MIC-O-MAP: A Technology Enhanced Learning Environment for Developing Micro-Macro Thinking Skills in Analog Electronics

Submitted in partial fulfilment of the requirements
of the degree of

Doctor of Philosophy

by

Anura Kenkre

Roll no: 114380001

Supervisor:
Sahana Murthy (IIT Bombay)

Interdisciplinary Program in Educational Technology

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Dedication Sheet

Dedicated
to

My mother, Mrs. Netra Kenkre, who is my source of inspiration.

Thesis Approval Sheet

This thesis entitled " **MIC-O-MAP: A Technology Enhanced Learning Environment for Developing Micro-Macro Thinking Skills in Analog Electronics** " by Anura Kenkre is approved for the degree of Doctor of Philosophy.

Examiners

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H. C. Pradhan

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Sridhar

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Supervisor (s)

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Chairman

S. Umasankar

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Date : 13-11-17

Place : MUMBAI

Abstract

Students should be able to correlate and apply the conceptual knowledge acquired from their classroom with the experiments carried out in laboratories. For this, students should be able to understand concepts and models at the 'microscopic level' (such as atoms or molecules), and link it to their corresponding observable / manipulable variables at the 'macroscopic level' (such as current and voltage). In this thesis, we refer to this as micro-macro thinking. It has been reported that students treat these two as disjoint sets, leading to lack of understanding of the complete system and difficulty in applying concepts to the real-world scenarios. The aim of this thesis is to design and develop a technology enhanced learning environment which will help students in developing this skill of micro-macro thinking.

In this thesis, we have designed, developed and evaluated MIC-O-MAP (MICroscopic Observations MAcroscopic Predictions), a TEL environment to develop students' micro-macro thinking skills. The key pedagogical features and learning activities in MIC-O-MAP include a simulation of the microscopic world, prediction questions, justification box, real world answer for comparison and judgement, assertion and reasoning questions with dynamic feedback and dynamically linked multiple representations. These features have been included based on the pedagogical theories of inquiry learning, self-regulated learning, question prompts, types of scaffolds and methods of feedback and assessment. The entire interactive process of learning with MIC-O-MAP is mediated by a pedagogical agent which addresses the queries in the mind of the student and allows repetition of a task till mastery is reached. The environment is semi-open ended so that every student can have a unique learning path and can trace this path while interacting with the environment. Design Based Research (DBR) methodology has been followed for the design and development of the MIC-O-MAP TEL environment. Two iterative DBR cycles were implemented. Six MIC-O-MAP modules in analog electronics were developed. Eight research studies using explanatory sequential mixed method approach were carried out that included quasi-experimental studies (Ntotal= 249) and qualitative strands. The participants were students from first year of science and engineering from colleges affiliated to University of Mumbai, a large public urban university in India.

Results showed that students who work with MIC-O-MAP develop micro-macro thinking skills compared to a control group. Interaction analysis showed that there exists a contrast in the interaction paths of students who scored high versus low on a post-test on micro-macro thinking after interacting with MIC-O-MAP. The high scorers extensively use MIC-O-MAP features and go back and forth for sense-making, whereas the low scorers linearly progress through a MIC-O-MAP module to completion. We have also identified productive actions which are actions that enable learners to effectively use the features of MIC-O-MAP for achieving the objective of connecting the micro-world dynamics and the macro-world processes of physical phenomena.

Contributions of the thesis are: MIC-O-MAP TEL environment which has been evaluated in multiple studies, 6 MIC-O-MAP modules in the domain of analog electronics, productive actions to be used while interacting with MIC-O-MAP, the instructional design template of MIC-O-MAP for further module creation and identification of different learning paths of students while interacting with MIC-O-MAP.

Keywords: MIC-O-MAP, Micro-Macro Thinking, TELE, Basic Analog Electronics, Student Interactions

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Abbreviation Notation and Nomenclature

MIC-O-MAP	MICroscopic-Observations-Macroscopic Predictions
TELE	Technology Enhanced Learning Environment
SIM	Simulation of the micro world
PQ	Prediction Questions
JUS	Justification Box
RWA	Real World Answer for Comparison and Judgement
ARQ	Assertion and Reasoning Questions
MR	Multiple Representation
LO	Learning Objective
GLO	Glossary
REF	Reference
DBR	Design Based Research
IDD	Instructional Design Document

Declaration

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

AKenkre

(Signature)

ANURA. B. KENKRE

(Name of the student)

114380001

(Roll No.)

Date: 14-11-17.

Chapter 1

Introduction

1.1 Background of the Research

Science and Engineering graduates are expected to be able to apply knowledge of mathematics, science, and engineering; design and conduct experiments, as well as to analyze and interpret data; design a system, component, or process to meet desired needs and identify, formulate, and solve engineering problems [Shuman et.al., 2005; Besterfield-Sacre et.al, 2000; Handler & Strudler, 1997]. These science and engineering process skills have been deemed to be important not only by educators but also by industries hiring science and engineering graduates [Lang et.al., 1999]. An effective way to facilitate the development of these skills is to engage students in authentic inquiry-based tasks which require them to apply their theoretical knowledge to real world situations. Such tasks involve making *micro-macro* links, that is, relating observable, tangible phenomena at the macroscopic level and their underlying structure, processes and unseen dynamics at the microscopic level.

Micro-macro thinking skill is developed is when learners understand to use relations between observed phenomena at the macroscopic level and the models of invisible particles such as atoms or molecules at as microscopic level [Meijer, 2011]. Learners need to describe, understand and predict the outcomes of phenomena at the macroscopic level by relating these to the scientific models of structures and processes at the microscopic level. The base of most key scientific abilities is being able to analyze dynamic processes and interactions on a microscopic level and establish co-relations to the outcomes which we can 'see' and measure at the macroscopic level in the real world.

Micro-macro thinking is an important skill to be developed as part of a school or college level curriculum, as it will help learners bridge the gap between theory and experiment. Theoretical concepts, typically learnt in the classroom often deal with microscopic models, intangible objects and invisible processes. On the other hand, in laboratory work, students observe real world macroscopic phenomena and make measurements of observable variables. Students are expected to link the two, for example use microscopic models to explain macroscopic phenomena, to obtain a complete and coherent understanding of the topic. In addition, micro-macro thinking is needed by science and engineering graduates once they enter the employment sector. For example, electronics engineers designing a circuit need to understand not only the current-voltage relationships but also concepts of electron motion, band gap, barrier potential etc and how they affect the current-voltage graph. Another example is that of pathologists who diagnose diseases mostly through analysis of tissue, cell, and body fluid samples. They have to understand and establish a link between different components of disease such as mechanisms of development, structural alterations of cells, and the consequences of changes (clinical manifestations).

However, micro-macro thinking has been found to be problematic for students as they have difficulty in bridging the mental gap between microscopic and macroscopic levels [Harrison & Treagust, 2003; Eilam, 2004; Gilbert & Treagust, 2009; van Berkel et.al., 2009]. During their learning process, students doing exercises and experiments and viewing demonstrations do not necessarily recognize that these parts of the curriculum are inter-related and are based upon a common underpinning. Instead, it seems that many students view these experiences in class as unrelated events and as increasingly unpalatable repetitions of tiresome homework problems and tedious lab measurements [Hinton & Nakhleh, 1999]. Hence, designing *explicit* teaching-learning activities for developing micro-macro thinking skill is necessary. It is important for instructors and curriculum designers to have in-depth knowledge of the problematic aspects of micro-macro thinking, understand what to be communicated to students and how to best communicate it to them [van Berkel, Pilot & Bulte, 2009].

1.2 Problem Statement

Based on Meijer's descriptions of microscopic and macroscopic levels [Meijer, 2011], we use the term 'micro-world' to refer to models of a system with structures at the level of molecules or atoms, often invisible particles with dimensions much smaller than we can observe, and their associated dynamics. We use the term ‘macro-world’ to denote directly observable real-world phenomena such mass, conduction of electricity, pressure, size, colour and their corresponding measurements We define ‘micro-macro thinking’ as the ability to establish a link between the variables in the microscopic world and their corresponding manipulable variables in the macroscopic world, in order to predict the functionality of the system. In a given situation, in order to establish this micro-macro link, sub-skills of making observations in the micro world, predicting macroscopic outcome, testing these outcomes against experimental evidence and revising predictions (if necessary) need to be developed.

There have been multiple attempts at developing solutions which can help students in developing this skill. Key Technology Enhanced Learning (TEL) environments are WISE (Web-based Science Environment) [Linn et.al. 2002; Williams & Linn, 2002], Web-based inquirer with modeling and visualization technology (WiMVT) [Sun & Looi, 2013] and Model-It [Fretz et.al, 2002; Stratford et.al, 1998], Co-Lab [Joolingen et.al. 2005] and Go-Lab [Govaerts et.al., 2013]. Face to face solutions include interventions such as ISLE [Etkina & Van Heuvelen, 2007] and MARS [Raghavan & Glaser, 1995]. Much of these efforts are at the middle and high school levels. At the tertiary education level, there exist ICT based learning materials such as TEAL [Dori & Belcher, 2005], PhET [Perkins et.al., 2006], and the Indian government’s ‘National Mission on Education through ICT’ [NMEICT, www.nmeict.ac.in], but most of them focus on domain concepts and not specifically on micro-macro thinking. PhET provides this implicitly and as resources for teachers but no explicitly targeted activities have been included for learners within the simulations. In these existing interventions, the teacher plays an important role by facilitating the process, giving prompts or grading the student’s efforts at a later stage [Raghavan & Glaser, 1995]. Many of these methods also include components such as lab work, field trips, discussions and assignments apart from the TEL environment itself.

The goal of this research work is thus to enable students to develop micro-macro thinking skills in learners at tertiary level science and engineering, through interaction with a TEL environment via a self-regulated learning mode.

1.3 Overview of solution: MIC-O-MAP

Our solution - MIC-O-MAP (MICroscopic-Observations-Macroscopic-Predictions) - is an integrated TEL environment explicitly addressing micro-macro thinking. Our target learners are at the tertiary educational level studying science or engineering, and the context of learning is self-regulated learning. MIC-O-MAP learning environment can also be used as a supplementary teaching material by an instructor. MIC-O-MAP contains prompts and scaffolds to provide the learner guidance on learning micro-macro thinking as they interact and do various learning activities within the TEL system.

In MIC-O-MAP, students go through an inquiry cycle by identifying variables, making observations of the processes in the microscopic world, predicting a macroscopic outcome based on a micro-macro link, evaluating their prediction post comparing it with an experimental evidence and arriving at a conclusion while testing and revising. The learning process is completed by writing a coherent summary by comparing the two worlds and establishing a link between them.

Features of MIC-O-MAP mapped to micro-macro thinking skills are shown in the Fig. 1.1. These features include a simulation of the microscopic world, prediction questions in the macroscopic world, a justification box to establish a link between the macroscopic prediction and microscopic observations, a real-world answer for comparing and testing the prediction and assertion and reasoning questions which provide prompts for identifying key areas of the micro world which need further observations or prompts towards establishment of a link between the macroscopic prediction and microscopic observations. Lastly, multiple representations are also provided for a coherent summarization of the topic. A screen shot of an activity in MIC-O-MAP learning environment depicting the pedagogical design features is shown in Fig. 1.2.

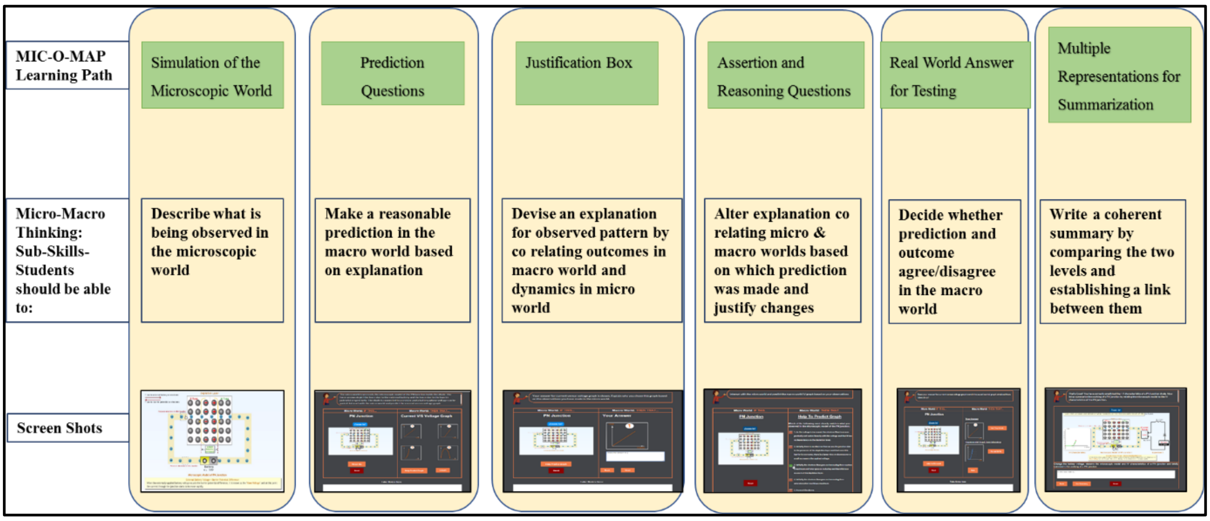


Figure 1.1. Micro-Macro Thinking Skills Mapped to Design Features

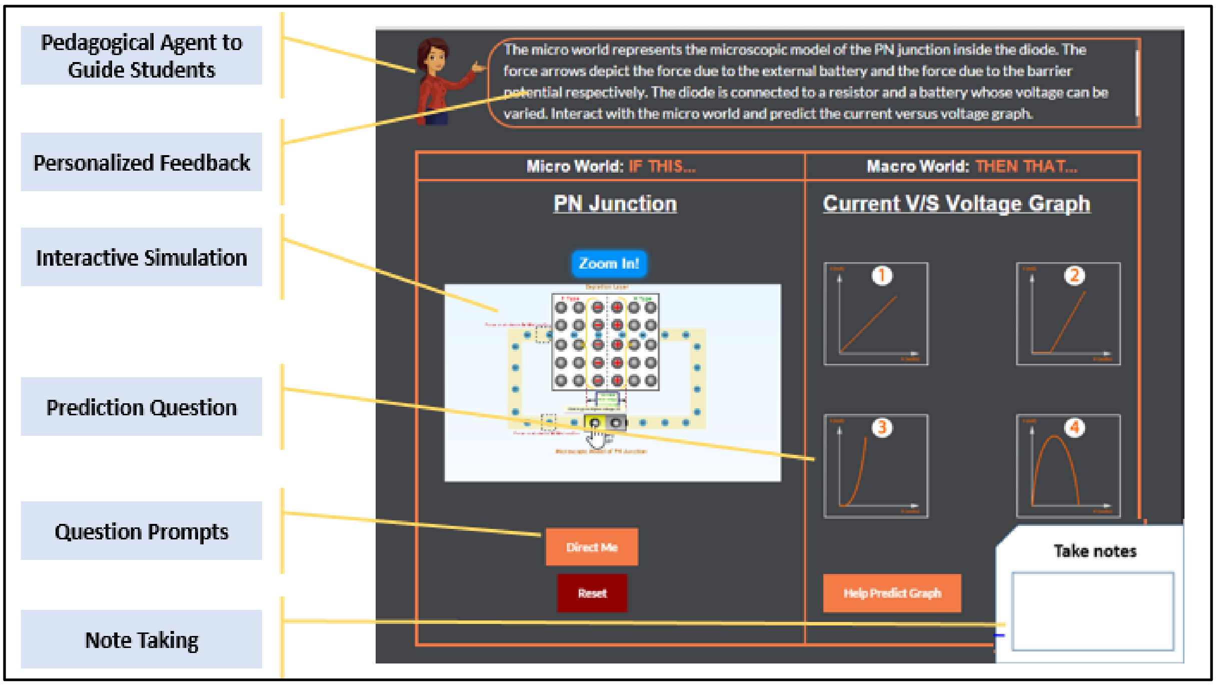


Figure 1.2. Pedagogical design features of MIC-O-MAP

These design features of MIC-O-MAP are rooted in the pedagogical theories of inquiry learning [Edelson, 2001], self-regulated earning [Winne, 2001; Zimmerman & Schunk, 2001; Winne & Hadwin, 1998], types of scaffolds [Azevedo et.al., 2004], question prompts [King, 1992; King & Rosenshine, 1993] and methods of feedback and assessment [Bull & McKenna, 2003; Nicol et.al., 2006]. Learners are involved in an inquiry cycle of making observations in the microscopic world of the given phenomenon, making a prediction in the macroscopic world based on a link between the micro world and macro world, testing this prediction against a real world experimental outcome and repeating this entire process for revision if needed. Based on theories of self-regulated learning, MIC-O-MAP provides learners a flexibility of following the suggestions and feedback given, or proceeding along an alternate path deemed more beneficial by themselves. Thus, actions of monitoring and judgement are required of students when they interact with MIC-O-MAP. At each stage learners are provided with scaffolds and prompts which aid in either making more careful observations or for establishing a micro-macro link. This entire activity is carried out in the form of a dialogue with an agent so as to ease the follow up of feedback.

The features mentioned in Fig. 1.2 help students develop micro-macro thinking in the following manner:

Establishing micro-macro link. micro-macro link is established when students are asked to make careful observations in a given simulation of the microscopic model and then use it to predict the macroscopic outcomes of the given physical phenomenon. When students are unable to make a prediction, or are falling short in establishing a micro-macro link, MIC-O-MAP provides them with a series of assertion and reasoning questions based on observations which aid in identifying key areas of the microscopic simulation wherein more careful observations are needed.

Strengthening micro-macro link. When students have made a prediction in the macro world based on their observations in the micro world, they are asked to justify this prediction by establishing a link between the micro and macro world. In case students are found to struggle with this link establishment and strengthening of the micro-macro link, then, they are provided with assertion and reasoning based question – inference based, which help them in thinking about the manner in which a macroscopic outcome is based on a microscopic process. In order to gain insight into which features will aid in executing this task of strengthening the micro-macro link, the pedagogical theories of formative assessment and feedback, question prompts as well as types of scaffolds were applied.

Integrating micro-macro link. There exists an integration of the micro-macro link when students summarize their complete understanding using multiple representations of the microscopic model, the macroscopic experimental evidence in the form of meter readings and a graphical outcome.

A flowchart giving an overview of the working of MIC-O-MAP is presented in Fig. 1.3.

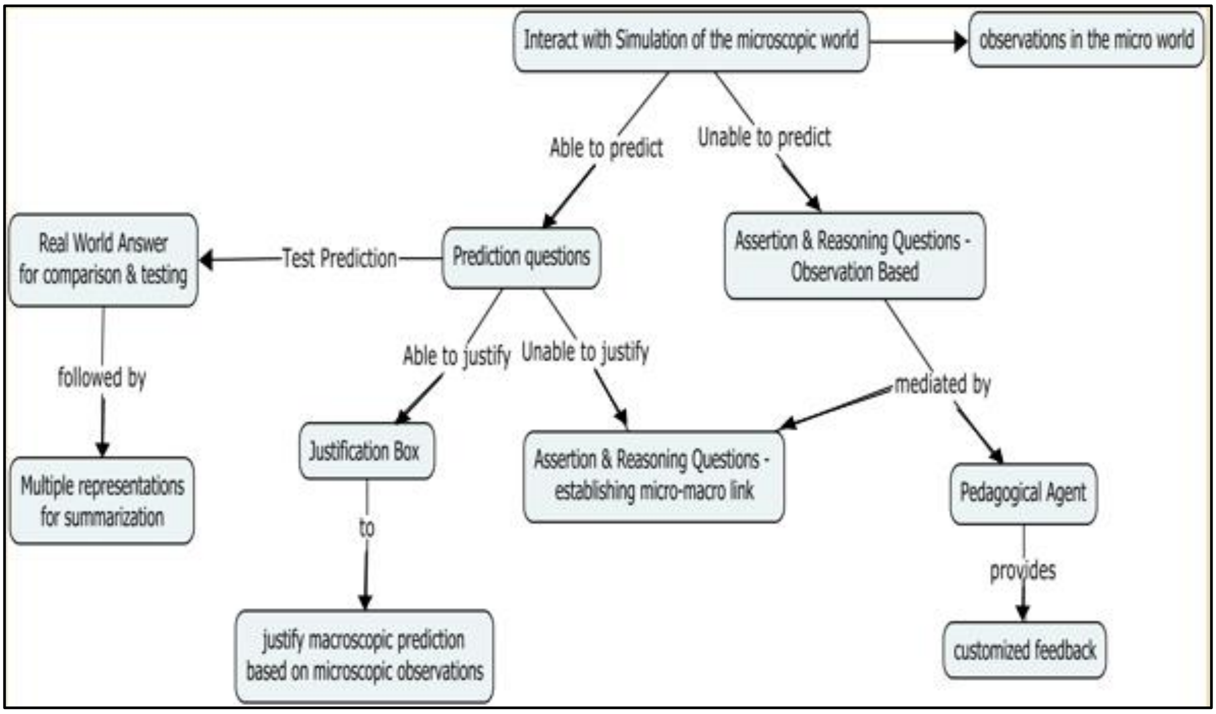


Figure 1.3. Overview of the working of MIC-O-MAP

MIC-O-MAP modules have been developed in the subject of Basic Analog Electronics within the domain of Physics at the 1st and 2nd year of undergraduate level. The topics chosen were such that they were common both to the lab experiments as well as taught as theory in the syllabus. Topics which have concepts consisting of both micro and macro worlds are best suited for learning using MIC-O-MAP. In such topics, there are important variables in the macroscopic world (i.e. observable/ measurable) and corresponding variables at a microscopic world (often invisible) which explain the mechanism for the macroscopic variable behaviour. Based on these criteria, MIC-O-MAP modules have been created for the topics of basic PN junction, conductivity in intrinsic semiconductors, formation and conductivity in extrinsic semiconductors, thermistors and light dependent resistors.

1.4 Research Methodology

We have followed a Design Based Research (DBR) methodology in order to design our learning environment. DBR is defined as a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories [Wang & Hannafin, 2005]. During the DBR process, researchers observe different aspects of the design using both quantitative and qualitative methods, address associated problems and needs, and document why and how adjustments are made [Collins et.al., 2004].

Two DBR cycles were undertaken in this research work. As depicted in Fig. 1.4, the first DBR cycle consists of an exhaustive literature review of micro-macro thinking and existing solutions for the development of this skill. This was followed by a gap analysis and a literature review of pedagogical theories for the identification of features to be incorporated into the TEL environment of MIC-O-MAP. Initially, a quasi experimental study was conducted to examine if students interacting with MIC-O-MAP develop micro-macro thinking. This was followed by qualitative studies for investigating the interaction paths along with identification of difficulties faced by students as they worked with MIC-O-MAP. This led to the revision of the MIC-O-MAP environment features based on the difficulties identified in the first cycle. A single group pre-post test research design was adopted in order to confirm that students interacting with the improvised version of MIC-O-MAP modules develop micro-macro thinking skills followed by a qualitative study to ensure that the difficulties in learning identified in cycle 1 have been addressed. Lastly, semi structured interviews were conducted in order to gather insight into the thought process of acquiring the micro-macro thinking skill.

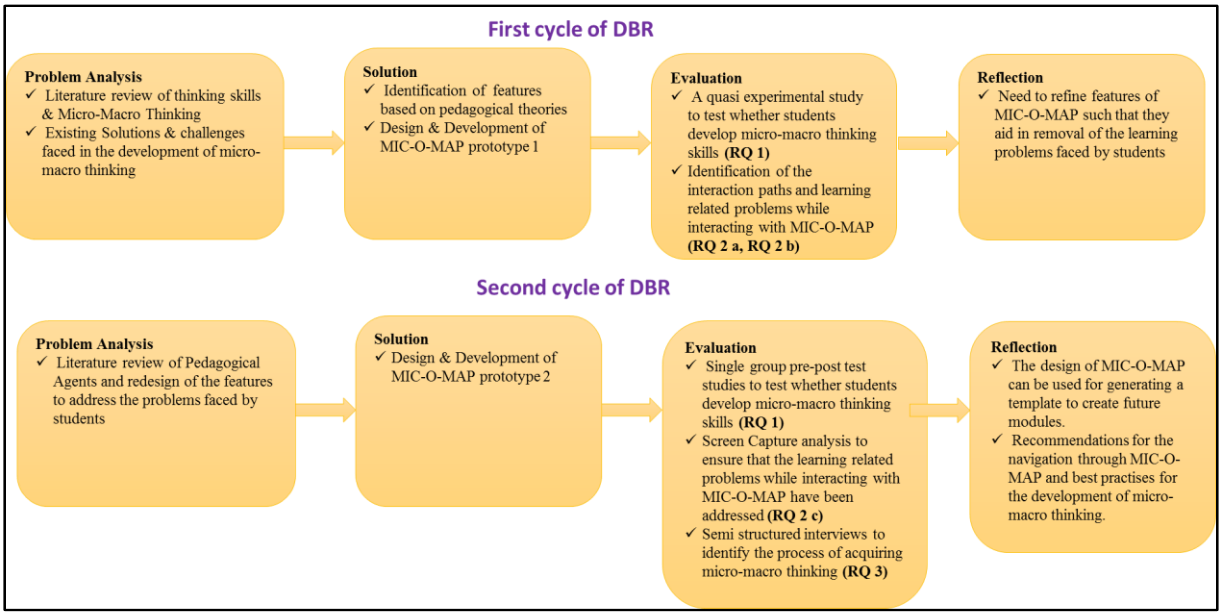


Figure 1.4. Design Based Approach for developing MIC-O-MAP

The research questions (RQs) emerged after a literature review of thinking skills in science and engineering, further scoped to the teaching-learning of micro-macro thinking, challenges faced by learners, existing solutions with a focus on TEL environments, and interaction of learners with TEL environments. The RQs are organized according to three themes:

Theme 1: Learning of micro-macro thinking using MIC-O-MAP

RQ1. Do students who work with MIC-O-MAP develop micro-macro thinking skills?

