get after running the simulation 3. What steps did you take if there was error in the Simulation run? Ans- step 1 :- Check the circuit step 2 :- Check either the dc power supply is "on" or not. 4. Did the Simulation run properly after the steps taken by you? Ans- yes 5. Plot the

characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- ok 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: ok Parameter on Y-axis: ok 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- What changes did you make in the settings? Ans- 8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- What change do you observe? Ans- What is the reason for the same? Ans- 9. Write the conclusion you draw from the experiment. Ans-

Student Name: Zeefa Shaikh Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- Settings : using Advance analysis 1 > Simulation properties > Advance analysis > select sweep analysis 1 and sweep analysis 2 > select DC source to specify sweep values. Then Run Simulation. 2. What message did you get when you run the Simulation. Ans- Simulation Successful. 3. What steps did you take if there was error in the Simulation run? Ans- No error occured during simulation process. 4. Did the Simulation run properly after the steps taken by you? Ans- No steps were taken as no error occured. 5. Plot the characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- Screen capture sent successfully using mail. 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: Screen capture sent successfully using mail. Parameter on Y-axis: Screen capture sent successfully using mail. 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- Yes What changes did you make in the settings? Ans- By double clicking on BJT the value of Beta is changed to gain common emitter characteristics plot. 8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- Yes What change do you observe? Ans- Graph is shifted upwards as compared to the original graph obtained previously. What is the reason for the same? Ans- Beta is dependent on base and collector of the BJT. So the graph shifts upwards as compared to the original graph. 9. Write the conclusion you draw from the experiment. Ans- In the common emitter configuration, the input port of the BJT is the connection from base to emitter.& the output port of the BJT is the connection from collector to emitter. The experiment works by systematically testing whether the BJT is OFF, ACTIVE or SATURATED.

Student Name: HEENA V. TAILOR Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- 1.Advanced analysis 2.DCsource1 is selected 3.very it from 0 to 5 volt in 100steps Reasons:Easy and fast analysis 2. What message did you get when you run the Simulation. Ans- no message 3. What steps did you take if there was error in the Simulation run? Ans- no error 4. Did the Simulation run properly after the steps taken by you? Ans- yes 5. Plot the characteristics using the plot tab and as per instructions in

the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- ok
6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: ok Parameter on Y-axis: ok 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- NO What changes did you make in the settings? Ans-
8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- YES What change do you observe? Ans- For same value Base current the Collector current is changed What is the reason for the same? Ans- Beta ratio gives control on collector current ,so as Beta changes collector current also changes for same Base current. 9. Write the conclusion you draw from the experiment. Ans- BJT is current controlled current device.collector current is constant .Beta factor affacts the output current.

Student Name: Kashmeera Sawant Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- advance analysis click on simulation properties select advance analysis select DCsource run simulation. reason for selection is we use this procedure for sweeping the Vce voltage. 2. What message did you get when you run the Simulation. Ans- simulation is successful 3. What steps did you take if there was error in the Simulation run? Ans- check the circuit diagram, power supply and its values. 4. Did the Simulation run properly after the steps taken by you? Ans- yes. 5. Plot the characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- yes. 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: yes. Parameter on Y-axis: yes. 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- yes. What changes did you make in the settings? Ans- By clicking on the BJT we changed the value of beta.
8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- Yes. What change do you observe? Ans- The graph shifted upwards compared to the original graph obtained. What is the reason for the same? Ans- As beta is dependent on base and collector of the bjt, we obtain the above changes.
9. Write the conclusion you draw from the experiment. Ans- We conclude that, the collector current is dependent on base current ,Ib is deciding factor for Ic. Vce increases rapidly and becomes constant after certain level.