This RQ was answered via quasi-experimental as well as pre-post research designs. Studies related to this RQ were conducted as part of both DBR cycles, and were performed with all MIC-O-MAP modules developed in this thesis.

Theme 2: Interaction of learners with MIC-O-MAP

RQ2.

a) What interaction paths do students follow as they learn with MIC-O-MAP?

b) What difficulties do learners face while interacting with MIC-O-MAP for developing micro-macro thinking?

c) What was the effect of the improvised design on learner's interaction with the various features of the learning environment?

These RQs were answered by interaction analysis via screen captures of learners' interaction with MIC-O-MAP. Studies related to this RQ were conducted as part of both DBR cycles. Findings of the study in the first DBR cycle informed the redesign of MIC-O-MAP for the second cycle.

Theme 3: Process of acquiring micro-macro thinking

RQ3. How does learner interaction with MIC-O-MAP lead to development of micro-macro thinking skills?

This RQ is answered by detailed qualitative studies including interviews and case studies. Studies related to this RQ were conducted as part of the second DBR cycle and gave rise to recommendations of best practices while learning with MIC-O-MAP.

1.5 Scope of the Thesis

This section describes the scope of the thesis along the following four aspects: domain, learner characteristics, context and technology.

Scope of Domain: The goal of this research work is rooted in establishing a link between what is observed in the microscopic world and the measurable parameters in the macroscopic or real world. Taking this into account, the modules developed are scoped to the domain of basic analog electronics within the larger subject domain of Physics. Topics within basic electronics domain are as the working of all electronic components requires an understanding of these topics. An understanding of the link between the readings measured in the laboratories and the theory in terms of the electron motion is crucial and forms the stepping stone for further complex devices and circuits.

Scope of Learner Characteristics:

Participants in the studies undertaken for the development, evaluation and refinement of MIC-O-MAP are students from undergraduate programs from various colleges part of Mumbai University, India. These students are 18-21 years of age and have a background of science in their higher secondary education. Students are varied in terms of their academic performance. Familiarity and ease in usage of technology is expected from the participants. Students are proficient in English and have opted for that as their language of instruction in graduation.

Scope of Context:

MIC-O-MAP is intended to be used as learning material that supplements the traditional curriculum. The focus of the learning context is self-regulated learning by students. MIC-O-MAP modules can be assigned as homework or in-class hands-on work by instructors, or they can be used by students for example, as they work on independent projects. Learning with MIC-O-MAP has been devised for the context of self-study. Facilitation by a mentor/teacher or collaborative learning will not be required while interacting with this TELE

Scope of Technology:

MIC-O-MAP is coded in HTML 5 and is compatible across different operating systems, screen sizes and browsers. It contains flash based simulations embedded into an HTML 5 based interface.

1.6 Thesis Contributions

Design, development and evaluation of TEL system

The pedagogical design of MIC-O-MAP, i.e. a TEL system for micro-macro thinking, has been elaborated by identifying the features and learning activities required for specific learning goals mapped to micro-macro thinking skills. The system MIC-O-MAP has been developed and evaluated in multiple empirical studies.

Learning Materials

Six modules for MIC-O-MAP in basic Analog Electronics domain have been developed. These can be found on the website of Project TELOTS at Educational Technology, IIT Bombay http://www.et.iitb.ac.in/telotsCompleted.html. The modules can be directly downloaded by interested students and teachers.

Process of Skill Acquisition

Qualitative analysis of on screen activity log gave insight into what students are doing while learning and the interviews gave insight into why they are undertaking a particular action. A combination of the two processes helped infer actions which led to development of micro-macro thinking. We refer to these actions as Productive Actions. Following these actions while interacting with MIC-O-MAP leads to optimizing the potential of each feature or a combination of features for the development of micro-macro thinking.

Resources for instructors: Recommendations are provided for instructors to guide students to learn productively from MIC-O-MAP. An Instructional Design Document template has been developed which can be used by other teachers or researchers for creation of new MIC-O-MAP modules in different topics and extending it to various domains. In addition, the source code is available for researchers to build further new modules.

1.7 Organization of the Thesis

The chapters in this thesis are organized as given in Fig. 1.6. Chapter 2 contains a literature review of thinking skills and micro-macro thinking with examples from multiple areas. This is followed by the analysis of existing solutions which comprise of technology based solutions, face to face solutions as well as blended solutions. A gap analysis is carried out which sets the broad goal for this research work 'To enable students to develop micro-macro thinking skills through interaction with a Technology Enhanced Learning (TEL) environment'. More detailed literature review is carried out in the area of student interaction and the cognitive process while interacting with a TEL environment. This leads to the identification of three themes which will be followed while carrying out this entire research work. Chapter 3 describes the survey of relevant methodologies for carrying out this research work and the reasons for choosing 'Design Based Research' and the steps using which MIC-O-MAP was developed.

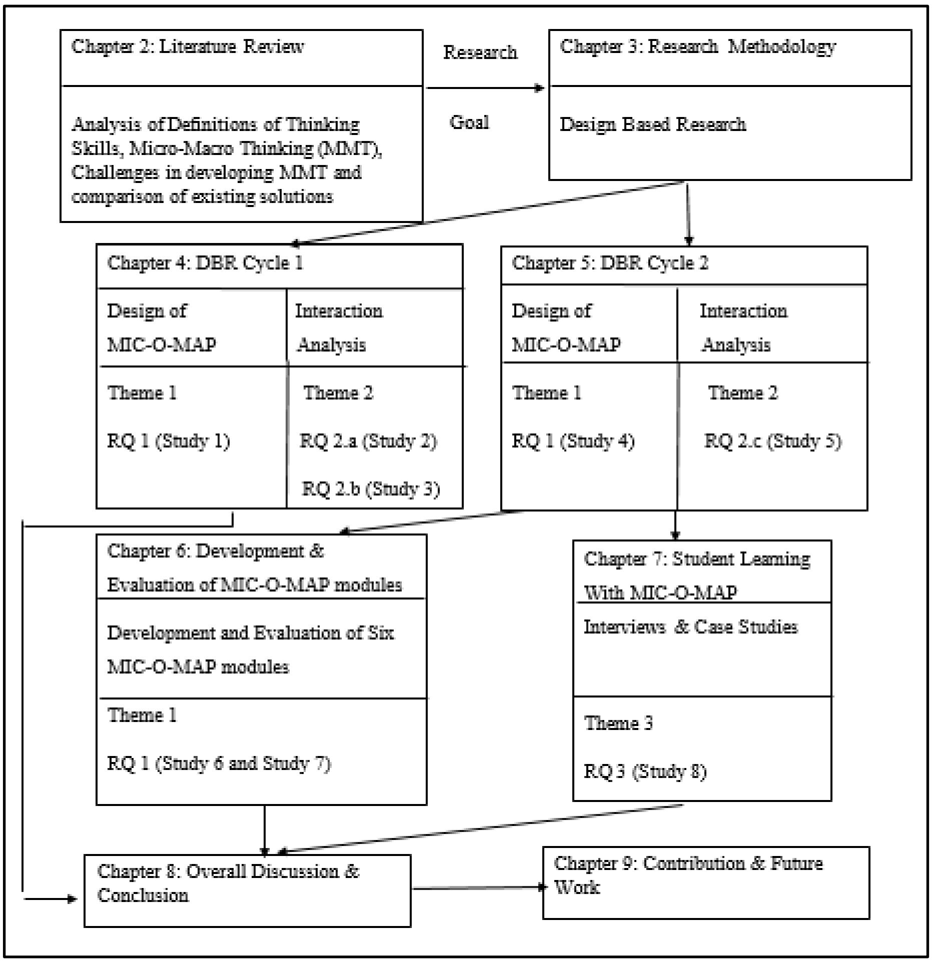


Figure 1.5. Organization of Thesis Chapters

The first cycle of DBR is discussed in Chapter 4 and details of three evaluation studies are described in this chapter. Similarly, the second cycle of DBR is described in Chapter 5 which begins with the identification and addressed problems of cycle 1. Within this cycle, details of two studies are described. Towards the end of Chapter 5, the design of MIC-O-MAP is completed. This is further used for the development and evaluation of multiple modules based on the same design template, which is explained in Chapter 6 along with corresponding evaluation studies. Chapter 7 explores the research question on the process of acquiring micro-macro thinking with MIC-O-MAP. The last two chapters, Chapters 8 and 9 contain the overall discussion along with contribution and future work of this thesis.

Chapter 2

Review of Literature

2.1 Organization of Literature Review

This chapter summarizes and synthesizes the literature on thinking skills, more specifically micro-macro thinking across different areas and its learning with the aid of technology enhanced learning environments. Challenges faced by learners in the process of learning the above, as well as the manner in which student-system interaction takes place are also reviewed. This review generates the three themes under which this research work has been carried out. The emerging research questions have been examined and investigated in accordance with each research theme.

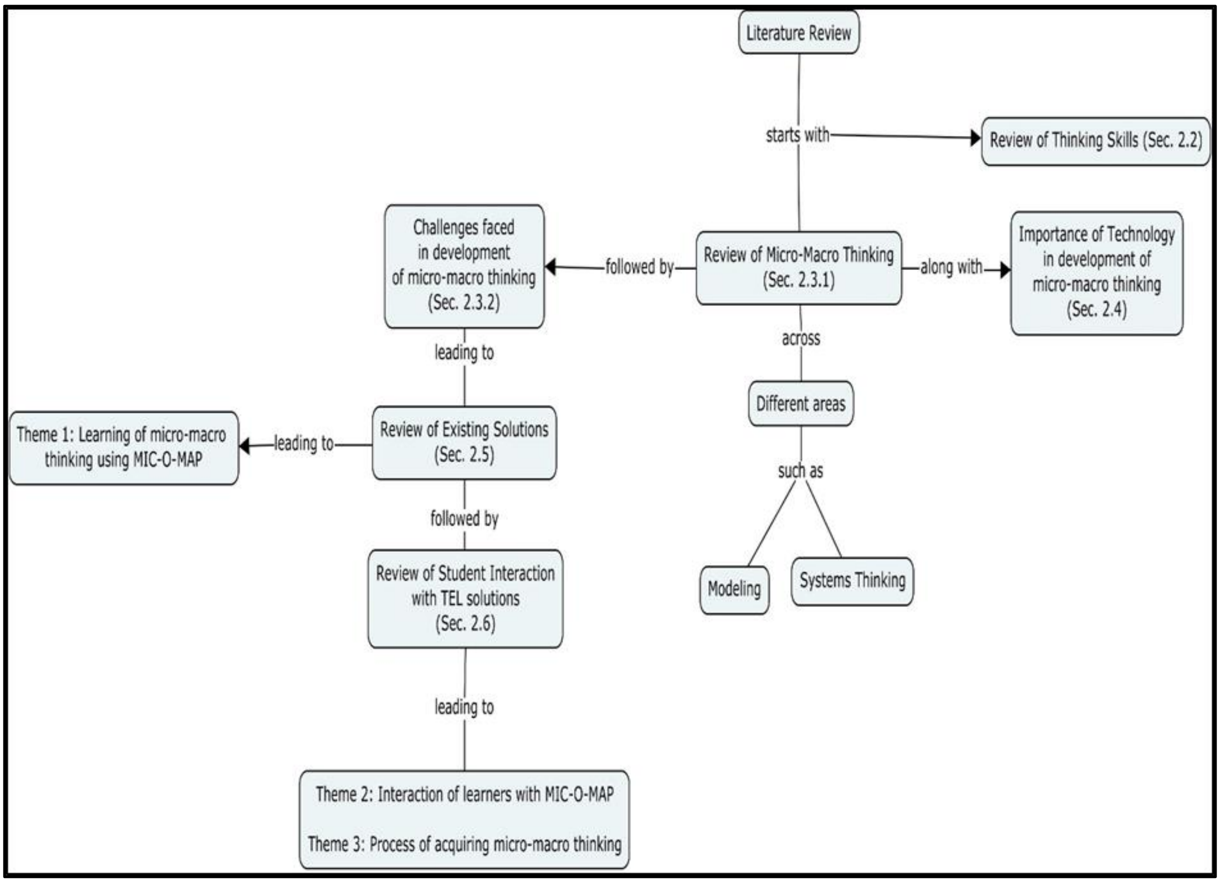


Figure 2.1: Organization of Literature Review

The literature surveyed in this chapter is initiated with a broad review of thinking skills in general, and establishment of the need and importance of micro-macro thinking specifically. Section 2.2 and 2.3 encompass various definitions and categorizations of thinking skills, and later narrows down to the specific skill of micro-macro thinking. Examples of micro-macro thinking have been discussed within the domains of science and engineering in order to establish its relevance. The aspect of usage of technology for the development of this skill has also been discussed in section 2.4.

Section 2.5 provides a detailed analysis of the existing solutions leading to the first theme of this research work i.e. learning of micro-macro thinking using MIC-O-MAP. Within this theme primarily quantitative studies will be carried out to evaluate if students develop this skill of micro-macro thinking. Face to Face solutions as well as blended solutions have been discussed. Almost all of these have the crux of the learning solution to be technology oriented. This analysis provides an insight about the features to be incorporated in learning environments aiming to develop micro-macro thinking.

Section 2.6 takes a step further into the literature associated with student interaction with technology based systems and possible reasons which ensure ‘good performance’. The manner in which students interact with TEL environments has been detailed out and the broad realm of possibilities in which student interaction can be recorded as well as analyzed to infer reasons behind positive learning outcomes has been examined. Existing techniques as well metrics for analyzing student behaviour- interaction with the environment as well reasons backing every choice made by the student have been discussed towards the end of this chapter. This establishes the need for theme 2 i.e. Interaction of learners with MIC-O-MAP which will deal with the manner in which students navigate through MIC-O-MAP and to test if students are using the MIC-O-MAP features for their desired purpose or if they are struggling with doing the same. Results from theme 2 are followed by theme 3 i.e. process of acquiring micro-macro thinking, in which we will be trying to figure out the thought process of students as they follow a unique interaction path. Capturing and using these insights gained from the analysis of this literature review has helped us establish the above three research themes which will be followed throughout this research work.

2.2 What are Thinking Skills?

Thinking skills are cognitive processes that human beings apply for sense-making, reasoning, problem-solving [Lipman, 2003]. These are sense making cognitive processes applied for problem solving and it is expected that students should apply these skills in new situations. Diverse research bodies have attempted defining this set of skills expected from science and engineering graduates. Thinking skills in engineering and science include system design, problem posing, estimation, algorithmic thinking, creation and revision of scientific models, data representation and analysis, and so on. The Accreditation Board for Engineering and Technology (ABET) is the body that periodically reviews every engineering program in the United States and determines whether they meet certain standards [ABET, 2014]. The skills mentioned below are listed as the ABET criterion which every engineering graduate must demonstrate:

a) an ability to apply knowledge of mathematics, science, and engineering
b) an ability to design and conduct experiments, as well as to analyze and interpret data
c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
d) an ability to function on multidisciplinary teams
e) an ability to identify, formulate, and solve engineering problems
f) an understanding of professional and ethical responsibility
g) an ability to communicate effectively

h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
i) a recognition of the need for, and an ability to engage in life-long learning
j) a knowledge of contemporary issues
k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

Similar skills have been reported to be important by professional bodies such as Washington Accord [Basri et.al., 2004] and Next Generation Science Standards (NGSS) [Duschl & Bybee, 2014]. National Association for Research in Science Teaching (NARST) [Lawson, 1989] has defined science process skills by bifurcating them into basic science process skills and integrated science process skills. The former including skills such as observing, inferring, measuring, communicating, classifying and predicting and the later including skills such as controlling variables, defining operationality, formulating hypothesis, interpreting data, experimenting and formulating models. These skills have also been listed under 21st century skills [Silva, 2009] and segregated into a learning hierarchy of lower order and higher order thinking skills using Revised Bloom's taxonomy levels [Anderson, 2001]. The practice of developing these skills is a representation of what scientists do as they engage in scientific inquiry and a necessary part of what students must do both to learn science and to understand the nature of science. Lastly, The Taking Science to School [Shouse et.al., 2007] report interprets the learning science perspectives by stating science education in grades K-8 needs and emphasizing three practices:

1. Building and refining theories and models
2. Constructing arguments and explanations
3. Using specialized ways of talking, writing and representing phenomena.

An effective way to facilitate the development of these skills is to engage students in tasks which require them to undertake the process of scientific inquiry within their undergraduate learning experience.

2.3 Micro-Macro Thinking

2.3.1 What is micro-macro thinking?

A major practice of scientists is planning and carrying out a systematic investigation, which requires the identification of what is to be recorded and, if applicable, what are to be treated as the dependent and independent variables (control of variables). Observations and data collected from such work are used to test existing theories and explanations or to revise and develop new ones. Real life examples of these include recording temperature differences and explaining these based on atoms, molecules and their vibrations, recording driving parameters such as acceleration/directions and devise explanations for these based on fuel capacity, force and pressure. Such tasks involve relations between observable, tangible phenomena at a macroscopic level and their underlying structure, processes and dynamics at a microscopic level.

Thinking skills related to establishing micro-macro link in systems have been reported in various fields. Research related to systems thinking discusses the need to be able to think backward and forward between general systems models and concrete objects and processes [Wilensky & Resnick, 1999]. In the teaching-learning of scientific modeling, an important aspect is to explain the macroscopic outcome or observed physical phenomena by applying a model at a microscopic level [Etkina et.al., 2006]. In all of these areas, macroscopic terms denote directly observable real-world phenomena such mass, conduction of electricity, pressure, size, colour and their corresponding measurements. Whereas microscopic terms refer to models with structures at the level of molecules or atoms, often invisible particles with dimensions much smaller than we can observe, and their associated dynamics.

We define 'micro-macro thinking' as the ability to establish a link between the variables in a micro-world and its corresponding manipulable variables in a macro-world in order to predict the functionality of the system. In a given situation, in order to establish this micro-macro link, sub-skills of making observations in the micro-world, predicting macroscopic outcome, testing these outcomes against experimental evidence and revising predictions (if necessary) need to be developed.

2.3.2 Importance and challenges of developing micro-macro thinking skills

During their learning process, students who perform the exercises and experiments, and view demonstrations do not necessarily recognize that these portions of the curriculum are interrelated and are based upon a common conceptual underpinning [Hinton & Nakhleh, 1999]. Development of micro-macro thinking skill is important as it will help to bridge the gap between theory and experiment. This is because real world phenomenon not directly observable and can only be seen through lab experiments. Students also require the micro-macro thinking skill when they are recruited and are expected to apply the knowledge gained by them in a real-world context, for example, in equipment design where they build complex circuits There exists a lack of application of conceptual understanding and a need for greater emphasis on the development of scientific skills and abilities so that students will be able to predict, test or evaluate conceptions and mimic the scientific procedures employed by scientists during sense making and inquiry. An effective way to facilitate the development of these skills is to engage students in tasks which require them to undertake the process of scientific inquiry within their undergraduate learning experience. Undertaking an inquiry-based learning task requires them to apply their theoretical knowledge to real world situations. Particularly in science and engineering domains, such tasks involve relations between observable, tangible phenomena at a macroscopic level and their underlying structure, processes and dynamics at a microscopic level.

Research shows that students have difficulty transferring from a macroscopic level of representation to the microscopic level [Gabel, 1998]. Students are not aware that models can be used for analysis, testing, verifying data and are unable to generate the cause for any new phenomenon that they are observing [Treagust, et.al., 2004]. Students are also found to be lacking in the ability to modify or generate a new theory using their existing knowledge [Treagust, et.al., 2004].

To avoid development of misconceptions, it is important for instructors and curriculum designers to have in-depth knowledge of the problematic features of micro–macro thinking and to understand what it is that is to be communicated to students and how this is best communicated to them [van Berkel et.al., 2009]. Learners need to describe, understand and predict the outcomes of phenomena at the macroscopic level by relating these to the scientific models of structures and processes at the microscopic level.

2.4 Importance of Technology

Technology based tools such as animations and simulations which help students connect between microscopic and macroscopic levels, have been shown to promote conceptual understanding [Kozma et.al., 1997]. Animations and simulations have tremendous potential to provide visual representations of dynamic phenomena that involve change over time, and the power to make the invisible visible [Rutten et.al., 2012]. Hence, they allow students to build mental models of physical phenomena. Simulations allow students to make predictions, and then test them by subsequent events. This helps them understand the mechanism underlying a phenomenon and can lead to the refinement of the conceptual understanding of the phenomenon [Windschitl & Andre, 1998; De Jong & Van Joolingen, 1998]. Simulations provide the opportunity for stating and testing hypotheses and multiple representations of physical phenomena such as diagrams and graphs [Blake & Scanlon, 2007].

A key affordance in computer-based learning environments is the ability to provide immediate feedback to students' responses. This allow learners to be active agents in the process of acquiring knowledge and support scientific practices. Prompting learners to articulate their thinking helps them become more aware of what they know, which then makes their thinking available to them for reflection, monitoring, and revision [Scardamalia et.al., 1989]. Receiving instant feedback on their actions can aid in the development of micro-macro thinking since it provides prompts a learner to reflect on elements of the microscopic world have links with macroscopic world. An articulation of these affordances and benefits of learning with technology sets the motivation for designing and building a technology enhanced learning environment MIC-O-MAP for the development of micro-macro thinking.

2.5 Existing Solutions

In addition to numerous technology enhanced learning environments that address concepts from various domains, researchers and educators have developed instructional interventions which have explicitly aimed at developing students' scientific abilities. Many of these have arisen as a result of the affordances provided by ICT based learning environments, and incorporate the recommended teaching-learning strategies discussed in the previous sub-section.

Face-to-face solutions include MARS [Raghavan & Glaser, 1995] and ISLE [Etkina & Van Heuvelen, 2007]. Model-based Analysis and Reasoning in Science (MARS) project comprises of a set of model-centered, computer supported, semester-long science curriculum for middle-school students designed to encourage conceptual understanding and to foster the development of model-based reasoning skills. The overall approach is to provide students with increasingly complex, interactive, explanatory models that can be directly manipulated by students. The models are implemented in an integrated computer-supported environment, but related activities with concrete materials such as hands-on activities, homework assignments, class discussions, etc are an important feature of the instruction. "Investigative Science Learning Environment (ISLE) – A Science Process Approach to Learning Physics." [Etkina & Van Heuvelen, 2007] is an interactive method of teaching which helps students learn physics by engaging in processes that mirror the activities of physicists when they construct and apply knowledge. These processes involve observing, finding patterns, building and testing explanations of the patterns, and using multiple representations to reason about physical phenomena.

Instructional interventions which target students' scientific thinking skills include WISE (Web-based Science Environment) which provides an Internet-based platform for middle and high school science activities [Linn et.al. 2002; Williams & Linn, 2002]. Web-based inquirer with modeling and visualization technology (WiMVT) proposes an inquiry cycle incorporating eight phases: Contextualize, Question & Hypothesize (Q&H), Premodel, Plan, Investigate, Model, Reflect, and Apply [Sun & Looi, 2013]. This is based on the POE (Predict-Observe-Explain) principle. Model-It argues that students go through an inquiry cycle in the following phases: planning, searching, synthesis, analysis, explaining and evaluate [Fretz et.al, 2002]. Similar cycles are proposed by solutions such as Co-Lab [Joolingen et.al. 2005], Go-Lab [Govaerts et.al., 2013], nQuire [Mulholland et.al, 2012; Villasclaras-Fernandez et.al, 2013], ModelingSpace [Avouris et.al. 2003] and Inquiry Island [White et.al, 2002] which suggest usage of netbooks in addition to the above technology based resources. SimQuest promotes discovery learning and suggest following the WHAT-IF format wherein WHAT-IF tests and the explicit knowledge tests are based on the analysis of intuitive knowledge as being characterised by a 'quick perception of anticipated situations' [Swaak & Jong, 2001].

Many of the above mentioned Technology Enhanced Learning Environments (TELE) address some of the aspects of micro-macro thinking, as discussed further. In WISE, the pattern of working involves articulating existing ideas, adding new ideas, distinguishing new ideas from existing ideas, and building a coherent argument by reflecting on the ideas in the repertoire [Linn & Chiu, 2011] The MARS curriculum focuses on engaging students in qualitatively reasoning using models. This is done by providing students with increasingly complex, interactive, explanatory models that can be directly manipulated. These models are implemented using a computer supported environment as well as related activities such as homework assignments and in class discussions, desk work and tests at the end of each unit. ISLE allows students to observe physical phenomenon, devise explanations for them, share their explanations in groups and then design testing experiments to determine if the explanations work. Finally, they apply these concepts to unfamiliar phenomenon. On similar lines, Co-Lab, is a learning environment in which groups of learners can experiment through simulations and remote laboratories, and express acquired understanding in a runnable computer model. WiMVT provides evidence for students mastering the skills of circuit diagrams; skills of connecting physical circuits and data analysis skills of experiments. The instruments used by students while developing these skills includes field notes, observation sheets, screen capture videos, face-to-face interviews, on-site videos and audios, and created learning artefacts. Lastly, ModellingSpace is an open learning environment that supports real-time and asynchronous collaboration of small groups of students engaged in problem solving.

Most of these learning environments also include components such as lab work, field trips, discussions and assignments apart from the ICT-based solution. In these existing interventions, the teacher plays an important role by facilitating the process, giving prompts or grading students' efforts at a later stage [Raghavan & Glaser, 1995; Etkina & Van Heuvelen, 2007]. Most of these solutions are focused on middle and high school science curriculum, while ISLE curriculum, which is mainly classroom-based has addressed high-school and introductory college courses. Table 2.1 compares and contrasts existing solutions representative of the following facets: learning goals, need for collaboration & a facilitator while learning, context/ setting for learning, the subject domain, targeted sample and lastly the theoretical underpinning for each solution.

Each of the seven learning environments surveyed in Table 2.1 below is corresponding to a unique learning goal and gives an overview of different target audiences and contexts of learning.

Table 2.1: Comparison of Existing Solutions

Learning Environment → / Design Features ↓	**ISLE**	**MARS**	**WISE**	**CO-LAB**	**WiMVT**	**Model-It**	**Modeling Space**
Learning Goal	Construct, evaluate physics knowledge	Qualitative reasoning with models	Go through inquiry cycles	Experimentation through simulation	Learning Science through Modeling	Modeling practices	Individual and collaborative modeling
Collaboration Needed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Theory	Scientific Inquiry	Scientific and model based reasoning	Scaffolded Knowledge Integration	Collaborative discovery learning	Predict-Observe-Explain principle	Learner Centered Design	Collaborative Learning
Setting	Blended	Classroom	Blended	Online	Blended	Blended	Online
Sample	pre-service high school physics and pre-service elementary science teachers	Middle school students	Middle school students	Upper secondary and first year university students	Lower secondary school students	Middle school students	High school students
Domain	Science	Science	Middle school earth and physical science, high school general science	water management, greenhouse effect, mechanics and electricity.	Science-Electronics	General Science	General Science
Teacher Required	As a mentor	Yes	Yes	As a mentor	Yes	Yes	Yes

2.6 Student Interaction with TEL Solutions

The analysis of the existing solutions showed that technology based solutions aid in developing micro-macro thinking. Every student interacting with a TEL environment for micro-macro thinking has a unique manner in which they proceed through the environment and execute each task. The development of micro-macro thinking correlated to the path undertaken by students while they interact with MIC-O-MAP, will aid the researcher in understanding if the design features incorporated in MIC-O-MAP are achieving its goal. MIC-O-MAP is a semi open ended TELE which provides instructions on navigating through the environment but does not make it mandatory. Every learner has a unique way of developing the skill of micro-macro thinking using MIC-O-MAP. We wanted to investigate this route of navigation through MIC-O-MAP for all learners, and also to gather an in depth understanding of the student actions which are productive and leading to the development of micro-macro thinking. In order to do this, we first undertook a literature review of the meaning of student interaction with any learning environment, more preferably, a technology enhanced learning environment. This literature review was necessary as we would be undertaking qualitative studies to gather insight into student behaviour while working with MIC-O-MAP.

Student interaction with the system can be at a very basic level of 'observation' mode, and can further progress right up to an 'experimentation' mode giving learners the experience of inquiry based learning. There exist various ways of classifying these levels in learning environments, such as:

i) 'control behaviour → interactive behaviour' [Bétrancourt, 2005]

ii) 'control → response → manipulate → co-construct' [Tang, 2005]

iii) 'observation → controlling →creation' [Pahl, 2004]

iv) 'no interactivity → navigation within the presentation → interaction with graphical model → interaction with simulation model → immersion' [Chick, et.al.; 2003]

Depending on different levels of interaction in learning environments, the following categories of interactive content presentation have been proposed: still images; animated pictures; visualization with display adjustments such as play-stop-speed; visualization selection and arrangement capabilities such as repeat-rewind; visualization with changing input-zooming,-panning; visualization with interactive decision points, for example, changing data while running; and finally visualization generated by students [El Saddik, 2001].

While undertaking any form of interaction, “the effectiveness, efficiency, and satisfaction with which specified users can achieve goals in any particular environment” is termed as the usability of the learning environment [Hornbaek, 2006]. An unproductive period represents time spent by the learner not actually working on the specific task or not working towards the specified goal involved in the task. It consists of time that the learner spends referencing help, thinking about what to do next and solving problems not directly associated with the task at hand [Wong, et.al.; 2003]. On similar lines, productivity concerns the amount of useful output that is obtained from user interaction with the system [Seffah, et.al.; 2006]. There are generally two types of user task actions, one that is productive and the other is unproductive wherein the productive user task actions are those that contribute to the task output [Macleod et al.;1997].

In section 2.6.1 & 2.6.2, we discuss the different types of interactions of a learner with any given technology based learning environment.

2.6.1 Types of Student Interactions with TEL Solutions

Interaction can be described in terms of multiple aspects related to a learner's control over system responses, adaptation of a system to user's input and provision for participation and communication [Sims, 1999]. The first classification of interactions in learning processes to reach wide acceptance was proposed by Moore (1989), who identifies three different types of interactions associated to learning by means of an e learning platform:

- Student- Student
- Student-Teacher
- Student-Content

In e-learning, every student must use the specific technologies, platforms, applications and templates available in order to interact with other students, teachers and content. An additional type of interaction which may reflect the information exchanges between students and system via a virtual learning environment is called student-system interaction [Hillman, Willis & Gunawardena, 1994]. Lastly, a new type of interaction added to Moore's classification, is called self-interaction, which refers to the self-regulation ability of each student as part of the self-directed learning process which is e-learning [Soo & Bonk, 1998]. This interaction is based on a reflexive thinking process undertaken by the student and does not generate any data in the learning environment in a natural way. This interaction undertaken by students, when analysed provides awareness into the success/failure of the student in using the system as well as the identification of areas which can be improvised upon based on the student interaction analysis.

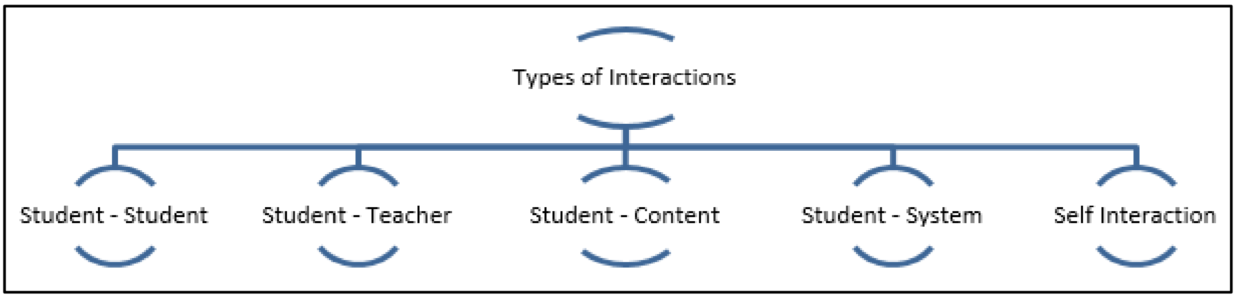


Figure 2.2: Types of Interactions

Learning with technology based solutions is a student-centered active learning process entailing students' self-propelled actions to acquire knowledge. After spending years in teacher-centered classrooms and being exposed to one way - teacher to learner- interaction, it is challenging for traditional learners to become active learners. It has been proposed to take into account the role of technologies in the interaction process [Finegold & Cooke, 2006; Roblyer & Wiencke, 2003]. Learners' familiarity with different functionalities of the interface increases their utilization, and each type of interaction depends on others in online learning environments [Sun & Hsu, 2013].

While undertaking student-content interaction analysis, there exists a vast realm of data analysis methods depending upon the information present at hand, reason being it will vary from one learner to another. Different activities and features are present in any learning environment and the frequency of use informs the feature adoption rate of the learner. A variety of methods encountered while undertaking interaction analysis have been described in this section, some of which are discussed below:

- Assignments, activities, goals, and assessments implemented within the learning environment should reinforce active learning—that is, the process through which students actively assimilate rather than passively absorb learning material. Flanders Interaction Analysis Categories System (FIACS) is a classic system of interaction analysis used to study what is happening in a classroom when a teacher teaches [Amatari, 2015].
- The Observation Schedule and Record (OSCAR) protocol was developed on similar lines as a 'sign and category' system' to include non-verbal categories of 'use of black board, use of slides, films and special teaching aids' [Medley & Mitzel, 1963].
- Clickstream Analysis is used for analyzing the record of screens or pages that user clicks on and sees, as they use a site or software product [Taniguchi, 2009]. Three levels of use have been identified under this type of interactions - Most Used, Moderately Used and Rarely Used [Malikowski, Thompson & Theis, 2007].

- Interaction Analysis is used to study the structure of events in a chronological order [Henderson & Jordan, 1995]. The learner's intellectual interaction with content leads to changes in the learner's understanding, perspective and the cognitive structure of the learner's mind [Moore, 1989]. It is suggested to investigate the pattern of interaction of learners with a given environment to examine how students initiate, lead or maintain interaction threads [Pawan et.al., 2003; Yang & Wu, 2011].
- Markov Models can be used to predict the interaction sequence for any given learning environment [Rychlik & Frendahl, 1993].

2.6.2 Learning Approaches based on Interaction

Learning is a process of active transformation of knowledge by the individual to extract meaning from the learning task [Brownlee & Joanne, 2001]. Students are also found to have different approaches to learning. Research has found that surface approaches to learning, such as memorising text, were linked to reproductive views of learning in that context and deep approaches to learning, were linked to beliefs that learning was a meaning making process [Marton & Säljö, 1976]. Students who take a surface approach towards learning are also called as passive or immature learners. Immature learners tend to organize their mental activities around topics rather than goals, promoting decontextualization and the inability to see the relevance of the learning activity to their lives [Scott Grabinger & Dunlap, 1995]. In contrast to this, students who undertake a deep approach towards learning are called intentional learners. Intentional learning is an achievement resulting from the learner's purposeful, effortful, self-regulated, and active engagement. So also, in order to be intentional learners, students must learn to learn as well as accrue knowledge. [Scott Grabinger & Dunlap, 1995].

Deep approaches to learning are where the learner has the intention to gain personal meaning and uses strategies that complement this intention by making links with prior knowledge [Biggs, 1985]. While interacting with any learning material or learning based tool, students should make an effort towards establishing links between the different elements and processes based on the topic of learning. The activities in the learning environment should be encouraging students towards becoming more mature and intentional learners instead of incidental learners where their goal remains to complete the task and not construct meaning based on their interactions.

Research also suggests that learning proceeds most rapidly when learners have frequent opportunities to apply the ideas they are learning and when feedback on the success or failure of an idea comes almost immediately [Roschelle, et.al. 2000]. The ability to transfer knowledge from the classroom to the real world implies learners must master underlying concepts, not simply memorize facts and solution techniques in simplified or artificial contexts. Technology provides enhanced capabilities to facilitate manipulation of parameters and experimentation which promote application oriented learning and avoid rote memorization.

2.7 Emergence of Research Questions

The analysis of existing solutions (Section 2.5) shows that they address the goal of developing micro-macro thinking, but implicitly and require multiple additional activities for a coherent understanding of the topic. Each existing solution contains pointers to multiple other places. Also, the existing solutions are resource intensive, might require classroom alteration to be undertaken and cannot be directly altered for creation of further modules as the source code remains unavailable. Besides, making changes in the existing systems according to each user's condition will require a lot of effort and will be time consuming. Time remains as a crucial factor also while learning with the existing solutions since one session might not be sufficient for teaching/learning the concept as well as for developing the skill, both mapped to various topics.

Technology based interventions which explicitly address the goal of establishing a link between the laboratory based macro world and a theoretical micro world do not exist within the domain of basic electronics at the university level. Students are expected to make these links between what is learnt in theory and the experiments performed in practical/laboratory so that they are able to successfully complete their final year projects or excel in inter collegiate competitions during their graduation years. Thus, an integrated technology based solution is needed for tertiary education which can be used for the development of micro-macro thinking, especially in the subject domain of electronics.

We aim to design a technology based learning environment which enables students to develop the skill of micro-macro thinking, having activities which explicitly encourage students to dive deep into the given macroscopic situation and its corresponding microscopic linkages, try and explicitly elaborate the establishment of a micro-macro link and further use this link to predict macroscopic solutions. This learning environment will host all activities and tasks on one single platform which will help on saving time. While the context of this learning environment remains self-regulated learning, it can also be used as supplementary teaching material, if required. At each stage, we will ensure that students link the two worlds and develop a coherent understanding of the topic.

This leads to the first theme of this research work, i.e. Learning of micro-macro thinking using MIC-O-MAP. Within this theme, we will investigate whether interaction with MIC-O-

MAP leads to the development of micro-macro thinking or if the existing visualizations without the scaffolds present in MIC-O-MAP are sufficient for this skill development.

RQ 1: Do students who interact with MIC-O-MAP develop micro-macro thinking abilities?

Section 2.6.1 showed that it is important that the student's interaction is studied carefully as it has been uncovered that the most important criteria for effective student - content interaction is designing a system. This type of interaction provides students with the opportunity browse and interact with the content on their own [Nandi, et.al, 2015]. Capturing students' interaction with MIC-O-MAP is deemed essential as it would enable the designers and researchers to further improvise the design structure of the environment. In order to design a system that allows students to seamlessly progress through cycles of making observations in the micro world, predicting outcomes in the macro world and testing it against a real-world answer, the second goal of this research work was to discover the interaction paths which students undertake while working with MIC-O-MAP.

This leads to the second theme of this research work i.e. Interaction of the Learner with MIC-O-MAP. Within this theme, we will investigate the different interaction paths adopted by students while interacting with MIC-O-MAP, reason being, that MIC-O-MAP is a semi open-ended learning environment and students have the flexibility to choose a learning path customized to their skill developmental stage.

RQ 2. a: What interaction paths do students follow as they learn with MIC-O-MAP?

Within Theme 2 - Interaction of learner with MIC-O-MAP, once we are aware of the path adopted by students for navigating through MIC-O-MAP, we will be analyzing what action is being performed by the student while navigating through a particular path. The goal is to develop and evaluate a task and function specific design which aids interaction and reduces unnecessary navigation within and between features of MIC-O-MAP. The following research questions will be examined in order to examine student interactions:

RQ 2. b: What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

RQ 2 c: What was the effect of the improvised design on students' interaction with the various features of the learning environment?

An overview of the approaches towards learning leading towards students becoming intentional learners is reported in section 2.6.2. **This leads to the third theme undertaken in this research work i.e. Process of acquiring micro-macro thinking.** The aim of this research theme is to identify processes through which the skill development takes places and makes the students interacting with MIC-O-MAP intentional learners. We aim to conduct qualitative user studies focused on effective usage of design ideas for execution of the tasks within the learning environment of MIC-O-MAP. We wish to map student actions to cognitive methods found to be effective while learning. The research question to be examined under Theme 3 is given below:

RQ 3: How does student interaction with MIC-O-MAP lead to development of micro-macro thinking skills?

2.8 Summary and Implications

A literature review of the existing solutions and challenges faced by students while developing micro-macro thinking skills led to the identification of the three research themes further mapped to research questions which will be investigated within each theme. The research method to be followed while carrying out this investigation will be discussed in the next chapter.

Chapter 3

Research Methodology

3.1 Introduction

The main research goal of this thesis is to develop micro-macro thinking skills among learners at the tertiary level, using MIC-O-MAP technology enhanced learning (TEL) environment. After reviewing current literature in relevant areas, we have more detailed insights into the themes and research questions which will be investigated in this research work within the above broad goal. To summarize the themes and research questions in this thesis:

Theme 1: Learning of micro-macro thinking using MIC-O-MAP:

RQ1: Do students who interact with MIC-O-MAP develop micro-macro thinking abilities?

Theme 2: Interaction of learner with MIC-O-MAP:

RQ2a: What interaction paths do students follow as they learn with MIC-O-MAP?

RQ2b: What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

RQ 2c: What was the effect of the improvised design on students' interaction with the various features of the learning environment?

Theme 3: Process of acquiring micro-macro thinking

RQ3: How does student interaction with MIC-O-MAP lead to development of micro-macro thinking skills?

3.2 Design Based Research

The choice of the methodology highly affects the manner in which the work is carried out and even the extent to which the desired research goal can be achieved or not. In traditional empirical predictive research, a new technique or device is put to the test in a controlled environment [Amiel & Reeves, 2008]. In traditional evaluation, an "intervention" such as an instructional program, a textbook, or a policy - is measured against a set of standards [Worthen & Sanders, 1987]. On the other hand, paradigms of qualitative research such as naturalistic and interpretative approaches support rich descriptions that illustrate explanations of a process, action, or interaction.

Educational problems are complex, non-linear, context dependent and involve multiple stakeholder. Such problems are addressed by iterative development and research, which take place through continuous cycles of design, enactment, analysis, and redesign [Cobb, 2001; Collins, 1992]. An approach which is in line with these goals is Design Based Research (DBR). DBR is a systematic but flexible methodology aimed to improve educational practices through iterative analysis, design, development, and implementation, based on collaboration among researchers and practitioners in real-world settings, and leading to contextually-sensitive design principles and theories [Wang & Hannafin, 2005]. Fig. 3.2 depicts the process of DBR:

For our research goal and research questions, we needed a method which not only tests success or failure but also focuses on interactions that refine our understanding of the learning issues involved. DBR goes beyond merely designing and testing particular interventions. It also undertakes analysis of student interactions with activities based on which redesign and refinement of activities, and ultimately refinement of the underlying interest-driven learning framework takes place [The Design-Based Research Collective, 2003]. A generic DBR process is depicted in Fig. 3.1 given below:

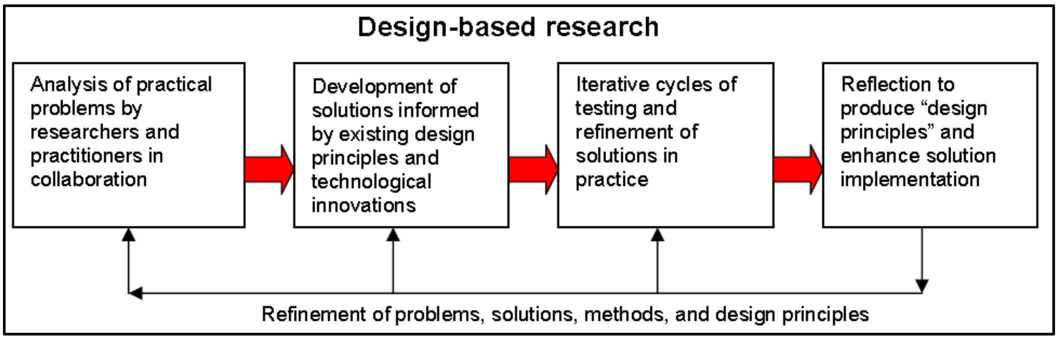


Figure 3.1: Steps of conducting Design Based Research

DBR is a suitable methodology for our research work for the following reasons:

- Iterative cycles of development, implementation, and study allow the designer to gather information about how an intervention is or is not succeeding in ways that might lead to better design [The Design-Based Research Collective, 2003]. In the process of designing MIC-O-MAP, a continuous literature review was carried out in order to address every problem identified in each DBR cycle. Not only the design features but even the implementation of MIC-O-MAP across multiple operating systems and screen sizes was tested to ensure compatibility in any machine.
- Researchers observe different aspects of the design using both quantitative and qualitative methods, address associated problems and needs, and document why and how adjustments are made [Collins et al., 2004]. In order to evaluate if MIC-O-MAP is suitable for the development of micro-macro thinking skills, mixed methods research was carried out wherein a quantitative study was followed by a qualitative study. The details of this evaluation are explained in Fig. 3.2.
- The outcomes from previously conducted designs provide explanatory frameworks "that specify expectations that become the focus of investigation during the next cycle of inquiry" [Cobb et al., 2003, p.10]. In each of the DBR cycles carried out in this research work, learning problems were identified while students interact with MIC-O-MAP and they were held as the focus for the literature review and redesign of the TEL environment in the next cycle.

DBR guides theory development, improves instructional design, extends the application of results, and identifies new design possibilities [Edelson, 2002; Gustafson & Branch, 2002; Reigeluth & Frick, 1999]. In a research study, the initial intervention may or may not have effectively solved the problem. If the intervention applied is not found to be effective; one can iterate the intervention until it becomes effective. Each iteration of modifying the intervention is termed as a research cycle. The important aspect of DBR is that the outcome/s of every research cycle is used as input for the next research cycle. This helps in augmenting the intervention on the basis of the 'failures' in the earlier research cycles. The cycles conclude after a particular version of the intervention shows desired results. In DBR, the conclusions of this process not only have the detailed log of the chronological development of the intervention but also the documentation of the problems recorded in the earlier cycles (along with the steps taken to address them).