Student Name: Sumedh Pathak Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- For sweep 1: DC Source 1 is selected with Voltage(emitter to collector voltage,Vce) as its parameter. Sweep starts with 00.000V and ends with 05.000V with No. of points =100. For sweep 2: DC Source0 is selected with Current(base current,Ib) as its parameter and Sweep starts with 0.000A and ends with 0.002A with No. of points =5 2. What message did you get when you run the Simulation. Ans- Simulation Completed Successfully. 3. What steps did you take if there was error in the Simulation run? Ans- 1)Check the Dc sources were working. 2)Check for circuit connections. 4. Did the Simulation run properly after the steps taken by you? Ans- Yes. 5. Plot the characteristics using the plot tab and as per

instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- At start collector current (Ic) increases rapidly with very small increase in Emitter Collector Voltage(Vce). After a certain limit the the collector current(Ic) remains constant in spite of increase in the Emitter Collector voltage(Vce). 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: At start collector current (Ic) increases rapidly with very small increase in Emitter Collector Voltage(Vce). After a certain limit the the collector current(Ic) remains constant in spite of increase in the Emitter Collector voltage(Vce). Parameter on Y-axis: At start collector current (Ic) increases rapidly with very small increase in Emitter Collector Voltage(Vce). After a certain limit the the collector current(Ic) remains constant in spite of increase in the Emitter Collector voltage(Vce). 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- Yes. What changes did you make in the settings? Ans- Changes were made ion Bf(Forward Beta) & Br(Reverse Beta). 8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- Yes. What change do you observe? Ans- The gain of the BJT was changed. What is the reason for the same? Ans- The operational conditions and the Ic/Ib ratio. 9. Write the conclusion you draw from the experiment. Ans- We can conclude that the Base current(Ib), is the deciding factor for the changes in Collector Current (Ic). Where the emitter collector voltage (Vce) seems to be irrelevant up to a certain point.

Student Name: NEHA V. PATIL Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- SIMULATION SETTINGS-ADVANCED ANALYSIS-SWEEP ANALYSIS-DC SOURCE.... 2. What message did you get when you run the Simulation. Ans- SIMULATION SUCCESSFULL 3. What steps did you take if there was error in the Simulation run? Ans- NO ERROR WAS OCCURED GOT O/P IN FIRST ATTEMPT
4. Did the Simulation run properly after the steps taken by you? Ans- YES 5. Plot the characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- ---- MAIL HAS BEEN SENT TO MRS. ANITA MAM."www.anitasd2008@gmail.com" 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: ---- MAIL HAS BEEN SENT TO MRS. ANITA MAM."www.anitasd2008@gmail.com" Parameter on Y-axis: ---- MAIL HAS BEEN SENT TO MRS. ANITA MAM."www.anitasd2008@gmail.com" 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- YES What changes did you make in the settings? Ans- BETA VALUE FRM 100 TO 200. 8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- YES What change do you observe? Ans- GRAPH SHIFTED UPWARDS THAN THE PREVIOUS PLOT. What is the reason for the same? Ans- BETA IS DEPENDENT ON BASE AND COLLECTOR CURRENT . 9. Write the conclusion you draw from the experiment. Ans- IT APPEARED THAT BASE CURRENT IS THE DECIDING FACTOR FOR COLLECTOR CURRENT, VCE BEING IRRELEVANT AS LONG AS IT IS ABOVE THE CETAIN MINIMUM LEVEL.

Student Name: Shraddha A Borhade Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power

Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- its as follows: 1-advanced analysis 2-sweep analysis 1 3-Type is DC Source 4-Instance is DC Source 1 5-Parameter is V 6-Sweep start from 00.000 V to 05.000 V 7-No of points=100 8-Close I have selected above settings because we are doing experiment for active region 2. What message did you get when you run the Simulation. Ans- As I clicked on run the simulation ,I got the message as "Simulation successfully completed" 3. What steps did you take if there was error in the Simulation run? Ans- if there was an error in my simulation process....I will check my simulation properties and values of DC sources. 4. Did the Simulation run properly after the steps taken by you? Ans- Yes........after rechecking my all procedure,circuit diagram,simulation properties,values my simulation process runs properly 5. Plot the characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: Parameter on Y-axis: 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- yes. What changes did you make in the settings? Ans- Click on Advanced setting to sweep the constant current source from 0 A to 2 mA in 5 steps for DCSource0.Let us decrease the voltage sweep of DC SOurce1 from 0V to 5v 8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- yes What change do you observe? Ans- There are four reasons in graph now...represented by IB4>IB3>IB2>IB1 What is the reason for the same? Ans- 9. Write the conclusion you draw from the experiment. Ans- It appears that base current is deciding factor for collector current,the Vce being irrelevant as long as it is above a certain minimum level.Each curve on the graph reflects the collector current of transistor,plotted over a range of collector-to-emitter voltages,for given amount of base current.transistor acts as a current regulator it is useful to express this proportion as a standard transistor performance measure