3.3 DBR applied to MIC-O-MAP development

The DBR framework has been adapted in our research in an attempt towards identification of the pedagogical features and learning activities required in a TEL environment to develop micro-macro thinking skills. The design-development-evaluation proceeds in a cyclic process of successive prototypes as shown in Fig. 3.2:

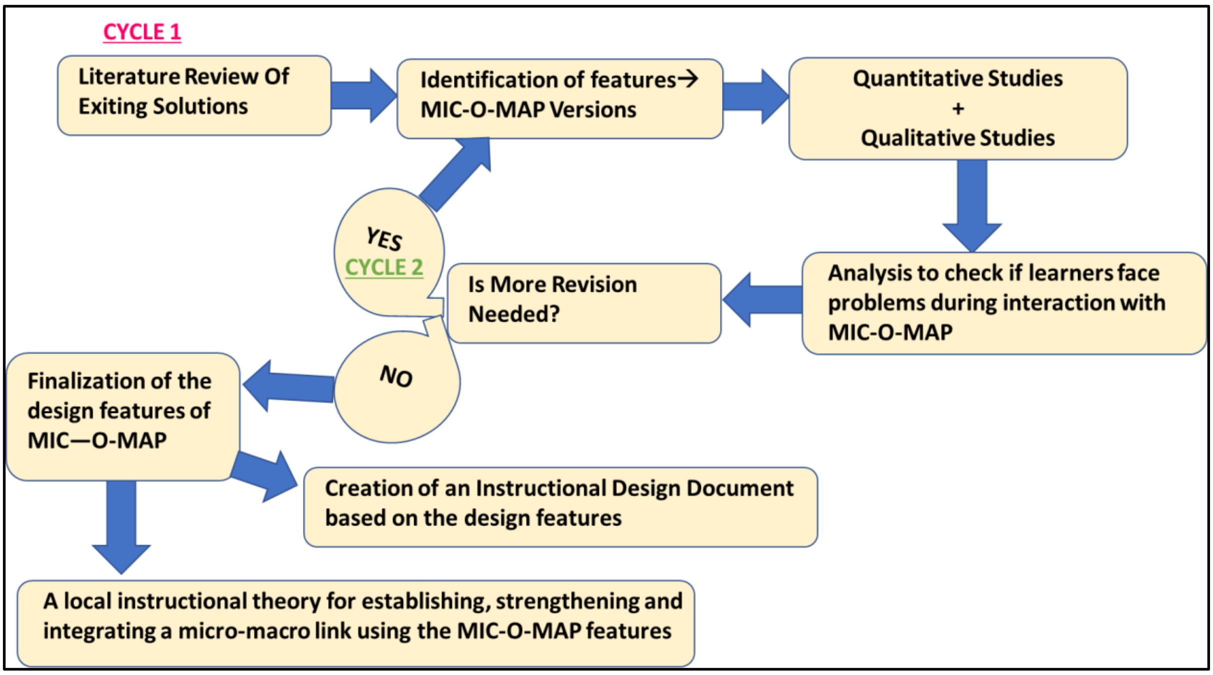


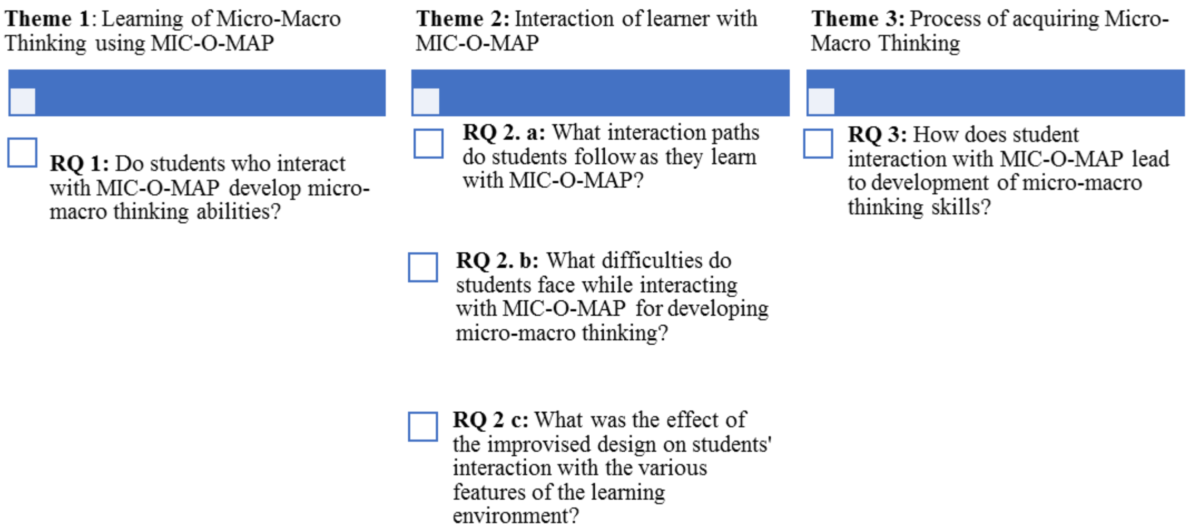
Figure 3.2: DBR cycle used for the development of MIC-O-MAP

In DBR CYCLE 1, a literature review of the thinking skills, definitions of micro-macro thinking associated with multiple areas such as systems thinking and modelling has been carried out. This was done in order to phrase our definition of micro-macro thinking and to articulate the sub skills of micro-macro thinking. This was followed by an analysis of the existing solutions for the development of this skill and an identification of the challenges faced by students for developing this skill. The affordances of technology were surveyed which would prove beneficial for the development of this skill and the context of learning was narrowed down to self-regulated learning with the target population belonging to tertiary level education. The pedagogical theories of inquiry thinking, self-regulated learning, types of scaffolds, question prompts and methods of feedback and assessment have been surveyed and the design features to be incorporated into MIC-O-MAP have been identified.

For evaluation, a mixed methods approach is followed. *Mixed-method* is “a procedure for collecting, analyzing, and ‘mixing’ both quantitative and qualitative methods in a single study or a series of studies to understand a research problem” [Creswell, 2013]. Specifically, the explanatory sequential design is followed, which occurs in two distinct interactive phases. It starts with the collection and analysis of quantitative data as a first phase. The second, qualitative phase of the study is designed so that it follows from the results of the first quantitative phase. The researcher interprets how the qualitative results help to explain the initial quantitative results. This format of the explanatory sequential design was found to be in accordance with the solution approach, and thus it was finalized as the research design within each DBR cycle.

The findings from the first cycle were used to inform DBR cycle 2. The quantitative study results helped conclude if students interacting with MIC-O-MAP develop micro-macro thinking skills where as the qualitative studies helped identify the learning problems while interacting with it. A second round of literature survey was carried out in order to address the learning problems identified from cycle 1. Specific features catered to each learning problem were incorporated into the TEL environment of MIC-O-MAP. In cycle 2, quantitative studies followed by qualitative studies were carried out in order to confirm that the learning problems have now been erased and that the design template of MIC-O-MAP can be used in order for further module creation.

A local instructional theory was also formulated wherein the students initially being with the establishment of a link between the micro and macro world using a combination of MIC-O-MAP features. Once they establish a link, it is strengthened and integrated using different MIC-O-MAP feature combinations. This entire process gives rise to the three research themes which will be followed in this work. The mapping of the themes with its corresponding research questions and studies have been depicted in Fig. 3.3.



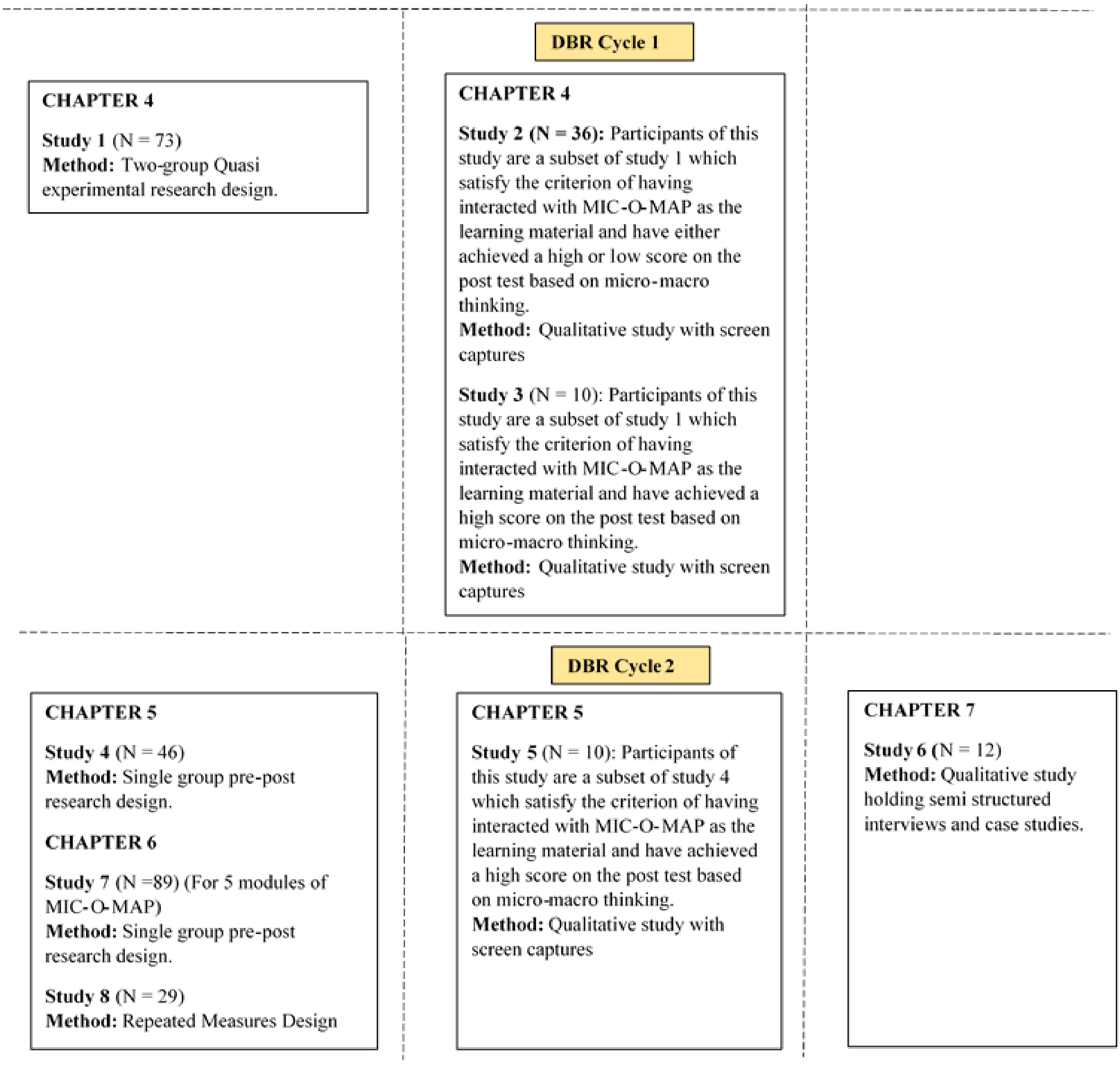


Figure 3.3: Mapping of the Research Questions & Studies to the Themes

In order to ensure that this design of MIC-O-MAP is suitable and customized to student learning needs, in Study 1, a two-group quasi experimental research study has been carried out wherein the only difference between the experimental group and the control group has been the learning material given to them. It has been ensured that rest all parameters are equivalent for the two groups, namely, their prior knowledge, random assignment of participants during the study and content equivalence, which is carried out by providing the control group with reading material which accounts for the prompts provided to the experimental group through the scaffolding features such as assertion and reasoning questions with customized feedback.

While these students were interacting with the learning material provided to them, the on-screen activity of the experimental group has been captured and analysed for two purposes:

- To identify the navigation paths of students as they interact with MIC-O-MAP (Study 2)

- To identify the challenges faced by students while interacting with MIC-O-MAP (Study 3)

The second cycle of DBR was started with a literature review of the ways in which the challenges identified from the first cycle can be erased. In order to ensure that students make a genuine effort to develop this skill, the literature associated with animated pedagogical agents was surveyed and the positioning of the assertion and reasoning question was refined. After redesigning the environment of MIC-O-MAP, in Study 4, a single group pre-post test study was carried out to find if there exists a statistical difference in the pre-test and post-test scores of these students on a test which measures micro-macro thinking skills. In addition to this, in Study 5, qualitative analysis was undertaken for the screen capture recordings and was further contrasted and compared with the same analysis carried out in the first cycle. This was done to test to what extent the challenges faced by students while interacting with MIC-O-MAP have been addressed. In Study 6, semi structured interviews were also conducted to get an insight into the process of acquiring the micro-macro thinking skill.

When there are no further difficulties faced by students while interacting with MIC-O-MAP, the design template of MIC-O-MAP was finalized and six modules on different topics within the subject domain of electronics were developed and tested for generalizability in Study 7 and 8.

Apart from logistics issues, the resources needed for coding and developing the MIC-O-MAP learning environment were identified and arranged. The first prototype of MIC-O-MAP was coded in flash, which further got revised into the coding language of Java but it was found to be incompatible in the operating system of Linux and would not get captured in all screen sizes. Finally, the learning environment of MIC-O-MAP was coded in HTML 5 with flash embedded into it. Professional programmers as well as interns were recruited for the process of coding the prototypes of MIC-O-MAP. They were paid the necessary remuneration for the same.

3.4 Ethical Considerations

The following issues were taken into consideration while finalizing the research methods and data analysis techniques:

- Deciding constraints on the research: As the research studies involved participants from basic science colleges, synchronizing research studies with the academic calendar was crucial. The necessary formalities to be carried out for getting permission and consent from the concerned authorities for conducting research studies were chalked out in advance. Official permissions were obtained after completing the required formalities and written documentation. Various issues related to actual conduction of studies were discussed with their teachers and principals. These issues involved: availability of computer and other laboratory resources for conducting studies, number of participants to be admitted for the study, adjustment of the academic load of the participants, requirement of supporting staff. Students participating in this research study were volunteers and were provided with participation certificates for attending the workshops arranged.

- Consideration of ethical issues: As the research studies involved human participants, the detailed guidelines were prepared for ethical consideration [Cohen, Manion & Morrison, 2000]. These guidelines mainly include:
    - Preparing procedures and documentation for taking informed consent from the participants: Participants were given a consent form before every research study. They were well-informed about the objective and procedure of the study. They were offered clarification by the researches in case they had any queries. After updating the participants with the full information, they were asked about their decision to participate in the study. They were allowed to discontinue participation from the study at any point of time. All the participants were assured that participation in the study would have no bearing on their grades and academic performance.
    - Maintaining anonymity and confidentiality of participants: Anonymity of all the participants was maintained throughout and all the data was given strict confidentiality.
    - Permission for publication: The necessary permissions for publication were sought from the participants.

3.5 Summary and Implications

By the end of this chapter, the overarching research methodology to be carried out throughout this work has been finalized as Design Based Research. Within each DBR cycle the explanatory sequential design of mixed methods research design will be undertaken wherein initially a quantitative study will be carried out followed by a qualitative study. Three research themes will be followed, namely, learning of micro-macro thinking using MIC-O-MAP, interaction of learner with MIC-O-MAP and process of acquiring micro-macro Thinking.

Based on this research methodology and themes which have been finalized, we first discuss the design and structure of MIC-O-MAP within the first cycle of DBR in chapter 4 along with the studies related to each theme as explained in Fig. 3.3.

Chapter 4

Design and Evaluation of MIC-O-MAP- DBR Cycle 1

4.1 Introduction

This chapter discusses the first cycle of DBR wherein the design, development and evaluation of the first prototype of MIC-O-MAP are detailed out. The pedagogical underpinnings on which MIC-O-MAP is based is initially discussed, followed by an explanation of the features and learning activities incorporated in MIC-O-MAP. Studies capturing insights related to the learning of micro-macro thinking using MIC-O-MAP (Theme 1) and interaction of learner with MIC-O-MAP (Theme 2) are discussed.

4.2 Pedagogical underpinning for the design of MIC-O-MAP

Effective pedagogical methods and processes of inquiry learning, self-regulated learning, scaffolding, question prompts and formative assessment and feedback are reviewed in order to orient the design features of the MIC-O-MAP TEL environment on a strong pedagogical base.

4.2.1 Inquiry Learning

Inquiry learning mimics authentic inquiry. Because they are closely related, they share the following constitutive cognitive processes [Quintana et.al., 2004]: orientation (identification of variables and relations); hypothesis generation (formulation of a statement or a set of statements, perhaps as a model); experimentation (changing variable values, making predictions, and interpreting outcomes); reaching conclusions (on the validity of the hypothesis); evaluation (reflection on the learning process and the acquired knowledge); planning (outlining a schedule for the inquiry process); and monitoring (maintaining an overview of the inquiry process and the developing knowledge) [De Jong, 2006].

In this learning environment of MIC-O-MAP, students go through an inquiry cycle in the following phases: Observations (Simulation of the microscopic model allows students to vary parameters by means of radio buttons, slider bars and observe corresponding outcomes in the simulation), Prediction (Students are expected to predict a macroscopic graphical answer based on their observations and provide a justification for the same which establishes a micro-macro link), Testing the prediction with respect to real world outcomes (Students are provided with a real world experimental outcome and are asked to judge whether their prediction is correct), Revision of Prediction (In case the prediction does not match the experimental outcome then students are provided with a series of assertion and reasoning questions with customized feedback mediated by a pedagogical agent and given pointers towards more careful observations or establishing a micro-macro link), Coherent Summarization (Students have to co-relate all representations of the micro world simulation, the macro world graphical outcome and the experimental setup with readings through meters and are expected to write a coherent summary.)

4.2.2 Self-Regulated Learning

Self-Regulated Learning (SRL) is an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition, motivation, and behavior in the service of those goals [Winne, 2001; Zimmerman & Schunk, 2001; Winne & Hadwin, 1998]. SRL is guided and constrained both by personal characteristics of the learner and by contextual features of the environment [Pintrich, 2000]. Thus, SRL models offer a comprehensive framework to examine how students learn and how they adapt during learning process. Learning in any environment requires a learner to regulate his or her learning, that is, to make decisions about what to learn, how to learn it, how much to learn, how much time to spend on it, how to access other instructional materials, how to determine whether he or she understands the material, when to abandon or modify plans and strategies, and when to increase effort [Deci et.al., 1996].

Self-regulation means being able to develop knowledge and skills which can be transferred from one learning context to another and from learning situations in which this information has been acquired to another work context. Recent studies have either attempted to identify the strategies learners use during learning with these environments [Greene & Land, 2000; Hill & Hannafin, 1997] or to identify the effectiveness of embedded strategies in these environments [McManus, 2000]. Embedded SRL strategies examples include advance organizers, navigation maps, note-taking, and search tools [Eom & Reiser, 2000; Hartley, 2001; McManus, 2000; Shapiro, 2000; Young, 1996]. SRL updates self-knowledge and perceptions about the task's changing states, thereby creating information that self-regulating learners can use to select, adapt, and even generate tactics [Butler & Winne, 1995]. SRL entails sensitivity to tasks' varying initial conditions and feedback generated by engaging with the task [Butler & Winne, 1995].

MIC-O-MAP is a semi open ended technology based learning environment wherein students have the flexibility to decide which learning path should be adopted, also, at each stage they have to make a choice with regards to the completion of the task, the extent to which they have gained knowledge and how to proceed further. They are expected to judge their development of the micro-macro thinking skills by means of the tasks presented to them and also are given the opportunity to restart the entire learning process if they figure need for the same. Since there is no aspect of peer learning or mentoring by a facilitator, the context of self-regulated learning has been incorporated into this system. Students decide for themselves the way in which the interaction process should proceed, with a subtle guidance provided to them as part of instructions in case are stuck at any stage during the learning process.

4.2.3 Types of Scaffolds

Scaffolding is a primary mechanism for relinquishing control of SRL to students as they develop competence and mastery in a given context [Azevedo & Hadwin, 2005]. It is suggested that scaffolding in Web-based learning environments just like in traditional, face-to-face learning environments should eventually result in self-regulated learning and lead to more self-reliant students [Winnips, 2001; Clark & Kazinou, 2001]. Scaffolding aids in self-monitoring which is defined as one's deliberate attention to an aspect of behavior that directs the learners' efforts to the learning task and assists them in evaluating the outcomes of these effort [Dabbagh

& Kitsantas, 2005]. Thus, scaffolds are tools, strategies, and guides used by human and computer tutors, teachers, and animated pedagogical agents during learning to enable them to develop understandings beyond their immediate grasp [Graesser et.al., 2005; Reiser, 2002].

Four types of scaffolds can be employed in the process of learning using hypermedia [Azevedo et.al., 2004]. These include conceptual scaffolds i.e. hints and prompts that are designed to provide guidance about what knowledge to consider during problem solving [Vye et.al., 1998], metacognitive scaffolds i.e. include human or nonhuman learning agents whose roles may include helping students with specific task-related tasks [Azevedo et.al., 2004], procedural scaffolds which assist students with learning how to use resources or how to perform certain tasks [Azevedo et.al., 2004] and lastly, strategic scaffolds which make students aware of different techniques for solving problems and expose students to the solution paths followed by other peers or experts [Azevedo & Lajoie, 1998; Lajoie et.al., 1998; Lajoie et.al., 2001]. Four attributes associated with scaffolding include: diagnosis, calibrated support, fading, and individualization [Azevedo & Hadwin, 2005]. The attributes of the scaffolds emphasized in the studies range from adaptive scaffolding based on on-going diagnosis, calibrated to the individual learner which may include some degree of fading [Hadwin et.al., 2005] to having the student engage in self-diagnosis with no other form of individualized support or fading [Choi et.al., 2005; Dabbagh & Kitsantas, 2005; Puntambekar et.al., 2007]. Scaffolding may support a range of instructional targets including:

a. learning domain knowledge (e.g., concepts, procedures, etc)
b. learning about one's own learning (e.g., metacognition, self-regulated learning)
c. learning about using the computer-based learning environment (e.g., procedures, embedded tools, functionality, etc)
d. learning how to adapt to a particular instructional context (e.g., engaging in adaptive help-seeking behavior, modifying contextual features to facilitate learning, etc.) [Azevedo & Hadwin, 2005].

MIC-O-MAP has multiple scaffolds embedded into it which are presented to the learner as and when required. Students indulge in a constant dialogue with a pedagogical agent which either gives instructions to proceed or conceptual scaffolds by means of question prompts and customized feedback. At each stage if students wish to visit a certain area of the learning environment, then it is allowed and they can change their answers. Students have to judge whether they are proceeding in the right direction or they need help. If they are unable to recollect prior knowledge, they can select the section which provides reading material to them and ensures that the knowledge needed for learning the given module is present, under the glossary section. Scaffolds which help them in navigating through the system, carefully think and proceed in the learning task given to them and ponder over the feedback presented, follow the feedback diligently, is to be executed by the learner and part of their metacognitive process.

4.2.4 Question Prompts

Research has shown that question prompts can facilitate explanation construction [King, 1992; King, 1990; King & Rosenshine, 1993], planning, monitoring, and evaluation [Davis & Linn, 2000] and making justifications [Lin et.al., 1999]. Compared with the no-question-prompt conditions, the students who received question prompts engaged in the following cognitive and meta cognitive activities:

a. making intentional efforts to identify factors, information, and constraints during the problem-representation process
b. organizing and planning for the solution process and articulating solutions explicitly
c. constructing arguments grounded in factors identified during problem representation and providing justification for each suggestion proposed
d. intentionally evaluating the selected solutions, comparing alternatives, and justifying the most viable solution.

Qualitative results have shown that the question prompts had an effect of directing student attention to important information they might have overlooked, thus facilitating awareness of what is known and not known. Without question prompts, the students seemed to have difficulty representing the problem and developing solutions. It was observed that the question prompts also helped the students to state their reasons for their proposed solutions and make their thinking visible. The justification prompts helped them to clarify, justify, and write down the reasons for their solutions that might not have been made explicit otherwise. Presumably, prompting learners to articulate their thinking helps them become more aware of what they know, which then makes their thinking available to them for reflection, monitoring, and revision [Scardamalia et.al., 1989]. The monitoring and evaluation prompts helped students think about alternative solutions and their viability, an aspect often overlooked by novice problem solvers.

Findings suggest that instructional designers should incorporate specific embedded scaffolds in hypermedia environments designed to foster students' conceptual understanding of complex topics [Azevedo et.al., 2004]. For monitoring, the system could encourage a student to engage in two specific monitoring activities (i.e., feeling of knowing and judging their learning) related to knowledge and monitoring progress toward goals. Students' use of effective strategies could be scaffolded within a technology based environment by providing online prompts, possibly from an embedded animated pedagogical agent [Mayer et.al., 2003].

Assertion and Reasoning Questions are included into the MIC-O-MAP environment which help the students in either locating the area of the simulation of the micro world which needs more careful observations or aids in establishing the micro-macro link between the micro world simulation and the macro world graphical outcome. There is customized feedback given to them which can be viewed based on the choice of the learner. This entire activity helps the learner to either establish or strengthen the micro-macro link, which is the crux of the micro-macro skill development process.

4.2.5 Methods of Feedback and Assessment

A large body of research in the area of formative assessment and feedback suggest creation and administration of online objective tests and quizzes that can be used by students to assess their understanding of a topic or area of study [Nicol et.al., 2006]. There is a role for online objective tests in the development of self-regulation. Research shows that students find such tests useful as a way of checking their level of understanding and that they will often make repeated attempts at such tests in order to enhance their knowledge and skill acquisition. Another format for online assessment involves students interacting with a simulation (e.g. of an engineering or business process). This can be a more effective form of self-assessment in that it aligns more closely than objective tests with the notion of self-regulation.

Effective feedback is described as information about how a person performs in the light of what was attempted – intent versus effect, actual versus ideal performance '(p46) [Wiggins, 2001]. In a simulation, the student gets direct, immediate and dynamic feedback about the effects of their actions [Thomas & Milligan, 2004]. Feedback within simulations is also likely to be clearer to the performer and its links to specific targets and standards more transparent. Good quality external feedback is information that helps students trouble-shoot their own performance and self-correct; that is it helps the students take action to reduce the discrepancy between their intentions and the resulting effects [Nicol et.al., 2006]. In higher education, most students have little opportunity to use directly the feedback they receive to close the gap and make performance improvements especially in the case of planned assignments. Invariably they move on to the next assessment task soon after feedback is received. While not all work can be re-submitted, many writers argue that re-submissions should play a more prominent role in learning [Boud, 2000]

Customized feedback in provided throughout the MIC-O-MAP environment which accelerates the learning process. Students are encouraged to take more efforts and think explicitly about the reasoning behind their decisions while interacting with MIC-O-MAP. The aim of this action if to make students inquisitive to learn more and help them develop the micro-macro thinking skill

4.2.6 Implications on the MIC-O-MAP Design

The last few sub sections discuss the theories which form the pedagogical basis of MIC-O-MAP. We now synthesize recommendations from these theories and present how they are applied to the design of MIC-O-MAP. Table 4.1 extracts out a feature on the basis of the pedagogical theories surveyed.

Table 4.1: MIC-O-MAP features based on Pedagogical Underpinnings

Theoretical Base	**Recommendation from theory**	**Why is this theory useful for developing the environment?**	**Feature/Process in the environment**
Inquiry Learning	Involve students in cycles of orientation, hypothesis generation, experimentation & reaching conclusions, evaluation, planning & monitoring [De Jong, 2006].	The development of the observe-predict-test-revise skills maps to the inquiry learning cycle.	Simulation of the microscopic world: Allows to make observation Prediction Questions and Justification Box: Allows to make a prediction in the macroscopic work & justify it on the basis of a micro-macro link. Real World Answer: Allows to test the macroscopic prediction against a real world answer. Assertion & Reasoning Questions with customized feedback: Provides prompts towards key areas where more observations need to be made or hints towards establishing a micro-macro link.
Self-Regulated Learning	learners set goals & regulate, and control their cognition in service of those goals [Winne, 2001; Zimmerman & Schunk, 2001; Winne & Hadwin, 1998].	We want students to reflect and decide their actions	Assertion & Reasoning Questions with customized feedback: Provides prompts towards key areas where more observations need to be made or hints towards establishing a micro-macro link. Pedagogical Agent: provides instructions and feedback via a dialogue with the learner Note Taking: Allows text entry for capturing key points Multiple Representation: For summarization and a complete understanding of the topic.
Question Prompts	conceptual scaffolds i.e. question prompts [Azevedo, et.al., 2004], exposure to different solution paths, navigation through dialogues and reasoning	Students should get feedback on their actions and pointers towards making careful observations or establishing a micro-macro link	
Feedback & Assessment	formative assessment at each stage & direct, immediate and dynamic feedback about the effects of their actions [Nicol & Macfarlane-Dick, 2006].		

4.3 Overview of MIC-O-MAP

As discussed in Chapter 2, micro-macro thinking constitutes a set of skills and sub-skills in which students learn to make observations in the micro world, make predictions in the macro world based on these observations, test predictions with respect to experimental results, and revise predictions if necessary.

The micro-macro thinking skill constitutes a set of skills and subskills in which initially students should be able to first accurately describe what is observed at a microscopic level. Based on these observations, they should be able to devise an explanation for an observed pattern. In the prediction phase, students should be able to state what might happen to the state of a system if a certain parameter was varied on the basis of an appropriate principles/theory and predict a macroscopic outcome based on the explanation for the observations.

In the testing phase, students should be able to analyze if the predicted answer tallies with the experimental outcome after performing the experiment. They should be able to decide whether the prediction and the outcome agree/disagree. In the revision phase, students should be able to alter the explanation based on which the prediction was made and justify the changes being made. They should be able to revise the explanation when necessary.

MIC-O-MAP features include a simulation of the microscopic world, prediction questions which allow the student to predict a macroscopic outcome, a justification box wherein the student can justify their prediction based on a micro-macro link, a real world answer for testing their prediction and assertion and reasoning questions which help students identify key areas and make more careful observations or inference based questions which help strengthen a micro-macro link. There exists customized feedback which is communicated to the students through a pedagogical agent in the form of a dialogue. Dynamically linked multiple representations have also been included in order to summarize their understanding of the topic. Features such as note taking, path tracing and answer retention have also been incorporated in order to smoothen this entire process of interacting with MIC-O-MAP. MIC-O-MAP features have been carefully included in order help students reach each of the three stages depicted in Fig. 4.1.

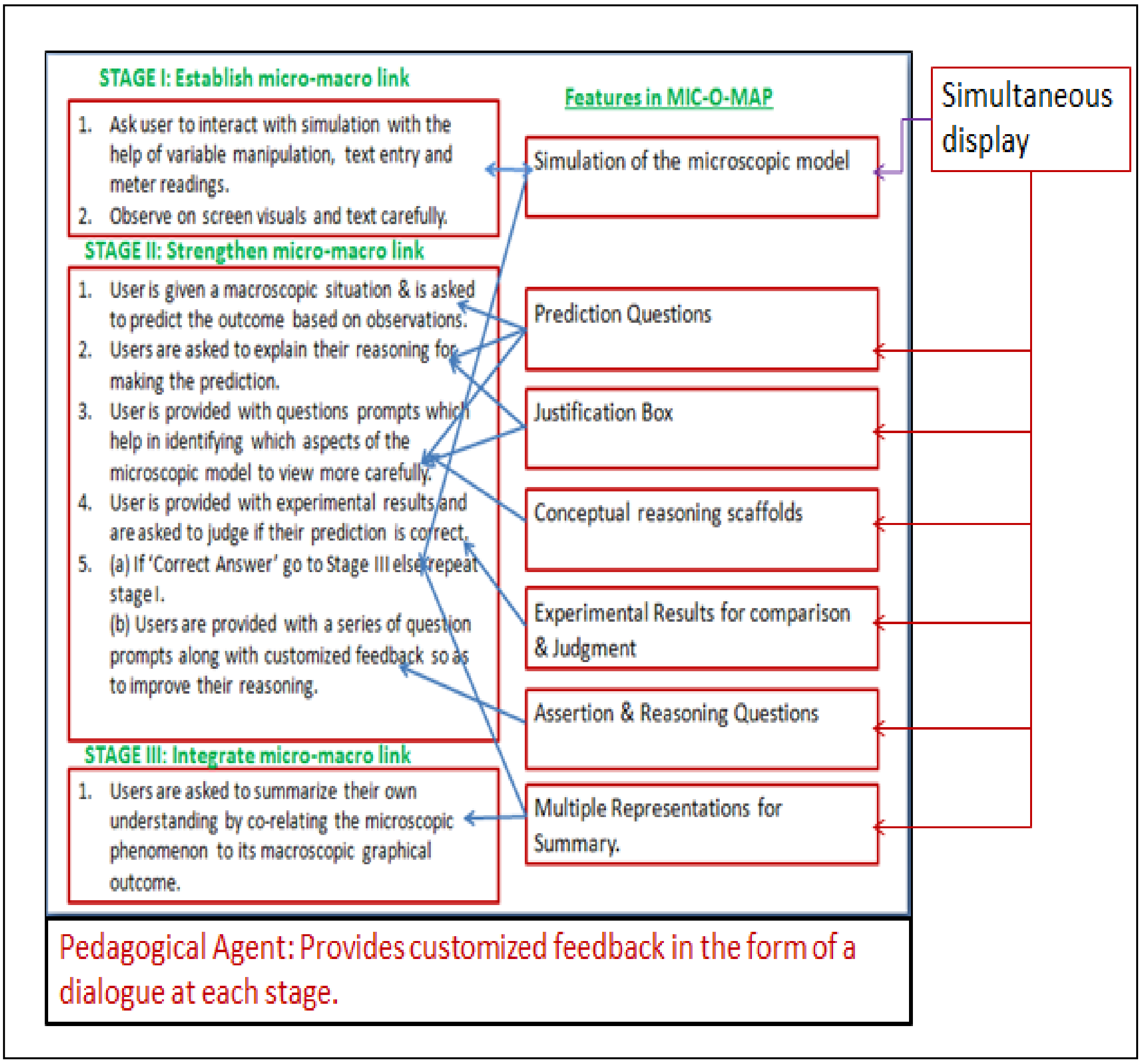


Figure 4.1: MIC-O-MAP Features Linked to Learning Stages

- *Establishing micro-macro link*: micro-macro link is established when students are asked to make careful observations in a given simulation of the microscopic model (often consisting of invisible particles) and then use it to predict the macroscopic outcomes of the given physical phenomenon (usually tangible and visible). Animations and simulations have tremendous potential to provide visual representations of dynamic phenomena that involve change over time, and the power to make the invisible visible [Rutten et.al., 2012]. This helps students understand the mechanism underlying a phenomenon and can lead to the refinement of the conceptual understanding of the phenomenon [Windschitl & Andre, 1998; De Jong & Van Joolingen, 1998].
- *Strengthening micro-macro link*: micro-macro link is strengthened when students are unable to make a prediction or are falling short in establishing this micro-macro link, and we provide them with a series of assertion and reasoning questions which aid in

improving their understanding and sense making of the physical phenomenon being observed. There exists a guided enquiry through a pedagogical agent beginning with the justification and reasoning given by the student behind a choice of prediction. This aids in strengthening the micro-macro link. There onwards they are asked multiple scaffolding questions along with customized feedback which either provides them with prompts for areas of the microscopic model which need more careful observations or aid them stregthening this link between the microscopic phenomenon and the macroscopic outcomes presented to them. Scaffolding components of different types – structural, reflective and subject-matter are required to improve learning outcomes [Fund, 2007]. Formative assessment in the form of rich and timely feedback, along with the opportunity to revise responses, has been shown to support the development of learner self-regulation [Nicol & Macfarlane-Dick, 2006]. In designing learning environments, research has shown that question prompts can facilitate explanation construction [Bereiter & Bird, 1985], monitoring and evaluation [Davis, 2000] and making justifications [Lin & Lehman, 1999]. At all times, an option is always there for them to take notes and save them. As students learn a topic, they have an inherent habit of writing down notes in their own language which they will be able to recollect at a later stage. By providing the option to take notes they can keep a tab of important points to be noted and need not put a load on their memory.

- *Integrating micro-macro link*: There exists and integration of the micro-macro link when students summarize their complete understanding using multiple representations of the microscopic model, the macroscopic experimental evidence in the form of meter readings and a graphical outcome. This aids in integrating the micro-macro link. Prompting learners to articulate their thinking helps them become more aware of what they know, which then makes their thinking available to them for reflection, monitoring, and revision [Scardamalia et.al., 1989]

The local instructional theory [Cobb et al., 2003], i.e description of a learning route based on a rationale for this learning environment is elaborated in terms of three stepping stones: namely, establishment of a micro-macro link, strengthening of the micro-macro link and integration of the micro-macro link. The mapping of the MIC-O-MAP features to these learning stages has been depicted in Fig. 4.2.

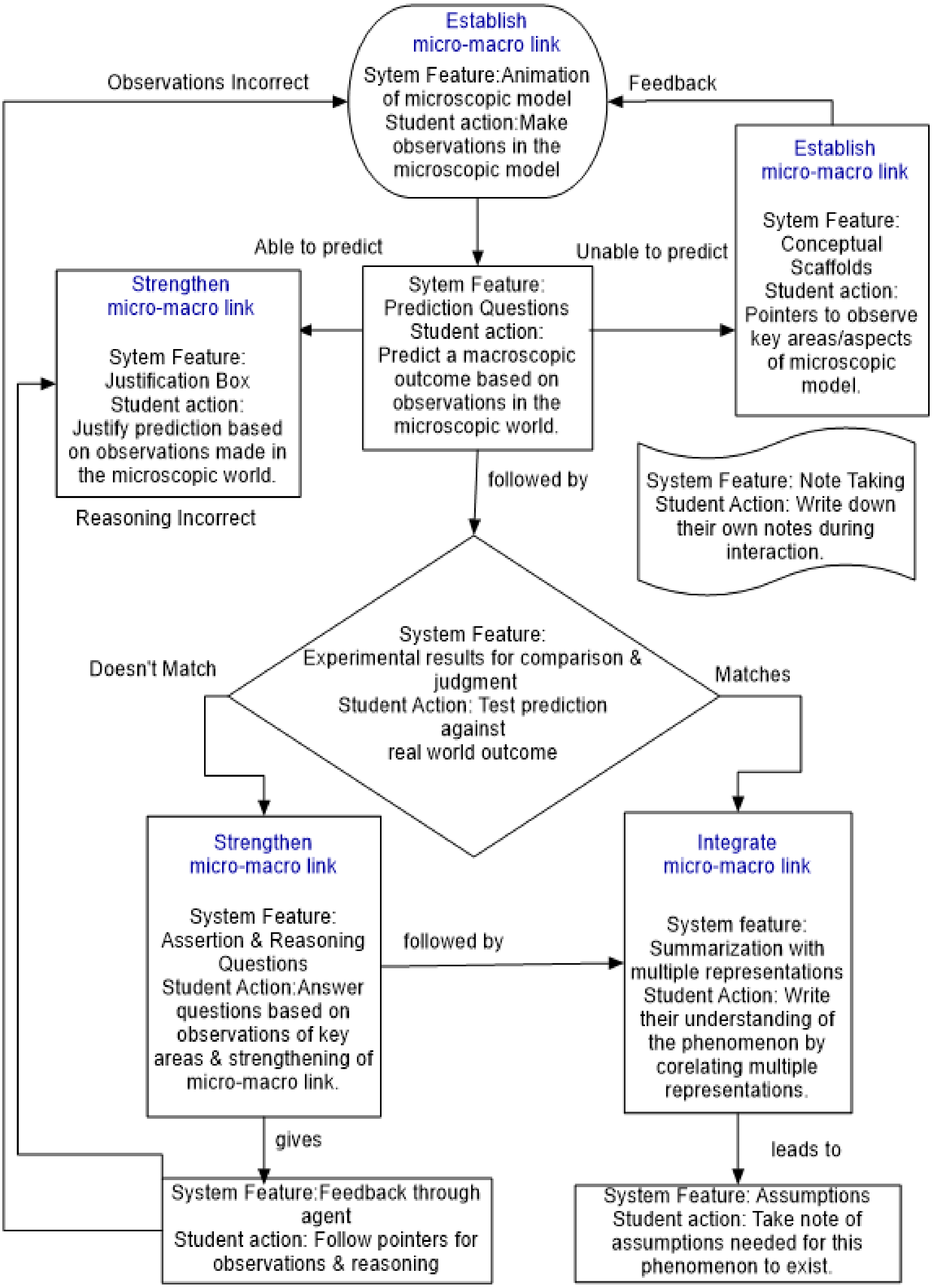
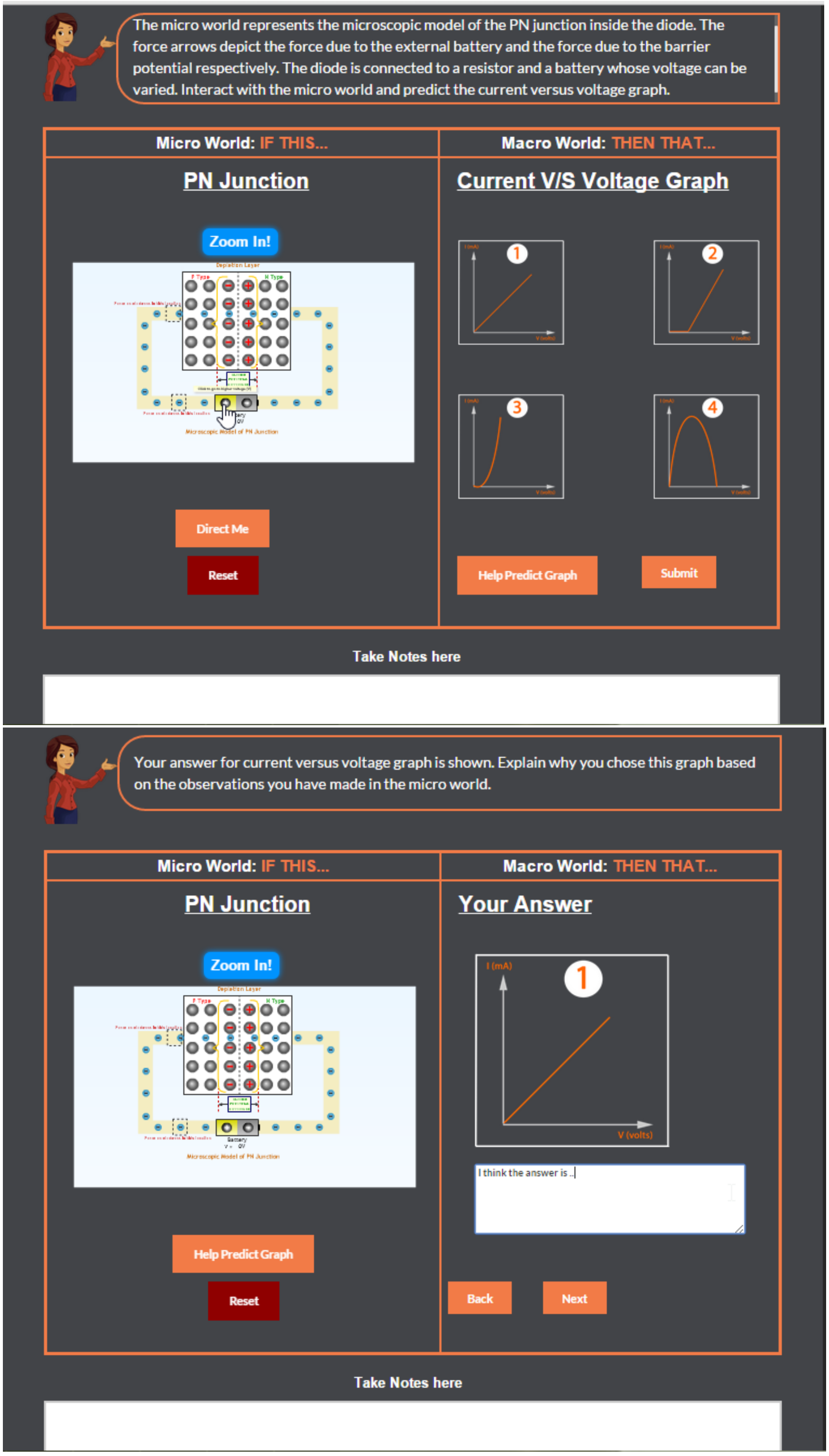


Figure 4.2. Overview of MIC-O-MAP TEL environment

4.4 Crucial Features of MIC-O-MAP TEL Environment

The detailed features of MIC-O-MAP which aid in developing micro-macro thinking skills are depicted in Fig. 4.3.



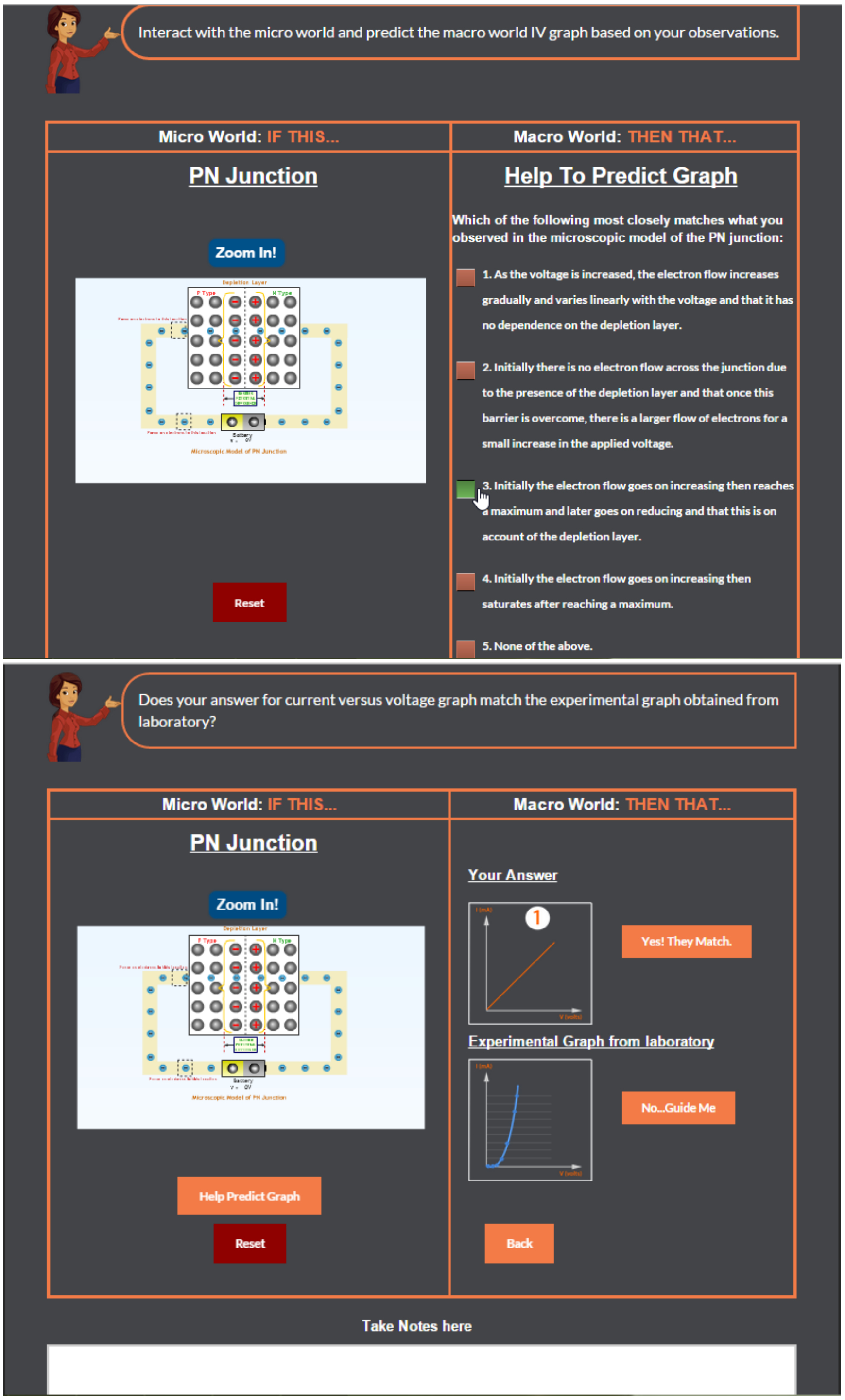


Figure 4.3: Screen shot of key MIC-O-MAP features

Top to Bottom- Simulation of microscopic model along with Prediction questions, Justification Box, Conceptual Scaffolds/Assertion and reasoning questions with customized feedback, Experimental Results for comparison and judgment, Pedagogical Agent and Note taking present in each screen window.

a) Simulation of the Microscopic Model

Students are provided with the microscopic model of a phenomenon and are asked to interact with it with the help of variable manipulation, text entry and meter readings as shown in Fig. 4.4. This feature encourages students to explore and interact, handle parameters and observe their results. Features such as isolation and manipulation of parameters helps students to develop an understanding of the relationships between physical concepts, variables and phenomena [Rutten, van Joolingen & van der Veen, 2012].

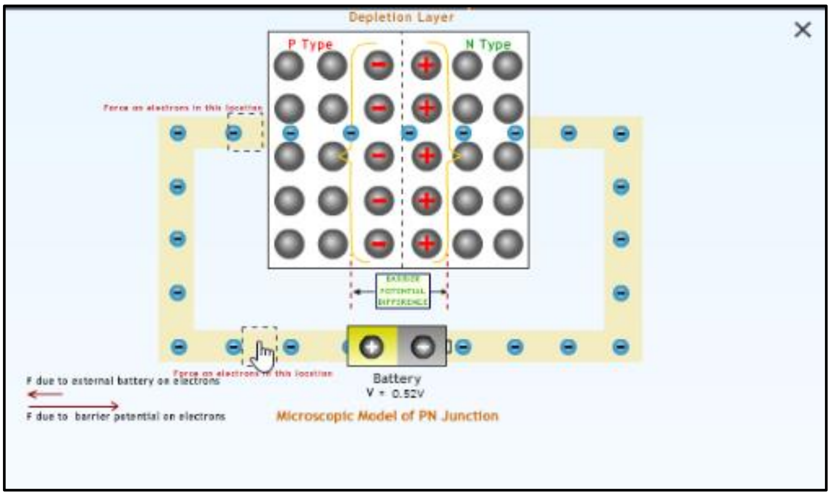


Figure 4.4: Simulation of the Microscopic Model

b) Prediction questions

Students are given a macroscopic situation and are asked to use the microscopic model in order to predict what might be the outcome of this situation as shown in Fig. 4.5. Learning material should provide opportunity for predicting the outcome of a situation/experiment [Wilkening & Sodian, 2005].

Figure 4.5: Prediction Questions

c) Justification box

When students predict the outcome, they are asked to write explanation on which their prediction is based, to give them the opportunity to reason and adapt a known model to the specifications of the given problem [Wells et.al., 1995]. This is shown in Fig. 4.6.

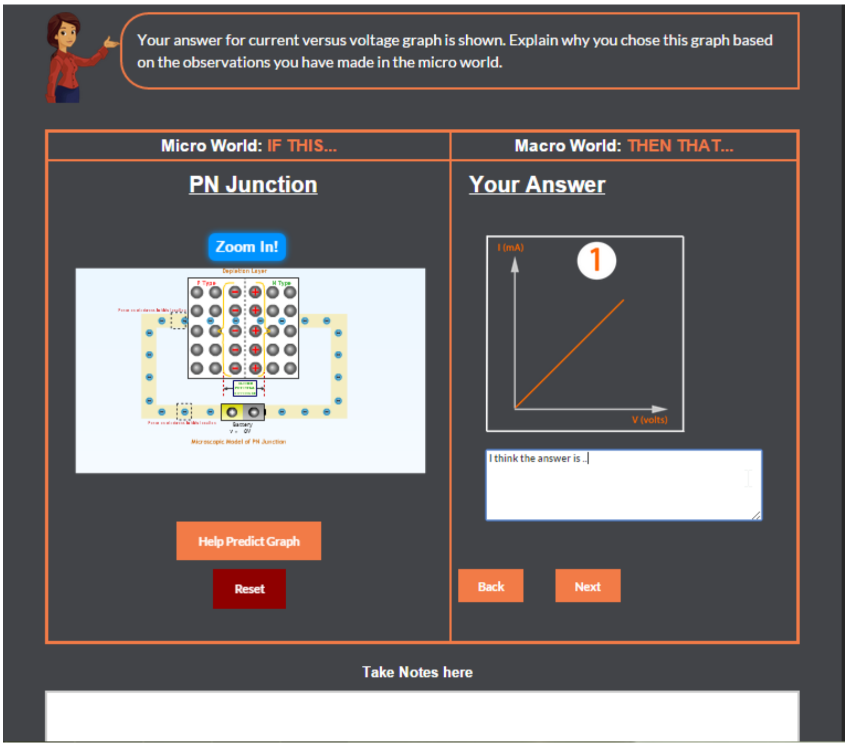


Figure 4.6: Justification Box

d) Experiment results for comparison & judgment

To test their prediction, students are provided with the experimental outcome of the situation and are asked to decide if their prediction is correct as shown in Fig. 4.7. This is important because students should be able to analyze the outcomes of an experiment and be able to justify their conclusions.