Student Name: Namrata Bhalerao Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- we selected advanced analyser in that we set DCsource 1 and DC source 0 . In DC source 1 we set the voltage from 0 to 5V and in DC source 0 we set the constant current source from 0 to 2mA in 5 steps.This settings were done to get a plot of Vce verse Ic at certain constant values of Ib 2. What message did you get when you run the Simulation. Ans- Simulation successfully completed 3. What steps did you take if there was error in the Simulation run? Ans- If the error would have occurred we would have checked our simulation settings and DC sources and also check the diagram if any mistake is their 4. Did the Simulation run properly after the steps taken by you? Ans- Yes 5. Plot the characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: Parameter on Y-axis:
7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- Yes What changes did you make in the settings? Ans- we have to change the values of DC source 0
8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- Yes What change do you observe? Ans- The plot of Vce verses Ic will change What is the reason for the same? Ans- Î² is dependent on values of Ic and Ib therefore as it changes currents also changes and there is change in plot
9. Write the conclusion you draw from the experiment. Ans- we can conclude that the base current is the deciding factor for collector current, the Vce is irrelevant as long as it is above a certain minimal level.

Student Name: Prasad Pratap Satam Task 1 Assemble the circuit to plot the Common emitter characteristics of BJT as per the instructions in the ppt
Save the circuit using screen capture on your computer and mail it. 1. Tick the components you have chosen to form the circuit. BJT
2. Tick the equipment you have chosen to form the circuit. DC Source â€“ Regulated Power Supply Ammeter Ground Task 2 Click on the Simulation settings tab and make the settings as per the ppt instructions. After the simulation settings are done, run the simulation. 1. Write down the Simulation settings you have chosen. Also write the reason for the selection Ans- we have chosen advanced analyser to sets the dc source 0 as constant current source of 2 ma and to sets dc source 1 as voltage source within the range of 0 to 5 volts ,to get a plot of Vce verses Ic at constant base current 2. What message did you get when you run the Simulation. Ans- simulation successfully completed 3. What steps did you take if there was error in the Simulation run? Ans- if there was error in the simulation , then i again check the circuit diagram whether it is right or not,also i am going to check dc sources and simulation settings . 4. Did the Simulation run properly after the steps taken by you? Ans- yes. 5. Plot the characteristics using the plot tab and as per instructions in the ppt. Save the obtained plot in your computer using screen capture and mail it. Ans- 6. For plotting the characteristics of BJT which parameters were considered? Parameter on X-axis: Parameter on Y-axis: 7. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Are you required to change the Simulation settings for obtaining the plot? Ans- yes What changes did you make in the settings? Ans- we have to change the value of dc source 0. 8. Change the ß of the BJT selected in your circuit and plot the Common Emitter characteristics. Do you observe any change in the plot? Ans- yes. What change do you observe? Ans- the out put characteristic will change. What is the reason for the same? Ans- because the Î² is depend upon the values of Ib(base current) and Ic(emitter current), As the Î² changes Ic and ib are also change. 9. Write the conclusion you draw from the experiment. Ans- we conclude that base current is the deciding factor for collector current ,the Vce being irrelevant as long as it is above a certain minimum level.