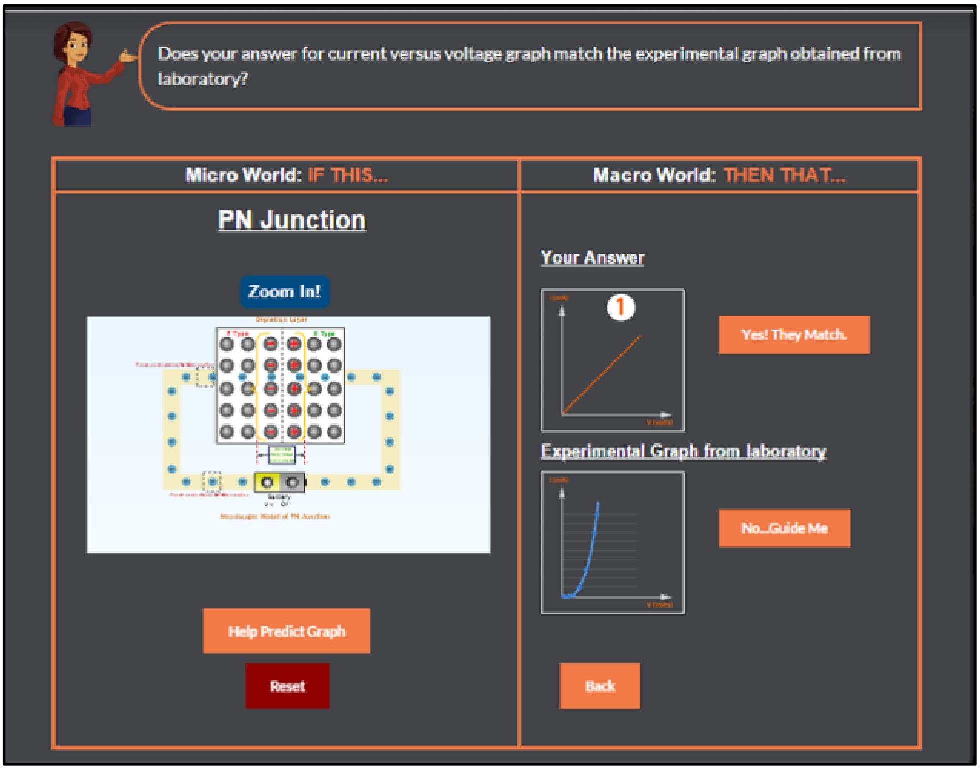


Figure 4.7: Experiment results for comparison & judgment

e) Assertion & Reasoning questions with customized feedback

During the revise phase, depending upon their prediction, students are provided with a series of multiple-choice questions along with customized feedback as shown in Fig. 4.8. This activity begins with showing the student their own prediction and justification. They are then asked questions related to possible observations they made in the microscopic simulation that might have led them to answer in that manner. For example, if the student choice is a graph in which current varies linearly with voltage, they are asked questions such as: 'Was there low electron flow initially?', 'Did the current increase only when you applied a certain amount of external voltage?' If their answers are not consistent with the microscopic model, then they are given feedback which helps them identify what was missed in their observations. They are asked interact with the simulation again and to note that particular aspect in the simulation. This is a very crucial feature and is based on designing instruction using building blocks such as hints, scaffolds, 'if-confused' and summarization [Wielinga et.al., 1992; Davis, 2000].

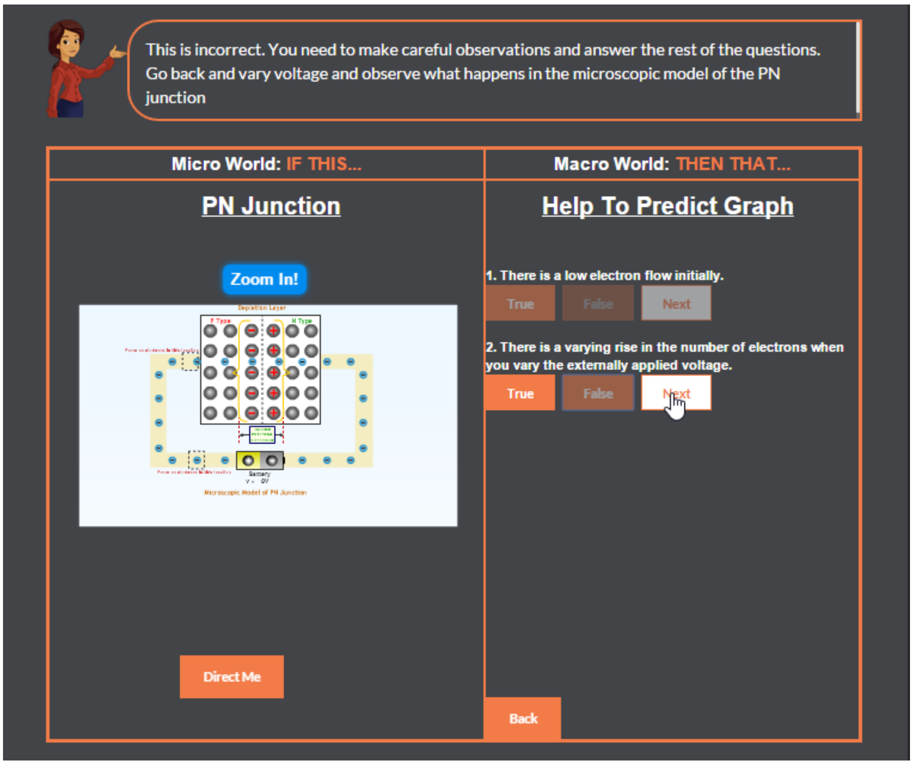


Figure 4.8: Assertion & Reasoning questions with customized feedback

f) Multiple representations of microscopic picture, macroscopic experiment and graph.

In order to summarize the activities in MIC-O-MAP, students are shown the working of the microscopic model of the PN junction, the experimental set up with meter reading is needed in understanding the underlying concepts, relations and processes [Kozma et.al., 1997]. This is depicted in Fig. 4.9.

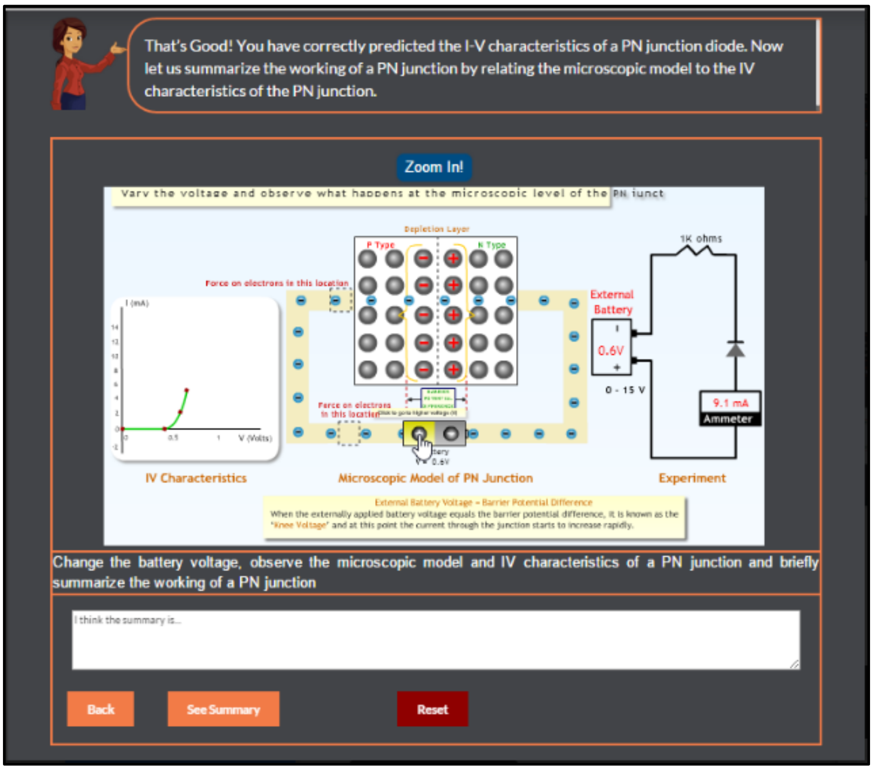


Figure 4.9: Multiple representations of microscopic picture, macroscopic experiment and graph.

4.5 Research Method

Within mixed methods research design, the explanatory sequential design is followed here where in quantitative data collection and analysis are followed up with qualitative data collection and analysis, leading to an interpretation of the data. The first study is a quantitative study which helps find if students who interact with MIC-O-MAP develop skills. This was done by undertaking a two-group quasi experimental research design. The second study is a qualitative study which follows the quantitative study. Within the second and third study, the on screen activity is recorded and analysed by means of the screen captures of the students belonging to the experimental group.

4.5.1 Research Questions

Under Theme 1 which addressed 'Learning of micro-macro thinking using MIC-O-MAP', the first study (Study 1) consisted of a two-group quasi experimental research design, and was used to answer the following research question:

RQ1: Did students who worked with the environment develop micro-macro thinking skills? After the first study the goal was to investigate the path adopted by students while learning with

MIC-O-MAP under Theme 2: 'Interaction of learner with MIC-O-MAP'. To address this goal, the following research questions were investigated in Study 2: RQ 2a: What interaction paths do students follow as they learn with MIC-O-MAP? and RQ 2b: What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

4.5.2 Materials

Two sets of learning materials in the same topic were developed for Study 1 – MIC-O-MAP modules in the topic of PN junction, and a conceptual visualization in the same topic. The experimental group learned from MIC-O-MAP while the control group learned from the conceptual visualization. Features needed for developing micro-macro thinking skills (discussed in Sections 4.2-4.4) are present in MIC-O-MAP whereas the conceptual visualization focuses mostly on the domain understanding and explanation of the given topic. The conceptual visualization contained multiple representations of microscopic phenomenon, macroscopic experiment and graph, as its key feature along with a theoretical summary and definitions. However, the conceptual visualization does not contain the scaffolds and question prompts present in MIC-O-MAP. Table 4.2 provides a comparison between the features incorporated in the MIC-O-MAP design and the design of the conceptual visualization.

Table 4.2: Comparison of features of MIC-O-MAP (experimental group learning material) and conceptual visualization (control group learning material)

	MIC-O-MAP features		**Conceptual Visualization features**	
Theoretical basis	Feature present in MIC-O-MAP	Type of feature	Is this exact feature present in conceptual visualization?	Is there an equivalent feature?
Inquiry Learning	Experimental Setup allowing variable manipulation (in this case, variation of voltage is allowed) along with an animation explaining what happens at the microscopic level of the PN junction	Simulation of microscopic model.	No	Yes -the simulation is a part of the 'Multiple representations of microscopic phenomenon, macroscopic experiment and graph.'
Inquiry Learning	MCQ asking student to predict the I-V characteristic curve of the diode.	Prediction Questions	No	Not present
Self-Regulated learning & Inquiry Learning	Answer space where student has to mention the justification behind the prediction.	Justification Box	No	Not present
Self-Regulated learning, Inquiry Learning & Scaffolding	Real world answer for comparison with prediction	Experimental Results for comparison and judgement	No	Not present

Scaffolding, Question Prompts, Formative Assessment & Feedback	A series of MCQs depending upon their prediction and the justification along with customized feedback	Assertion and reasoning based questions with customized feedback	No	Not present
Scaffolding	MCQ for assumptions accounted for while making prediction and immediate feedback for the same.	Assumptions	No	Not present
Scaffolding	Simultaneous representations of the experiment, microscopic picture as well as the graphical representation.	Multiple representations of microscopic phenomenon, macroscopic experiment and graph.	Yes	Same feature present
Scaffolding	Definitions of technical terms. For example: 'n type semiconductor' ' p type semiconductor' 'doping'	Glossary	Yes	Same feature present
	Are these features present in MIC-O-MAP?	Is there an equivalent or similar feature?	Features present only in conceptual simulation	
Scaffolding	Yes	It is present as part of ‘Multiple representations of microscopic phenomenon, macroscopic experiment and graph.’	Summary	Theoretical Summary
Formative Assessment & Feedback	Yes	It is present throughout the learning environment but not as separate assessment in question and answer format, instead, it is embedded into different features such as Conceptual scaffolds, assertion and reasoning questions and prediction questions.	Separate assessment questionnaire	Questionnaire

4.6 Study 1 - Two Group Quasi Experimental Research Design

4.6.1 Results of the pilot study

Before the main study, a pilot study was conducted to test the validity and usability of the learning materials in TEL environment and the validity of the post-test. During the pilot study, the learning materials, followed by the post-test were administered to a sample of students equivalent to those in the main study. Three students from first year science and engineering course worked with the learning environment for 45 minutes. They were given no additional information, but their clarification questions were noted. Then they worked on the post-test and the average time required was noted. Finally, students were asked about their perceptions on the learning environment. Results of the pilot study showed that students did not have conceptual difficulty understanding the material or the post-test questions. Clarifications asked related to the post-test were used to refine the wording of the questions to remove ambiguity. The time required for the post-test was used as a benchmark for the post-test time interval for the main study. A key point mentioned by students was that they could reason better using the learning environment since they were guided by the prompts to think about what was happening in the microscopic model in the simulation.

4.6.2 Participants

Students from the 1st year undergraduate science and engineering programs from various colleges under Mumbai University, India, were chosen as the sample. Formal invitations were sent to the departments of 12 colleges and students were asked to formally register with us for the study. The topic being learnt using the learning environment was P-N Junctions from the subject of physics. This topic is traditionally taught in the second year of Engineering program. We chose 1st year students since we wanted students to have prior knowledge of XII standard science, but we wanted them learn the topic for the first time using the learning environment.

All these students had learned the domain knowledge present in the TEL environment in their college classes. To check if the experimental and control groups were equivalent in terms of prior knowledge, we compared their XII standard examination scores for the subject of physics. We performed an independent samples t-test and found that there was no statistically significant difference between the groups at $p<0.05$ level ($t=0.412$, $p=0.685$). This indicated that the overall achievement level of the students was equivalent in terms of their prior knowledge in the chosen domain, Physics, (same as that of the TEL environment) on a traditional exam. Thus, the overall achievement level of the two groups was equivalent.

4.6.3 Procedure

A quasi experimental research design was adopted. The students (N=73) who arrived at the experiment venue were assigned to two groups by randomized assignment. Group 1 (Experimental group) contained 37 students while Group 2 (control group) contained 36 students. Students in the experimental group were given the MIC-O-MAP TEL environment as the learning material. Students in the control group were given the conceptual visualization which contained the same animation of the microscopic phenomenon as in MIC-O-MAP, but did not contain the scaffolds and prompts such as justification box for prediction reasoning or assertion questions and feedback. The control group students, in addition, were given a 2-page write-up containing a description of the macroscopic experiment and its microscopic explanation. This write-up is given in Appendix C. This was done to ensure that the information contained in both the learning materials was equivalent.

A total time period of 1 hour was allotted to the students for learning the topic. At the end of the hour, a new physical phenomenon was presented to the student by means of a simulation depicting its microscopic explanation. Students were asked to interact with a simulation depicting the working of a PN junction diode in reverse biased conditions. Earlier, while interacting with the TEL environment, PN junctions in forward biased condition was chosen as the topic. Hence, the microscopic model of the same material (PN junction) was altered on account of its biasing conditions and students had to make sense of the altered microscopic model and predict its macroscopic experimental outcome. Students were asked to answer post-test questions related to the new phenomenon. These post-test questions tested the students' micro-macro thinking skills of making the prediction, testing the prediction by comparing with given experimental results, and revising the prediction if necessary.

4.6.4 Data Sources and Instruments

In order to answer RQ1 related to students' development of micro-macro thinking skills, we administered a post-test which contained open ended questions that mapped to each micro-macro thinking sub skill. These questions were given to 5 subject matter experts to test content and construct validity. Examples of post-test questions are: 'Given beside is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its current-voltage (I-V) characteristics as the voltage is increased.' Or 'Given below are the I-V characteristics when this experiment is performed in a lab. Is the graph drawn by you same as this? List all the differences between the I-V characteristics drawn by you and the ones obtained in the experiment.' This is also shown in Appendix B.1.

To evaluate the answers of the students to the post-test questions, scientific abilities rubrics [Etkina et.al., 2006] were used. These rubrics are designed to specifically assess prediction and testing skills, and have been validated in several experiments. There are four rubric items corresponding to each sub skill of making an observation, devising an explanation for an observed pattern, predicting an outcome based on the explanation and testing the prediction against experimental evidence. All of these are listed in Appendix D. A sample rubric item for related to prediction ability is shown in Table 4.3 below:

Table 4.3. Sample rubric item

Sub-ability	*Score 0: Missing*	*Score 1 Inadequate*	*Score 2: Needs improvement*	*Score 3: Adequate*
Is able to make a reasonable prediction based on an explanation	No attempt is made to make a prediction.	The prediction made does not follow from the explanation.	A prediction is made that follows from the explanation but may contain minor errors or does not incorporate assumptions.	A prediction is made that follows from the explanation and incorporates assumptions.

4.6.5 Data Analysis

An inter-rater reliability analysis was performed to determine consistency among raters who would be graded the post-tests and the Cohen's Kappa statistic was determined. The Mann-Whitney U-test was used to determine statistical significance in the differences in the post-test scores on prediction-testing-revision skills. This test is used to compare differences between two independent groups when the dependent variable is ordinal and not normally distributed. The test ranks the sample values from both sets of data. The inter-rater reliability for the raters was calculated using the statistic of Cohen's Kappa, ($\kappa = 0.839$, $p = 0.000$). This indicates that there was a very high agreement between the rubric scores allotted by the two raters.

4.6.6 Results

Table 4.4 shows the mean rubrics scores of students' post-test performance related to micro-macro thinking skills of describing observations, devising explanations for an observed pattern, make predictions based on explanations, deciding whether the prediction and the experimental outcome agree and revising the explanation when necessary. Table 4.5 shows the Man Whitney U-test results.

Table 4.4. Post-test scores of experimental and control groups

Students should be able to:	Experimental Group Mean Rubric Score N=37	Control Group Mean Rubric Score N=36
Describe observations without explanations	*M* = 1.97, *SD* = 0.644	*M* = 1.77, *SD* = 0.637
Devise an explanation for an observed pattern	*M* = 1.62, *SD* = 0.758	*M* = 0.83, *SD* = 0.845
Make prediction based on explanation	1.62 (0.794)	1.19 (0.524)
Decide whether the prediction and the experimental outcome agree	2.27 (1.017)	1.83 (0.810)
Revise the explanation when necessary	0.64 (0.856)	0.22 (0.590)

Table 4.5. Mann-Whitney U-test Scores

Students should be able to:	U value	p value
Describe observations without explanations	562.00	0.195
Devise an explanation for an observed pattern	342.50	0.000
Make prediction based on explanation	437.00	0.003
Decide whether the prediction and the experimental outcome agree	455.00	0.014
Revise the explanation when necessary	475.50	0.008

The results show that the experimental group showed a statistically significant difference at p=0.05 level in their improvement in their skills of making predictions, testing them and then revising them as compared to the control group. There is no statistical significant difference for the sub skill of making observations without explanations.

4.6.7 Discussion of Study 1

Based on the results from section 4.6.6, it is found that MIC-O-MAP is useful in developing most skills of micro-macro thinking. For the sub-skill of describing observations, the existing simulations which are present in the Conceptual Visualization learning material are sufficient. For the skills of devising an explanation for an observed pattern, predicting an outcome based on this explanation, testing the prediction against an experimental outcome and revising the explanation when required, the experimental group which learned with MIC-O-MAP had statistically significantly higher scores than the control group. From this we infer that MIC-O-MAP features and learning activities were responsible for student learning of most micro-macro thinking skills.

The next step is to track the learning path followed by the experimental group students as they work with MIC-O-MAP. MIC-O-MAP is a semi open-ended environment, i.e. instructions are provided to the learner but there exists a flexibility of following any alternate path other than that which is suggested. We would like to check if students are following the feedback given to them and its effect on their learning. So also, if students undertake a particular path, then is it same for all leaners or is it similar to certain group types? The following study is a qualitative study with the experimental group wherein their onscreen activity is recorded and analysed to mark their learning path and examine if they face any problems while navigating/learning with MIC-O-MAP.

4.7 Study 2 and Study 3 – Screen Capture Analysis

4.7.1 Interaction Analysis

The onscreen activity of each student was recorded and later analyzed using the methodology of interaction analysis. Interaction Analysis has been used to analyze video records for many different purposes and on a large variety of topics [Henderson & Jordan, 1995]. The screen recordings of each student were first transcribed. The entire screen activity was analyzed in accordance with the steps included in interaction analysis methodology. The structure of events provides the chronological time [Henderson & Jordan, 1995]. This provides analysts with a standardized time line for the activities they observe on tapes from a variety of perspectives, namely the total time spent by each student, the time spent on each activity, percentage of time spent on each activity, sequence of activities, responses given by high and low scorers to the feedback, etc. The time log also gives an insight into beginnings and endings. We always want to observe the starting up and winding down process because significant interactions tend to happen at these junctures [Henderson & Jordan, 1995]. Segmentation speaks about events of any duration which are always segmented in some way. They have an internal structure that is recognized and maintained by participants [Henderson & Jordan, 1995]. We took notes of the ways in which students tried to interact with these features of the TEL environment. Initially, we allocated codes for each line that was transcribed. Later revised these codes and related them to each other in order to establish a behavior pattern for student who had high scores in the post-test (High Scorers) as opposed to those students who had low scores in the post-test (Low Scorers). Using this we were able to establish a behavior pattern for student who had high scores (High Scorers) as opposed to those students who had low scores (Low Scorers).

Constructivist theories of learning consider that students' existing understanding should be considered when developing teaching and learning programmes. Events that surprise create conditions where students may be ready to start re-examining their personal theories. As far as students are concerned, unless students are asked to predict first what will happen, they may not observe carefully. Writing down their prediction motivates them to want to know the answer. Asking students to explain the reasons for their predictions gives the teacher indications of their theories. This can be useful for uncovering misconceptions or developing understandings they have. It can provide information for making decisions about the subsequent learning. Fig. 4.10 is a concept map which incorporates the various features of MIC-O-MAP and also provides indications for the possible paths students can undertake while interacting with the learning environment.