References

Abdulwahed, M. (2009). Constructivist PBL approach in teaching embedded systems hands-on course, comparative study. *Reading,* (November). doi:10.13140/2.1.2323.9369

Abdulwahed, M., & Nagy, Z. K. (2011). The TriLab, a novel ICT based triple access mode laboratory education model. *Computers & Education, 56*(1), 262–274. doi:10.1016/j.compedu.2010.07.023

American Association of Physics Teachers. (2014). AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum. *AAPT Resources,* 29. doi:10.1119/1.4914580

Balamuralithara, B., & Woods, P. C. (2009). Virtual laboratories in engineering education: The simulation lab and remote lab. *Computer Applications in Engineering Education, 17*(1), 108–118. doi:10.1002/cae.20186

Banerjee, G., Patwardhan, M. & Murthy, S. (2014). Learning Design Framework for constructive strategic alignment with visualizations. *22nd International Conference on Computers in Education*, 963-968.

Bhargava, P., Antonakakis, J., Cunningham, C., & Zehnder, A. T. (2005). Web-based virtual torsion laboratory. *Computer Applications in Engineering Education, 14*(1), 1–8. doi:10.1002/cae.20061.

Biggs, J. (1996). Enhancing teaching through constructive alignment. *Higher education*, *32*(3), 347-364.

Biggs, J. B., & Collis, K. F. (1982). *Evaluation the quality of learning: the SOLO taxonomy (structure of the observed learning outcome)*. Academic Press.

Bonatti, D., Pasini, G., Peretto, L., Pivello, E., & Tinarelli, R. (2007). A novel approach for laboratory activities in e-learning courses. *2007 IEEE Instrumentation & Measurement Technology Conference IMTC 2007,* 1–6.

Bryce, T. G. K., & Robertson, I. J. (2008). What can they do? A review of practical assessment in Science. *Studies in Science Education, 12*(1), 1–24. doi:10.1080/03057268508559921

Castles, R. T., Member, G. S., Zephirin, T., Member, S., & Lohani, V. K. (2010). Design and implementation of a mechatronics learning module in a large first-semester engineering course. *Imaging, 53*(3), 445–454.

Chen, S. (2010). The view of scientific inquiry conveyed by simulation-based virtual laboratories. *Computers & Education, 55*(3), 1123–1130. doi:10.1016/j.compedu.2010.05.009

Cooper, M. (2005). Remote laboratories in teaching and learning – issues impinging on widespread adoption in science and engineering education. *International Journal of Online Engineering, 1*(1).

Corter, J. E., Esche, S. K., Chassapis, C., Ma, J., & Nickerson, J. V. (2011). Process and learning outcomes from remotely-operated, simulated, and hands-on student laboratories. *Computers & Education, 57*(3), 2054–2067. doi:10.1016/j.compedu.2011.04.009

De, D. M., Gómez-estern, F., & Dormido, S. (2012). A new Internet tool for automatic evaluation in Control Systems and Programming. *Computers & Education, 59*(2), 535–550. doi:10.1016/j.compedu.2011.12.016.

De Jong, T., & Ferguson-Hessler, M. G. (1996). Types and qualities of knowledge. *Educational psychologist*, *31*(2), 105-113.

Dies, A., Technology, I., & American, A. (n.d.). Remote augmented reality engineering labs.

Domin, D. S. (1999). A review of laboratory instruction styles. *Journal of Chemical Education, 76*(4), 543. doi:10.1021/ed076p543

Dreyfus, A. (2007). Manipulating and diversifying the levels of difficulty and task - sophistication of one and the same laboratory exercise. *European Journal of Science Education, January 2015,* 37–41. doi:10.1080/0140528860080103

Duis, J. M., Schafer, L. L., Nussbaum, S., & Stewart, J. J. (2013). A process for developing introductory science laboratory learning goals to enhance student learning and instructional alignment. *Journal of Chemical Education, 90*(9), 1144–1150. doi:10.1021/ed4000102

Duis, J. M., Schafer, L. L., Nussbaum, S., Stewart, J., Carlson, M., & Samozvanov, Y. (2004). Instruments for assessing practical skill development in a first-year chemistry laboratory course, 2004.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. Journal of advanced nursing, 62(1), 107-115.

Fang, X. D., Luo, S., Lee, N. J., & Jin, F. (1998). Virtual machining lab for knowledge learning and skills training. *Computer Applications in Engineering Education, 6*(2), 89–97.

Feisel, L. D., Ph, D., & Peterson, G. D. (2002). A colloquy on learning objectives for engineering education laboratories. *Engineering Education*.

Galloway, K. R., & Bretz, S. L. (2015). Development of an assessment tool to measure students' meaningful learning in the undergraduate chemistry laboratory. *Journal of Chemical Education,* 150311144105003. doi:10.1021/ed500881y

Ganiel, U., & Hofstein, A. (1982). Objective and continuous assessment of student performance in the physics laboratory. *Science Education, 66*(4), 581–591. doi:10.1002/sce.3730660409

Garnett, P. J., Garnett, P. J., & Mark W Hacking. (1995). Refocusing the chemistry lab: a case for laboratory-based investigations. *Australian Science Teacher Journal, 41*(2), 26–32.

Gomes, L., & García-zubía, J. (n.d.). *Advances on remote laboratories and e-learning experiences*.

Halstead, E. (2016). Effects of reducing scaffolding in an undergraduate electronics lab. *American Journal of Physics, 84*(7), 552–556. doi:10.1119/1.4953346

Harms, U. (n.d.). Introduction, virtual and remote labs, demonstration of examples. *Engineering Education*.

Hart, C., Mulhall, P., Berry, A., Loughran, J., & Gunstone, R. (2000). What is the purpose of this experiment? or can students learn something from doing experiments? *Journal of Research in Science Teaching, 37*(37), 655–675. doi:10.1002/1098-2736(200009)37:7<655::AID-TEA3>3.0.CO;2-E

Helmut, B., Jörg, K., Wolfram, S. (2003). A combined virtual and remotely accessible microprocessor laboratory. *Structure*.

Herold, D. K. (2010). Mediating media studies – stimulating critical awareness in a virtual environment. *Computers & Education, 54*(3), 791–798. doi:10.1016/j.compedu.2009.10.019

Hesser, T. L., & Bunyea, S. R. (2016). Development and implementation of problem-based chemistry experiments for engineering students in a multi-disciplinary course. *ASEE Annual Conference and Exposition, Conference Proceedings, 2016 June*.

Hofstein, A. (2004). The laboratory in chemistry education: thirty years of experience with developments, implementation, and research. *Chemistry Education, Research and Practice, 5*(3), 247–264.

Hofstein, A., & Lunetta, V. N. (2004). The laboratory in science education: foundations for the twenty-first century. *Science Education, 88*(1), 28–54. doi:10.1002/sce.10106

Høivik, H. (2009). Learning labs: the new classroom. *Educational Research,* 2421–2426.

Humos, A. A., Alhalabi, B., Hamza, M. K., Shufro, E., & Awada, W. (2005). Remote labs environments (RLE): a constructivist online experimentation in science, engineering, and information technology. In 31st Annual Conference of IEEE Industrial Electronics Society, 2005, IECON 2005, 2156–2161.

Jonassen, D. H. (1997). Instructional design models for well-structured and III-structured problem-solving learning outcomes. *Educational Technology Research and Development*, 45(1), 65-94.

Kim, J. (2012). An ill-structured PBL-based microprocessor course without formal laboratory. *IEEE Transactions on Education, 55*(1), 145–153. doi:10.1109/TE.2011.2156797

Krivickas, R. V. (2007). Laboratory instruction in engineering education. *Global Journal of Engineering Education, 11*(2).

Limniou, M., Papadopoulos, N., & Whitehead, C. (2009). Integration of simulation into pre-laboratory chemical course: computer cluster versus WebCT. *Computers & Education, 52*(1), 45–52. doi:10.1016/j.compedu.2008.06.006

Ma, J., & Nickerson, J. V. (2006). Hands-on, simulated, and remote laboratories: a comparative literature review. *Computing, 38*(3). doi:10.1145/1132960.1132961

Martínez, G., Naranjo, F., Pérez, Á., Suero, M., & Pardo, P. (2011). Comparative study of the effectiveness of three learning environments: hyper-realistic virtual simulations, traditional schematic simulations and traditional laboratory. *Physical Review Special Topics - Physics Education Research, 7*(2), 1–12. doi:10.1103/PhysRevSTPER.7.020111

Mikropoulos, T. A., & Natsis, A. (2011). Educational virtual environments: a ten-year review of empirical research (1999 – 2009). *Computers & Education, 56*(3), 769–780. doi:10.1016/j.compedu.2010.10.020.