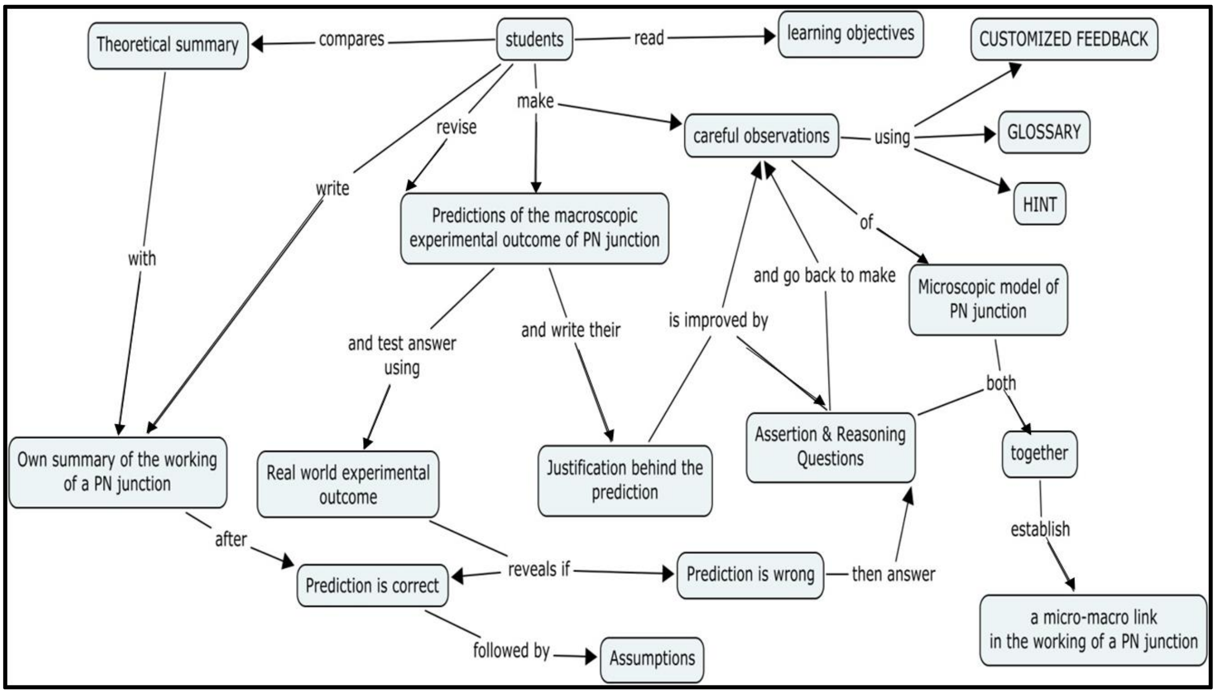


Figure 4.10: Features & interaction paths in MIC-O-MAP

4.7.2 Participants and Procedure

For Study 2: A total time period of 1 hour was allotted to the students for learning the topic. The topic being learnt using the learning environment was P-N Junctions (forward biased) from the subject of physics. The students were asked to explore the learning environment- MIC-O-MAP, and try to attempt every task in it. Once a student completed interacting with MIC-O-MAP, he/she was asked to raise their hand and the screen capture was stopped and saved. This screen capture video was later replayed, transcribed and coded in order to examine the interaction path adopted by each student and the logic behind each choice made by them while working with MIC-O-MAP. This was an important analysis as it would bring insight into the interaction path adopted by students while developing micro-macro thinking skills. As students interacted with the MIC-O-MAP TEL Environment, they on screen activity was being captured by means of a recording software described in section 4.7.3.

For Study 3: In order to get an idea of the various student behaviours, purposive sampling was conducted within the participants in the experimental group of Study 1, to obtain 12 participants who scored high on the TEL environment post-test, that is, those who developed micro-macro thinking, and 12 participants who scored low on the TEL environment post-test, that is, those who did not develop micro-macro thinking. The rubric scores were used to identify high and low scorers: students in the top third were labelled as the ‘high-scorer’ group and students at the bottom third were labelled as the ‘low-scorers’. The entire on screen activity of these students was analysed for the action performed by them on screen and the logic of thought behind the same.

4.7.3 Data Sources and Data Analysis

For Study 2: While students studied the material, their screen activities were captured by My Screen Recorder software, screen-recording software. Post the study, all these screen capturers were analyzed and later coded in accordance with the interaction pattern observed. This is known as Clickstream Analysis i.e. analyzing the record of screens or pages that user clicks on and sees, as they use a site or software product [Taniguchi, 2009]. Students were classified as high and low scorers on the basis of their scores in the micro-macro thinking based post-test and later we tried to identify a common interaction pattern for high and low scorers respectively. The recordings range from 29 to 32 minutes, which reflects the time spent with by the student with the TEL environment.

For Study 3: The screen recordings of each student were first transcribed. As explained in section 4.7.2, screen capture logs of high scoring students (N= 10) from the experimental group were chosen for the analysis as these students had statistically higher scores on the micro-macro thinking based post-test. We wanted to investigate the manner in which they interact with the learning material and how the learning process takes place. The transcripts were segmented by activities in the learning material. The entire screen activity was analysed from a variety of perspectives, namely the total time spent by each student, the time spent on each activity, percentage of time spent on each activity, sequence of activities, responses given by high and low scorers to the feedback, etc. An example of a time log is given in Table 4.5 and that of a transcript is shown in Table 4.6.

Table 4.5: Time Log example

Start time (min)	End time (min)	Content in the learning material	Student's actions
0.00	0.24	Learning Objectives	Read
0.24	6.40	Simulation of the microscopic model-Radio buttons to vary voltage and view animation along with on screen text	Vary radio button for voltage
6.40	7.19	Circuit diagram along with four options of graphical outcomes.	Selects one of the options and clicks on SUBMIT

Table 4.6: Transcript example

Student 1	Code
Student reads Prediction question (cursor movement). In this attempt, she chooses wrong choice for prediction and does not write a justification. Student goes back to simulation and interacts with it. She comes back to Prediction Question, chooses the same graph and attempts the justification.. She does not write anything initially (cursor keeps blinking in justification box and no text written). After some time she writes a justification for the chosen graph. Chosen graph is incorrect but reason is partially correct. She goes back and interacts with the simulation and attempts the justification again.	Make informed choice in multiple choice question in prediction activity. Basis for justification-reason micro to macro link

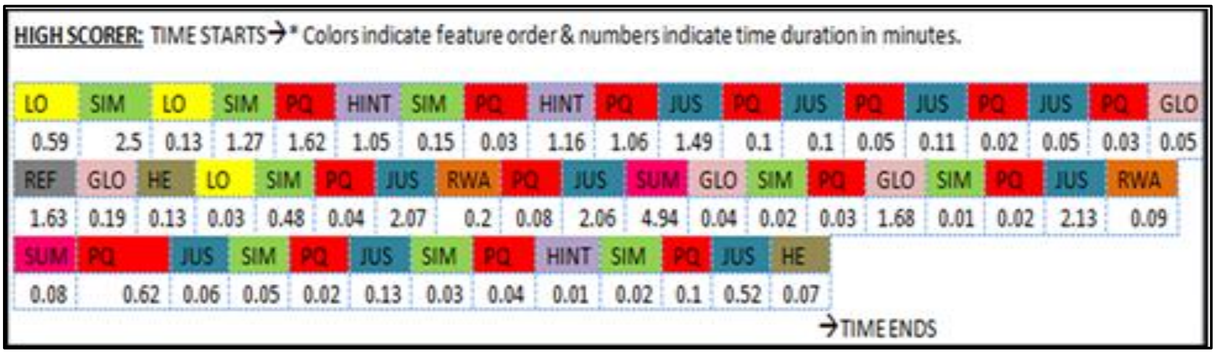
We took notes of the ways in which students tried to interact with these features of MIC-O-MAP. Initially, we allocated codes for each line that was transcribed. Later revised these codes and related them to each other in order to establish a behavior pattern for High scorers as well as Low Scorers. Table 4.7 shows the coding scheme applied in our study.

Table 4.7: CODING SCHEME

Activity / feature in interactive visualization	Students' behavior pattern	Code
Home page learning objectives	Read on screen text	Read learning Objectives
Simulation of microscopic model	Vary parameters and make careful observations of its effect in simulation	Interact with Simulation
Prediction Questions	Observe the experimental set up, view zoomed in image to co relate it to animation, and choose one graph.	Make informed choice in multiple choice question in prediction activity
	Keep choosing graphs till one of them matches with real world answer	Guess answers in multiple choice prediction activity
Justification Box	Try to correlate observations in animation of microscopic picture to the macroscopic graph and write a justification	Basis for justification-reason micro to macro link
	Copy on screen text on X and type same text into --- or write about content not present in MIC-O-MAP and write a justification	Basis for justification- given on screen text
Conceptual Reasoning Scaffolds	Use conceptual questions to note which area of animation is to be viewed and make careful observations accordingly	Reasoning using conceptual reasoning scaffolds
Assertion and reasoning questions	Answer assertion and reasoning questions and try to improve our observations or reasoning by either going back and viewing animation or rephrasing justification.	Assertion and reasoning questions to improve reasoning
	Treat Assertion and reasoning questions as a question and answer activity and click on all answers until you get 'correct' as feedback.	Assertion and reasoning questions treated as Q&A without further application
Multiple representations for summarizations	Co relate the microscopic phenomenon to its macroscopic outcome and write summary.	Link microscopic phenomenon to its macroscopic outcome and write a coherent summary

4.7.4 Results

For Study 2: Given in Fig. 4.11 and Fig. 4.12 are the learning paths of typical high scoring students and low scoring students.

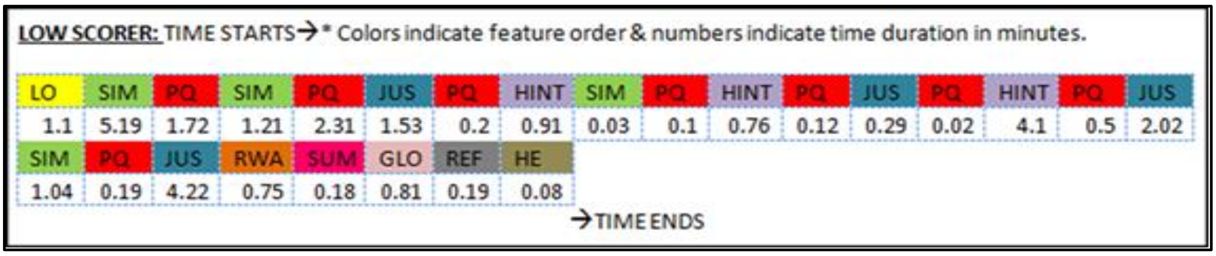

HIGH SCORER: TIME STARTS→ * Colors indicate feature order & numbers indicate time duration in minutes.

LO	SIM	LO	SIM	PQ	HINT	SIM	PQ	HINT	PQ	JUS	PQ	JUS	PQ	JUS	PQ	JUS	PQ	GLO
0.59	2.5	0.13	1.27	1.62	1.05	0.15	0.03	1.16	1.06	1.49	0.1	0.1	0.05	0.11	0.02	0.05	0.03	0.05
REF	GLO	HE	LO	SIM	PQ	JUS	RWA	PQ	JUS	SUM	GLO	SIM	PQ	GLO	SIM	PQ	JUS	RWA
1.63	0.19	0.13	0.03	0.48	0.04	2.07	0.2	0.08	2.06	4.94	0.04	0.02	0.03	1.68	0.01	0.02	2.13	0.09
SUM	PQ	JUS	SIM	PQ	JUS	SIM	PQ	HINT	SIM	PQ	JUS	HE						
0.08	0.62	0.06	0.05	0.02	0.13	0.03	0.04	0.01	0.02	0.1	0.52	0.07						

→TIME ENDS

Figure 4.11. Order in which features were viewed-high scorer

Figures 4.11 & 4.12 indicate a typical order in which high and low scorers interact with each feature in TEL ENVIRONMENT respectively. Here, the codes being followed are as followed: LO: Learning Objectives, SIM: Simulation of the microscopic model, PQ: Prediction Question, Conceptual reasoning scaffolds: HINT, GLO: Glossary, REF: References, HE: Help, JUS: Justification Box, RWA: Experimental results for comparison and judgment, A&RQ: Assertion & Reasoning Questions, SUM: Multiple representations for summarization, A: Assumptions.


LOW SCORER: TIME STARTS→ * Colors indicate feature order & numbers indicate time duration in minutes.

LO	SIM	PQ	SIM	PQ	JUS	PQ	HINT	SIM	PQ	HINT	PQ	JUS	PQ	HINT	PQ	JUS
1.1	5.19	1.72	1.21	2.31	1.53	0.2	0.91	0.03	0.1	0.76	0.12	0.29	0.02	4.1	0.5	2.02
SIM	PQ	JUS	RWA	SUM	GLO	REF	HE									
1.04	0.19	4.22	0.75	0.18	0.81	0.19	0.08									

→TIME ENDS

Figure 4.12. Order in which features were viewed-low scorer

Figure 4.11 indicates that a typical high scorer initially makes careful observations, then tries to answer the macroscopic prediction based question but if unable to do so then makes use of the conceptual reasoning scaffolds feature to take note of which area of the microscopic model is to be viewed more carefully. After this, makes an informed choice of prediction and tries multiple attempts at justifying it. Once a prediction is made, he/she tries to judge it in comparison with an experimental answer, if they are correct then they proceed to the feature wherein they summarize the entire working establishing a link between the microscopic phenomenon to its macroscopic outcome. In case their prediction is incorrect then they go to assertion and reasoning based questions and try to improve their reasoning by making more careful observations or rephrasing their justification behind the prediction. And finally, they answer questions based on assumptions which are crucial to be noted and kept in mind while making predictions. High scorers also view features like glossary, help, and references but spend little time on it.

On a similar note, Figure 4.12 explains the interaction pattern of a typical low scorer. A low scorer also begins by reading the learning objectives and interacting with the simulation of the microscopic model but when confronted with a prediction based question, they make a choice mostly by picking one of the options and try to proceed and check if the answer is correct. In order to provide a justification for the prediction, they mostly copy the on-screen text and type the same answer for multiple attempts at justifying their predicting of the macroscopic outcomes. In case they go wrong they either directly proceed to summarizing the entire working or they treat the assertion and reasoning questions as a typical question and answer task. This text which is typed by them as justification is either copied from conceptual reasoning scaffolds or the glossary section. These students also view features of help and references to a minimal extent [Kenkre & Murthy, 2014].

For Study 3: Post transcription and coding screen capture logs, we analyzed the data under the following parameters:

- Learning Time

On an average, all the students spent around 30 minutes interacting with all the features of MIC-O-MAP. Table 4.8 shows the time spent by students on different MIC-O-MAP features. Low scorers spent double the amount of time in an attempt to answer the prediction questions in comparison with high scoring students. In contrast to these high scorers spent double the amount of time while revising their justification and while answering the questions based on assumptions. The time spent for activities like prediction questions, usage of experimental results for comparison and judgment and assertion and reasoning questions was found to be statistically significant.

Table 4.8: Time spent on different MIC-O-MAP features

For interacting with LEMA: Total time spent- high scorers (31.28 min), low scorers(30.92 min)							
For each feature in LEMA	Time Spent (min)		% Time Spent(min)		t value	p value (at 0.05 level)	Significance
	low scorers	high scorer	low scorers	high scorer			
Simulation of microscopic model	8.75	6.49	28.32	21.39	-1.851	0.622	N
Prediction Questions	4.99	2.59	16.15	8.53	-2.416	0.003	Y
Justification Box	8.08	7.24	26.15	23.86	-0.607	0.352	N
Conceptual reasoning scaffolds	0.69	1.33	2.23	4.38	1.116	0.774	N
Experimental answer for comparison & judgement	0.78	0.44	2.52	1.45	-2.641	0.019	Y
Assertion and reasoning based question	0.33	1.1	1.06	3.62	1.211	0.049	Y
Summarization with multiple representations	4.31	6.16	13.95	20.3	1.162	0.333	N

To understand possible reasons for the different time spent by students, we compare the interaction behaviour of students from the low and high scoring groups respectively. Table 4.9 tells us how many times each code related action was performed by high and low scorers while interacting with MIC-O-MAP.

Table 4.9: Frequencies of Behaviour

Code	Low scorers	High Scorers
Read Learning Objectives	12	12
Interact with Simulation	46	49
Make informed choice in multiple choice question in prediction activity	2	11
Guess answers in multiple choice prediction activity	10	1
Basis for justification-reason micro to macro link	4	26
Basis for justification- given on screen text	20	1
Reasoning using conceptual reasoning scaffolds	8	16
Assertion and reasoning questions to improve reasoning	0	4
Assertion and reasoning questions treated as Q&A without further application	1	0
Link microscopic phenomenon to its macroscopic outcome and write a coherent summary	5	7

Table 4.9 indicates the total number of times a certain activity was performed in the manner described in the code. For example: While writing a justification behind the prediction, high scorers made 26 attempts on an average to establish a micro to macro link whereas low scorers made 4 attempts to do the same. On the other hand low scorers made 20 attempts in copying on screen text whereas in the high scorers only 1 attempt to copy text was seen. Similarly, while making a prediction itself, high scorers made 11 attempts in order to make an informed choice of the graph whereas low scorers made 2 attempts for the same. Low scorers took 10 attempts in order to guess the graph until it is correct where as high scorers showed only 1 instance of guesswork. This establishes a stark difference in the reasoning method of students who score high and those who score low.

4.7.5 Discussion of Study 2 and Study 3

Towards answering RQ 2a: 'What interaction paths do students follow as they learn with MIC-O-MAP?', results from the previous section indicate that all High Scorers show similar patterns in their interaction paths, i.e. they make an informed choice of prediction post interacting with the simulation of the micro world and based on a micro-macro link inferred with the aid of assertion & reasoning questions where as low scorers follow a linear and chronological order of navigation while interacting with MIC-O-MAP, making multiple attempts at a prediction until it matches with the real world outcome and treating the prompts as assessment. In contrast to this, low scoring students were found to follow a linear path wherein they attempted each task one after another in the order in which it is presented and were found to be keen on moving ahead to view what is next and complete interaction with the entire module. These interaction paths of high scoring students will be compiled later to suggest an ‘effective interaction’ path while working with MIC-O-MAP such that it will help in extracting out maximum benefit from the learning environment.

Towards answering RQ 2b: ‘What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?’, a comparison was carried out to examine the visit to any feature of MIC-O-MAP. In cycle 1, design features such as an animation of the microscopic picture, prediction questions, justification box, real world answer for comparison and judgement, assertion and reasoning questions with customized feedback and multiple representations for summary have been included for developing the skills of making observations, predictions, testing predictions against real world outcomes and revising predictions when necessary. Table 4.10 summarizes to what extent each MIC-O-MAP feature was used by the high scorers in developing each skill.

Table 4.10. Usage of MIC-O-MAP features by high scorers in post-test

Skills	Feature	Example	Evidence from qualitative analysis (attempts by total number of students in group)
Observe	SIM (Simulation of microscopic picture)	Allows to manipulate variables and observe effects. Note effects one variable on other entities.	88 attempts by high scorers to interact with simulation
	MR (Multiple Representation)	simultaneous display of experimental set up & microscopic picture of the diode.	
	ARQ (Assertion & Reasoning Question)	micro questions/micro-macro questions / C questions	
Explain	SIM (Simulation of microscopic picture)	Allows to manipulate variables and observe effects. Note effects one variable on other entities.	26 attempts by high scorers to write the basis for justification as a reason using a micro to macro link where as 1 attempt to write on screen text.
	Justification Box	Allows text entry where students can write their justification behind their choice of prediction.	
	ARQ (Assertion & Reasoning Question)	micro-micro questions / macro-macro questions / micro-macro questions	20 attempts by high scorers to follow pointers and indulge in sense making
Predict	SIM (Simulation of microscopic picture)	Allows to manipulate variables and observe effects. Note effects one variable on other entities.	11 attempts by high scores to make informed choice in multiple choice question in prediction activity & 1 attempt in guess work.
	PQ (Prediction Question)	Choose one graph relating macroscopic variables	
Test	RWA (Real World Answer for comparison & Judgment)	Decide whether predicted graph matches with real world answer.	High number of attempts in making an informed prediction proves a good decision making & judgment skill.

In spite of the fact that students were able to develop the observe-predict-test-revise skills and in turn the broader skill of micro to macro thinking, we noticed that there were some problems which came across as students interacted with this system. For example, even though high scoring students made an informed choice of prediction, they had to view the microscopic model 88 times, make a choice of prediction 132 times and justify this choice with a micro to macro link 62 times. Table 4.11 summarizes the findings and possible reasons for each problem that students face. In the next DBR cycle, we refine the design of MIC-O-MAP to address each learning related problem:

Table 4.11. Problems from cycle 1 design and possible reasons for them

Problems from Experiment 1	Evidence for the problem for High Scorers (N=10)	Possible reason for problem (speculative)
Struggle in establishing a micro-macro link in first/second attempt, making an informed prediction and phrasing a justification.	No. of visits to Prediction Question feature: 132. No. of visits to Justification feature: 62. Making an informed choice of prediction: 11 Attempts to establish a micro to macro link while writing justification: 26.	Disjoint activities- detailed question prompts and scaffolds i.e. assertion and reasoning questions are included in the revision phase only.
Following feedback was tedious.	No. of visits to Animation of micro world: 88. No. of visits to Question prompts: 34 Attempts to follow pointers and indulge in sense making: 20	Overload on memory to recollect pointers from feedback while interacting with animation of microscopic model. Perceiving question prompts as assessment.
Navigation difficulty while interacting with the environment.	Number of visits to each feature is very high in comparison with the action taken i.e. attempts to view/edit their previous choice/answer written.	Features are included in a linear manner and in order to view the first features you had to compulsorily visit all other features. On coming back /previous choices/answers were erased.

4.8 Discussion and Summary of DBR – Cycle 1

Based on the results and discussion of all the three studies undertaken in the first cycle of DBR, we can conclude that MIC-O-MAP is a suitable self-learning environment for students for learning micro-macro thinking skills in PN junction topic. The qualitative analysis also informs us that in spite of working with the same learning environment, all students do not follow the same path while navigating through MIC-O-MAP, rather, those students who score high follow a similar path and those who score low follow another yet distinct yet similar path. These two paths are contrasting and can be used to suggest the best possible way while interacting with MIC-O-MAP so as to ensure that students develop the skill of micro-macro thinking and use all features presented to them in an optimal manner. The on-screen recordings of the high scoring students were analysed to investigate the frequencies of simply visiting/clicking on a feature versus following a logic and thinking before taking each step.

The frequency analysis findings provide insight into the following implications, we also propose possible solutions towards addressing the same in the next chapter:

- A difficulty in establishing a micro-macro link is showing up in being able to arrive at a correct prediction based on careful observations. A possible solution could be simultaneous display of microscopic model, macroscopic prediction and conceptual scaffolding prompts in order to ease establishing the linkage.

- Following instructions given in feedback is tedious. This tends to increase load on memory. Low scorers spend time in memorizing and do not reach the revision phase, some get answers correct, some misjudge and some go back chose the correct answer and then proceed. They end up treating the Assertion & Reasoning Questions as a summative evaluation. Possible solutions to address these can be:
  - Simultaneous display of Assertion & Reasoning Questions, microscopic models and macroscopic predictions.
  - Technique of giving feedback can be altered: It will be in the form of a dialogue with a pedagogical agent.
  - Revision phase will be infused and merged into the main sequence mediated by a pedagogical agent who makes this process explicit and friendly. The idea of getting assessed or examined gets ruled out.
  - Notes taking section wherein students can write down important points which might need recall at a later point of time.

4.9 Summary and Implications

As part of this chapter we have reported the design features of MIC-O-MAP incorporated based on pedagogical theories. The results of a controlled experimental study are also reported wherein it was tested whether MIC-O-MAP is effective in the development of micro-macro thinking skills as compared to a control group which received a traditional learning materials not containing scaffolds present in MIC-O-MAP. Post the quantitative evaluation, we have also undertaken qualitative studies to understand the interaction paths of high as well as low scoring students and their behaviour in terms of visiting a feature of MIC-O-MAP and the purpose behind the visit.

Towards the end of this chapter where we have reported findings from the quantitative as well as qualitative studies, we have identified learning based problems faced by students while interacting with MIC-O-MAP and possible solutions for the same. These solutions will be implemented in Chapter 5 where wee undertake the second cycle of DBR and examine if students are able to develop micro-macro thinking skills and if the learning based problems faced by them in cycle 1 of DBR fade away post incorporation of new features.

Chapter 5

Design and Evaluation of MIC-O-MAP- Cycle 2

In Chapter 4, we saw that there was a statistically significant difference in the post-test scores of the experimental group that learned with MIC-O-MAP and the control group. In a qualitative study of the screen recordings of students in the experimental group, we examined the interaction patterns adopted by them while they learned with MIC-O-MAP. We found differences in the manner in which different students interacted with the learning material, and also recorded problems related to navigation as well as learning that students faced with MIC-O-MAP.

The goal of this second iteration of DBR is to understand why students might be taking multiple attempts at choosing a correct prediction, providing a justification for the same by establishing a micro-macro link between the microscopic dynamic processes and the macroscopic visible measurable outcomes.

5.1 Problem Analysis

Study 3 has been analyzed in section 4.7 of chapter 4, findings from which resulted in possible learning related problems being faced by students while interacting with MIC-O-MAP. In order to go one step deeper and analyze these problems further the qualitative data from Study 3 has been reported here in Fig. 5.1. For this analysis, we have chosen to focus on the students who scored high in the post-test in Study 3 for examining their navigation paths and the actions performed while working through this path. The reason for opting to examine the learning behaviour of high scorers is because this set of students have managed to gain benefit from the features and learning activities of MIC-O-MAP, and have used the features productively for the development of micro-macro thinking skills. This behaviour of high scorers will be contrasted with the behaviour of low scorers in the post-test to test if there exists a difference in the two.