Merrill M.D. (1983). Component display theory. *Instructional-design theories and models:*

An overview of their current status, 1, 282-333.

Mishra, P. & Koehler M. (2006): Technological pedagogical content knowledge: a framework for integrating technology in instructor knowledge. *Instructors College Record*, *108* (6), 1017–1054.

Millar, R., Tiberghien, A., & Le Marechal, J. -F. (2003). Varieties of labwork: a way of profiling labwork tasks. *Teaching and Learning in the Science Laboratory,* 9–20. doi:10.1007/0-306-48196-0_3

Montes, S., Castro, A. B., & Hern, A. (2010). How to motivate students to work in the laboratory: a new approach for an electrical machines laboratory. *Practice, 53*(3), 490–496.

Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments. *Educational Psychology Review, 19,* 309–326. doi:10.1007/s10648-007-9047-2.

Murthy, S., Iyer, S., & Warriem, J.(2015): ET4ET: A large-scale professional development program on effective integration of Educational Technology for engineering faculty. *Journal of Educational Technology & Society*.

Nichols, M. (2018). A theory for elearning. Pre-Discussion Paper. *International Forum of Educational Technology & Society, 6*(2), 1–10.

Nikolic, B., Radivojevic, Z., Djordjevic, J., & Milutinovic, V. (2009). A survey and evaluation of simulators suitable for teaching courses in computer architecture and organization*. IEEE Transactions on Education, 52*(4), 449–458.

Nonclercq, A., Biest, A. Vander, Cuyper, K. De, Leroy, E., Martinez, D. L., Robert, F., & Instrumentation, A. (2010). Problem-based learning in instrumentation: synergism of real and virtual modular acquisition chains. *Science, 53*(2), 234–242.

Päivi, T. (1999). Towards expert knowledge? A comparison between a constructivist and a traditional learning environment in the university. *International Journal of Educational Research, 31,* 357–442.

Pati, B., Misra, S., & Mohanty, A. (2011). A model for evaluating the effectiveness of software engineering virtual labs. In 2012 IEEE International Conference on Technology Enhanced Education (ICTEE).

Pereira, C. E., Paladini, S., & Schaf, F. M. (2012). Control and automation engineering education: combining physical, remote and virtual labs. In International Multi-Conference on Systems, Signals & Devices, 20–23 March 2012.

Phan, H. P. (2011). A cognitive multimedia environment and its importance: a conceptual model for effective e-learning and development. *E-Learning, 10*, 199–221.

Powell, A., Adsit, J., Jones, K. (August 2010). Goals, guidelines, and standards for student scientific investigations. *iNACOL*.

Rutten, N., van Joolingen, W. R., & Van Der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 58*(1), 136–153. doi:10.1016/j.compedu.2011.07.017

Scalise, K., Timms, M., Moorjani, A., Clark, L., Holtermann, K., & Irvin, P. S. (2011). Student learning in science simulations: design features that promote learning gains. *Journal of Research in Science Teaching, 48*(9), 1050–1078. doi:10.1002/tea.20437

Schmidt-Borcherding, F., Hänze, M., Wodzinski, R., & Rincke, K. (2013). Inquiring scaffolds in laboratory tasks: an instance of a “worked laboratory guide effect”? *European Journal of Psychology of Education, 28*(4), 1381–1395. doi:10.1007/s10212-013-0171-8

Stricker, D., Weibel, D., & Wissmath, B. (2011). Efficient learning using a virtual learning environment in a university class. *Computers & Education, 56*(2), 495–504. doi:10.1016/j.compedu.2010.09.012

Surgenor, B., & Firth, K. (n.d.). The role of the laboratory in design engineering education. *Materials Engineering*.

S. Murthy and S. Iyer (2013). Guidelines and templates for planning, conducting and reporting educational technology research. *IIT Bombay Inter-disciplinary program in Educational Technology Technical Report TR-ET-2013-01*.

Tokdemir, G., & Bilgen, S. (2008). Remote lab effectiveness assessment model. In 2008 11th International Conference on Optimization of Electrical and Electronic Equipment, 22-24 May 2008.

Unal, C., & Ozdemir, O. F. (2013). A physics laboratory course designed using problem-based learning for prospective physics teachers. *European Journal of Science and Mathematics Education, 1*(1), 29–33.

Urban-Woldron, H. (2009). Interactive simulations for the effective learning of physics. *Journal of Computers in Mathematics and Science Teaching, 28*, 163–176.

Wang, F., & Hannafin, M. J. (2005). Design-based research and technology-enhanced learning environments. *Educational Technology Research and Development, 53*(4), 5–23.

Wang, G., & Wayne, F. (2010). Preview, exercise, teaching and learning in digital electronics education. In ASEE 2010 Annual Conference, ASEE.

Wang, Y., Zhang, L., Sheng, Y., & Zhang, H. (2008). Design and implementation of principles of computer organization virtual lab based on component. *Advances in Blended Learning, 60673164,* 35–45.

Watson, T. J., & Science, A. (2005). The role of the laboratory in Undergraduate Engineering Education. *Journal of Engineering Education,* January.

Wieman, C. (2015). Comparative cognitive task analyses of experimental science and instructional laboratory courses. *The Physics Teacher, 53*(6), 349–351. doi:10.1119/1.4928349

Wirth, J., Künsting, J., & Leutner, D. (2009). The impact of goal specificity and goal type on learning outcome and cognitive load. *Computers in Human Behavior, 25*(2), 299–305. doi:10.1016/j.chb.2008.12.004

Yang, Y., Xiao, Z., Cui, J., & Lin, X. (2012). Virtual laboratory for optical communication Engineering Education. In 2012 IEEE International Conference on Technology Enhanced Education (ICTEE), 3–5 Jan. 2012.

Publications

Journal

1. Anita S.Diwakar, Santosh Noronha. "ADVIcE: Interactive tool to help engineering instructors effectively integrate virtual labs in their teaching" submitted to Australasian Journal of Educational Technology – under review.
2. Anita S.Diwakar, Santosh Noronha.Effectiveness of Virtual laboratories in engineering education. What do we measure?" in the Journal of Engineering Education Transformations, January 2016.

Conferences

1. Anita S.Diwakar, Swati Mahajan, Sangeeta Kulkarni. "A pilot study: The effect of using Virtual laboratory on students' conceptual understanding in Mobile Communications" in T4E 2016, The 8th IEEE International Conference on Technology for Education, December 2-4, 2016, Indian Institute of Technology Bombay, Mumbai.
2. Anita S.Diwakar, Santosh Noronha.Effectiveness of Virtual laboratories in engineering education. What do we measure?" in ICTIEE 2016, International Conference on Transformations in Engineering Education, College of Engineering Pune from 8th to 12th January 2016.
3. Anita Diwakar, Santosh Noronha and Sudhir Agashe, "Virtual and Remote triggered Industrial Automation Labs: Collaboration case study", REV 2015, 12th International Conference on Remote Engineering and Virtual Instrumentation, Bangkok, Thailand from 25th to 28th February 2015.
4. Anita Diwakar, Sushanth Poojary, Santosh Noronha and Kannan Moudgalya, "Control Systems Virtual labs: Technological and pedagogical perspectives", IEEE MSC 2013.
5. Anita Diwakar, Mrinal Patwardhan and Sahana Murthy, "Pedagogical Analysis of Content Authoring Tools for Engineering Curriculum", International Conference on Technology for Education 2012, IIIT Hyderabad on 18-20 July 2012.
6. Anita Diwakar, Sushanth Poojary and S.B.Noronha, "Virtual labs in engineering education: Implementation using free and open source resources", IEEE International conference on Technology Enhanced Education ICTEE 2012, Amrita University, Kerala on 3-5 January 2012.

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