We have tried to gather insight into the reasons behind any choice of feature which students choose to interact with. Within the high scoring students, we have segregated them into groups who got the prediction right in the first attempt and those who got the prediction wrong in the first attempt. Further, we wanted to examine the reasons for which both these groups of students interact with the assertion and reasoning questions, i.e. what which purpose and out of these students how many of them result into high scorers or low scorers. The reason behind carrying out this analysis is that the reasons for the learning problems reported in section 4.8 in the discussion of DBR cycle 1 are speculative. We now, wanted to gather evidence for these problems which will set the motivation for the second DBR cycle. Fig. 5.1 is colour coded wherein each colour depicts the same category, for example: blue colour depicts number of students who attempted prediction (later may have got it right or wrong), the yellow colour depicts number of students who have attempted the prediction question and have also tried answering the assertion and reasoning questions for multiple reasons, the pink colour depicts the number of students who are high scorers and the grey colour depicts the number of students who attempted prediction but have not answered the assertion and reasoning questions. The arrows help in reading the chart, from the left to right where we start with the total number of students in each group- number of students who got the prediction right and number of students who got the prediction wrong.

Total no of students: 37, Total no of high scorers: 10, low scorers:10

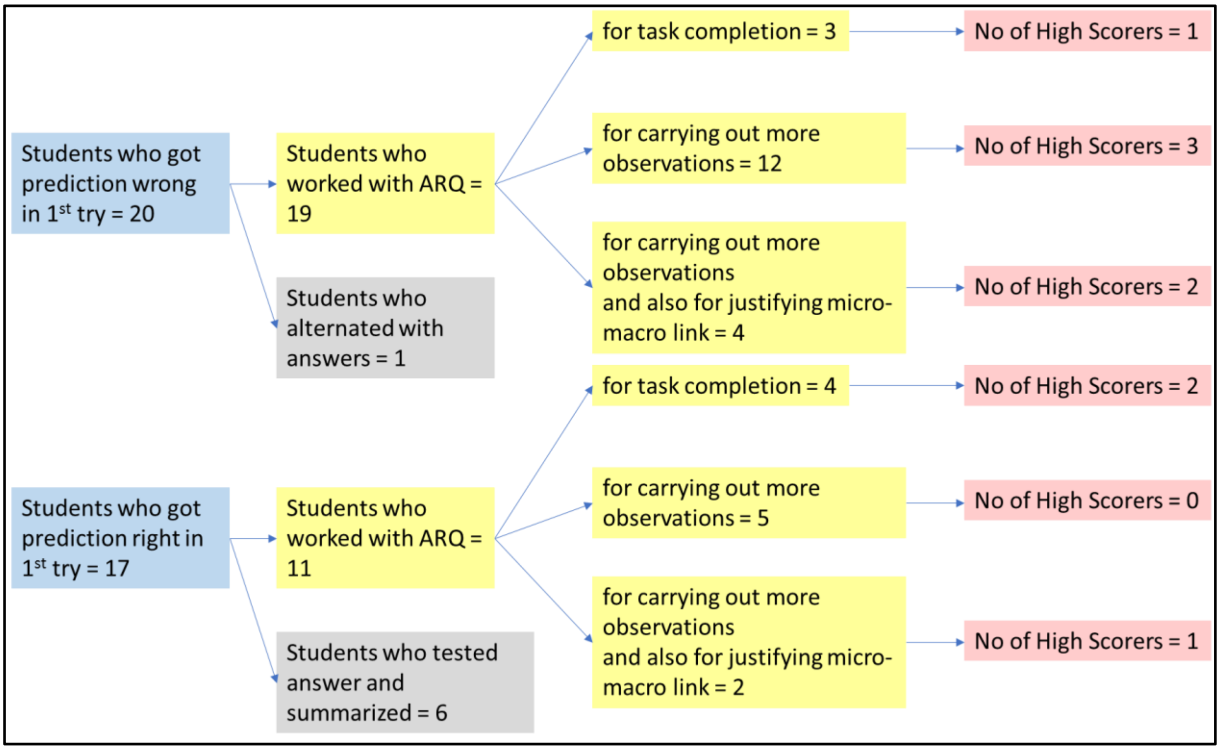


Figure 5.1: Analysis of students' choices in first attempt on Prediction

It was noted that within the group of high scorers, except one student who got all answers correct, all high scorers interacted with assertion and reasoning questions either to make more careful observations or to improvise their reasoning. 6 out of 10 high scorers have got the prediction of macroscopic outcome incorrect in the first attempt, but they have worked through a combination of either using the assertion and reasoning questions for either making more careful observations or for further improvisation of the justification for the macroscopic prediction based on a micro-macro link. The remaining 3 out of 10 high scorers who have got the prediction correct in the first attempt have still worked through a round of answering the assertion and reasoning questions and interacting with simulation of the microscopic world while phrasing their justification for the macroscopic prediction. The above analysis of Fig. 5.1, in addition to the findings from section 4.8 from chapter 4, lead to following indicators that need improvements:

- **Problem 1: Students struggle in establishing a micro-macro link in first/second attempt, making an informed prediction and phrasing a justification**.

Based on the findings from the qualitative interaction analysis (Chapter 4, Section 4.7.6) we observed that in spite of the assertion and reasoning question being present in the learning environment students are not using them as intended, a possible reason being that they appear only when the student opts to revise their answers after testing the prediction. Conceptual scaffolds include hints and prompts that are designed to provide guidance about what knowledge to consider during problem solving [Vye et al., 1998; Azevedo et.al., 2004[. These prompts are to be provided when the learner is facing a problem in comprehending the content presented to them. Keeping this in mind, we decided to infuse the revision phase into the main phase of making observations, devising explanations for the observations made, predicting outcomes based on the observations and lastly testing the predictions against experimental outcomes. The assertion and reasoning questions will now also be segregated into 'Micro-Macro Link based Questions', 'Microscopic Observation based Questions', 'Macroscopic Prediction based Questions' and 'Confounding Questions'. These will be detailed out in section 5.2.2. They will present on screen under the title of 'Direct Me' as well as 'Help to Predict Graph'. The student can opt to click on either of these options in accordance with their requirement for assistance.

- **Problem 2: While number of observations in the simulation was high, the number of times feedback from the question prompts was followed by students was much lower**.

As a student attempted answering a question, we provided a feedback which was customized and directed the students towards either making more careful observations or establishing a micro-macro link. But, this entire process was linear i.e. the assertion and reasoning questions along with their feedback were visible only towards the end when the students have tested their prediction and have judged their prediction to be incorrect. In order to follow the feedback given with the questions, students would have to restart and locate the feature where a rework from their end was expected. We found that students were taking multiple iteration rounds simply to go through the questions and read the feedback once more and locate the area where the feedback is to be implemented.

Metacognitive scaffolds may include human or nonhuman learning agents whose roles may include helping students with specific task-related tasks [White, Shimoda, & Frederiksen, 2000; Azevedo et.al., 2004]. In order to make this entire process of providing students feedback without giving them a feeling of judgement easier, the inclusion of pedagogical agent was considered who would mediate this process and could be accessed at any point of time. The option of 'View Feedback Again' with the icon of the agent will be included which will help students recollect what was told to them as part of the feedback and they would view this as well as work with any other feature of MIC-O-MAP simultaneously.

- **Problem 3: Students left the task of answering conflict resolution questions half way after getting multiple answers incorrect**.

While students who reached the revision phase and tried attempting the assertion and revision questions, we had provided a visual cue of a tick and cross which implied getting the answer correct or wrong. It was observed that as the frequency of incorrect answers increased, students were found to switch and move on to the next feature. As mentioned in problem 2, mediating this process by means of a dialogue with a pedagogical agent would help in removing the possible notion of assessment and aid in following the feedback provided.

- **Problem 4: There existed a navigation difficulty while interacting with the environment**.

When students interact with MIC-O-MAP, we inferred through the screen capture analysis that they are undergoing multiple rounds of the entire environment, at times resetting the system and writing the same answer multiple times in order to reach a certain task. Even when students want to improve their answers, they were required to begin again by choosing earlier options once again. It was leading to distraction from the main task of establishing a micro-macro link between the observations made in the simulation of the micro world and the macroscopic graphical outcome of the experiment.

Procedural scaffolds assist students with learning how to use resources or how to perform certain tasks [Azevedo, Verona, & Cromley, 2001; Azevedo et.al., 2004]. In the second version of MIC-O-MAP, we will to provide students with the option of tracing their path so that locating the area which needs more work can be located with ease by simply hitting the back button. So also, all of the user choices will be retained so that they need not write anything from start time and again. Lastly, a scratch pad will also be given so as to allow taking down notes in their own words and aid recollection of information provided to them either in glossary or in feedback or simply to write down the observations made by them.

5.2 Refining Design Features of MIC-O-MAP

In this section, we have discussed solutions in order to address the problems identified in the previous section. We have tried to ensure that students go through the learning cycle of three stages wherein initially students establish the micro-macro link by making careful observations, strengthen this micro-macro link by making an informed choice of prediction in the macro world, justify this prediction based on observations in the micro world, test these predictions against real world outcomes and at each time if they feel that they need assistance in establishing or strengthening this link, then they can use the feature of assertion and reasoning questions.

While interacting with MIC-O-MAP, students are provided with feedback for their choices while answering assertion and reasoning questions mediated by a pedagogical agent incorporated into MIC-O-MAP, so as to eradicate the perception of assessment. Customized feedback is provided in the form of a dialogue with the student and at each stage, while making observations in the micro world, while predicting an outcome in the macro world and while justifying the prediction based on a micro-macro link. The assertion and reasoning questions are now displayed simultaneously while making observations in the micro world and a note taking section is also included so as to ease out the load on working memory and to provide directions and assistance in strengthening the micro-macro link. This is done in order to reduce the overload on the student's memory and help reduce the struggle faced by them in establishing as well as strengthening the micro-macro link. Lastly, path tracing and retention of all answers in also incorporated into MIC-O-MAP so as to ease out the difficulty in navigation.

5.2.1 Incorporating a Pedagogical Agent and Note Taking

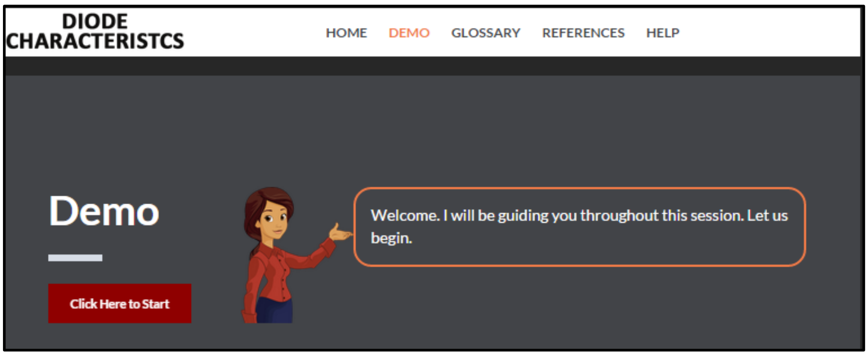


Figure 5.2: Incorporation of a Pedagogical Agent

Learners in the adaptive-scaffolding condition, in which students had access to a tutor to regulate their learning who assisted students in establishing goals, monitoring emerging understanding, using effective strategies, and providing motivational scaffolding [Azevedo et.al., 2004]. Learners in the no-scaffolding condition and the fixed-scaffolding condition (who were given a list of expert-set sub goals to guide their learning) were less effective at regulating their learning and exhibited great variability in self-regulating their learning during the knowledge construction activity [Azevedo & Cromley, 2004]. In order to provide real time and adaptive scaffolding, it is important to diagnose at risk students early and monitor them via a pedagogical agent who provides individualized feedback [Gobert et.al., 2012]. This scaffolding design leads to a guided system; that is, striking a balance between open-ended and guided inquiry [Kirschner et.al., 2006; Hmelo-Silver et.al., 2007] such that students can be assessed on inquiry skills and so that they are provided with support so they do not flounder or engage in haphazard inquiry [Buckley et.al., 2006].

Animated Pedagogical Agents (APAs) are lifelike characters designed to facilitate learning in computer-based environments [Moreno & Flowerday, 2006; Baylor & Ryu, 2003; Bradshaw, 1997; Craig et.al., 2002; Johnson et.al., 2000]. The most sophisticated APAs are two- or three dimensional anthropomorphic (i.e., humanlike) characters that advise and provide feedback to students [Lester et.al., 1998]. They have a strong visual presence and the purpose of enhancing learning [Moreno, 2004]. The role of an APA is to promote student learning, such as guiding students' attention in interactive multimedia environments [Moreno, 2004], providing students with feedback, modeling, and guidance [Moreno et.al., 2001], or increasing active learning [Mayer & Moreno, 2002]. The presence of another intelligent being co-existing and interacting with you facilitaties persuation [Fogg & Tseng, 1999]. It makes the environment more human like, engaging and motivating [Moreno & Flowerday, 2006].

In the revised version of MIC-O-MAP, we included a correspondence between the pedagogical agent and the learner in the form of a dialogue. Multiple facets can be incorporated mediated through a dialogue such as prompts which push students to carefully view and establish a link between microscopic world based observations and macroscopic outcomes. These were named as 'Conflict Resolution Dialogues'. We also included 'Sense Making Dialogues' in the revised version of MIC-O-MAP wherein multiple Assertion & Reasoning Questions (ARQs) are asked customized to the students' answers. While the first version of MIC-O-MAP also contained Assertion and Reasoning Questions, in the revised version, we have improvised and made these questions more specific and based on two directions – one is wherein the learner is given specific prompts about the key areas in the micro world which require more observations and the next direction is wherein the learner needs assistance in establishing or strengthening the micro-macro link. These ARQs provide appropriate scaffolding to generate correct understandings and developing explanations and arguments to deepen their understanding. They will be explained in more detail towards the end of this section.

5.2.2 Assertion & Reasoning Questions for strengthening micro-macro link

Assertion & Reasoning Questions were incorporated in both the versions of MIC-O-MAP in order to aid students in capturing and transferring insights with respect to the observations made and the link between these microscopic observations and the macroscopic outcomes. In the first version, all of the questions were presented together and were presented to the students one after another. In the revised version of MIC-O-MAP, these questions are explicitly positioned under the headings of ‘Observation based Questions’ and ‘Inference based Questions’. The rationale behind this bifurcation is that getting students attention towards the action expected from them, i.e. answering each question based on the difficulty faced by them and follow the feedback to address that difficulty. ARQs are a sophisticated form of MCQ that aims to encourage higher order thinking on the part of the student [Williams, 2006]. Essentially, learners arrive at meaning by actively selecting and constructing their own knowledge through experience. The main virtue of the ARQ test item is that ‘its structure facilitates the construction of questions that test student learning beyond recall [Connelly, 2004].

In particular, higher level thinking and application of key concepts may sometimes be more easily constructed using this format, than by using a conventional multiple-choice approach alone’ [Connelly, 2004]. ARQs have been identified to be belonging to the very highest level in the cognitive hierarchy because they contain elements of all the other categories. Like traditional MCQs, ARQs present students with a number of possible solutions. In contrast to traditional MCQs, however, ARQs also include a true/false element.

We have altered the design of MIC-O-MAP from version 1 to version 2 in a manner that the concept behind the questions is retained with respect to the content yet the manner in which they are presented varies i.e. previously all the questions would be presented at once to the learner and in the next version the questions are presented to the learner based on the difficulty faced by them. To begin with we ask the student to clearly articulate and commit to one statement which he/she considers to be appropriate and correct for the given situation. On the basis of the choice of answer posted by the student, the next string of questions changes. These questions belong to four categories:

- Micro-Macro Link based Questions: These lead students to make careful observations, pointing to specific variables in the simulation. Also, some of these questions emphasize that students should make micro and macro connections i.e. help them realize that there exists a connection between micro and macro worlds. The goal on incorporating these is that after answering these questions, students start seeking micro-macro connections more frequently and on their own. An example of such a question is given below:

  What do you think is the nature of the relation between conductivity and temperature?

    - *Conductivity increases as the temperature is increased.*
    - *Conductivity decreases as the temperature is increased.*

- *Conductivity stays the same as the temperature is increased*

  This question has the following feedback: ‘Recollect the definition conductivity i.e it is a measure of the amount of electrical current a material can carry. And a rise in temperature increases the current flowing through the circuit.’ It helps in linking the macroscopic element of temperature to microscopic elements of electrons and conduction band.

- Microscopic Observation based Questions: These lead students to make careful observations, pointing to specific variables in the simulation. An example of such a question is given below:

  In the simulation, what is the effect of increasing the temperature?

  - *A rise in the number of electrons in the conduction band.*
  - *A fall in the number of electrons in the conduction band.*

  With the feedback ‘Carefully observe the number of electrons getting excited as you increase the temperature’ for the incorrect answer. It helps in directing the student’s attention to aspect of observing the number of electrons in the conduction band in the microscopic world.

- Macroscopic Prediction based Questions: These aid students in trying to think of a pattern in which the macro variables are related to each other. An example of such a question is given below:

  Did you notice that the bulb glows brighter as you increase the amount of temperature?

  With the feedback of ‘Vary the temperature and carefully observe the brightness of the bulb at each value.’

- Confounding Questions (CQ): These point students towards the fact that they need to go through the entire simulation once again in order to make sense of it. An example of such a question is given below:

  Which of the following most closely matches what you observed in the microscopic model? With none of the above as one of its options. If the student chooses this option, then they are told that they need to revisit the microscopic model and undertake another round of sense making with the microscopic model.

For some of these questions, students have to commit to an answer of the type True/False or commit to one of the choices given and then they are presented with the next set of related questions along with customized feedback mediated by the pedagogical agent which helps them deep dive into observations and linkages arising out of them. We will also be including a Note taking section into the environment so as to reduce the load on working memory and also serve a purpose to aid in strengthening the micro-macro linkages. Incorporating reflective activities is important to encourage an understanding-oriented approach. After completing their task, learners deliberately reflect on their experience to abstract the lessons learned and to consider how they performed in their self-directed learning [Hmelo et.al., 2000]

5.3 Evaluation of Redesigned MIC-O-MAP

5.3.1 Research Method

The explanatory sequential design is followed here where in quantitative data collection and analysis are followed up with qualitative data collection and analysis, lastly, leading to an interpretation of the data. Study 4 is a quantitative study which helps find if students who interact with the refined version of MIC-O-MAP develop micro-macro thinking skills. This was done by undertaking a single group pre-post research design. We do not need a control group here since it has already been proved with the results of Study 1 that students learning with MIC-O-MAP have higher scores on a micro-macro thinking skill test as compared to students who learn using traditional material (control group). Study 5 is a qualitative study which follows the quantitative study. In this study, the on-screen activity of students is recorded and analyzed by means of the screen captures. The mapping between the themes and the detailed description of these studies is provided in the sections below.

5.3.2 Research Questions

Under Theme 1 which addresses the idea of 'Learning of micro-macro thinking using MIC-O-MAP', the Study 4 has been carried out which consists of a single group pre-post test research design, and was used to answer the following research question:

RQ1: Did students who worked with the environment develop micro macro thinking skills?

Post ensuring that students who interact with the refined version of MIC-O-MAP develop micro-macro thinking, the goal was now to confirm that the challenges faced by students while interacting with MIC-O-MAP, identified in Study 3, have faded away. In order to address this goal, the following research question has been investigated in Study 5, under Theme 2: 'Interaction of learner with MIC-O-MAP':

RQ 2.c: What was the effect of the improvised design on students' interaction with the various features of the learning environment?

Section 5.3.3 and Section 5.3.4 provide the details about each study and findings from the same.

5.3.3 Study 4: Single Group Pre-Post Test Research Design

5.3.3.1 Participants

Students from the 1st year undergraduate science and engineering programs from various colleges under Mumbai University, India, were the participants of this study. Formal invitations were sent to the departments of 12 colleges and students were asked to formally register with us for the study. The topic being learnt using the learning environment was P-N Junctions from the subject of physics. This topic is traditionally taught in the second year of Engineering program. We chose 1st year students since we wanted students to have prior knowledge of 12th standard science, but we wanted them learn the topic for the first time using the learning environment.

5.3.3.2 Procedures and Data Sources

The students (N=46) who arrived at the experiment venue given MIC-O-MAP as the learning material. Before interacting with MIC-O-MAP, physical phenomenon was presented to the student by means of a simulation depicting its microscopic explanation. Students were asked to interact with a simulation depicting the working of a PN junction diode in reverse biased conditions. They had to later answer pre-test questions related to this phenomenon. These pre-test questions tested the student’s skills of making observations, predictions, testing the prediction by comparing with given experimental results, and revising the prediction if necessary. Students were then allowed to interact with MIC-O-MAP and a total time period of 1 hour was allotted to the students for learning the topic of PN junctions in forward biased conditions. Here, the microscopic model of the same material (PN junction) was altered on account of its biasing conditions and students had to make sense of the altered microscopic model and predict its macroscopic experimental outcome. At the end of the hour, students had to view the earlier simulation once again and answer a post-test having the same questions testing students’ skills of making observations, predicting outcomes, testing them and revising when necessary.

The post-test questions and rubrics used for data analysis were same as those used in the DBR Cycle 1- Study 1 discussed in section 4.6.4 of chapter 4. An examples of post-test questions is: ‘Given beside is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its current-voltage (I-V) characteristics as the voltage is increased.’ The detailed post-test questionnaire is given in Appendix B.1 As reported in Section 4.6.5, the inter-rater reliability for the raters was calculated and the value of Cohen's Kappa was found to be 0.839 with $p<0.001$.

5.3.3.3 Data Analysis

The Wilcoxon signed-rank test was the statistical test used to determine differences in the pre-test and post-test scores on observation-prediction-testing-explanation skills. It is the nonparametric test equivalent to the dependent t-test. It is used to compare two sets of scores that come from the same participants. This can occur when we wish to investigate any change in scores from one time point to another, or when individuals are subjected to more than one condition. This test is used when the dependent variable is ordinal, for example, in this analysis we have used a Likert scale for grading the tests and the independent group consists of related groups or matched pairs, i.e. the same subjects present in both groups.

5.3.3.4 Results

The average learning time was 43.9 minutes. Table 5.1 shows the mean rubrics scores of students' pre-test and post-test performance related to the skills of describing observations, devising explanations for observed patterns, making predictions and deciding whether the prediction matches experimental. The Wilcoxon signed-rank test was performed to determine if the scores were significantly different.

Table 5.1: The Wilcoxon signed-rank test results from Study 4

Ability to	*Pre-test [Mean rubric score]* (S.D) N=46	*Post-test [Mean rubric score]* (S.D) N=46	*Z value*	*p-value*
Describe observations without explanations	1.27 (0.962)	1.84 (0.851)	-3.953	0.000
Devise an explanation for an observed pattern	1.48 (1.12)	2.13 (0.694)	-3.018	0.003
Make prediction based on explanation	1.75 (0.829)	2.53 (0.694)	-4.284	0.000
Decide whether the prediction and the experimental outcome agree	2.42 (1.177)	3.0 (0.000)	-2.887	0.004

The results showed a statistically significant difference at $p=0.01$ level in their improvement in their skills of making observations, predictions, explanations and testing them. For the ability of describing what is being observed without any explanation, pre-test versus post-test scores showed statistical difference ($p=0.000$). For the ability of devising an explanation for an observed pattern, pre-test versus post-test scores revealed a statistically significant difference at the level of $p<.01$ ($p=0.003$). For the ability of making a prediction based on explanation, pre-test versus post-test scores revealed a statistically significant difference at the level of $p<.01$ ($p=0.000$). Within the ability of testing a prediction, for deciding whether the prediction and the outcome agree, pre-test versus post-test scores revealed a statistically significant difference at the level of $p<.05$ ($p=0.004$).

5.3.3.5 Discussion of Study – 4

Study 4 was carried out to examine if the refined version of MIC-O-MAP helps students in developing micro-macro thinking skills, further operationalized as the skills of making observations in the micro world, devising explanations for the observed patterns, predicting an outcome in the macro world based on a micro-macro link and being able to judge if the predicted outcome and the real world experimental outcome agree. In order to answer RQ 1: Do students who interact with MIC-O-MAP develop micro-macro thinking abilities? a single group pre-post research design was carried out and a Wilcoxon signed-rank test was performed to determine if the scores on the post-test were higher and statistically significant as compared to the pre-test scores on a test evaluating the micro-macro thinking skills.

After we found that students learned micro-macro thinking by interacting with MIC-O-MAP, we also wanted to test if the challenges identified in Study 4, which students faced while interacting with MIC-O-MAP have faded away. This set the motivation to carry out Study 5 in which we analyze the screen captures of the students who received high scores on the test capturing their micro-macro thinking skills.

5.3.4 Study 5: Qualitative Study with Screen Captures

5.3.4.1 Participants and Procedure

Purposive sampling technique was used in order to choose the students who received high scores on the micro-macro thinking skills test in Study 4 explained in section 5.3.3. These students were chosen since they show a mark of having developed micro-macro thinking skills very well and their screen capture recordings would be compared with those of the high scoring students from Study 3. This would help in contrasting the two in order to confirm that the learning challenges being faced by students have been addressed by the refined design of MIC-O-MAP.

A qualitative analysis was conducted similar to Study 3 explained in section 4.7 of chapter 4 and same codes were allocated post viewing the screen recordings.

5.3.4.2 Data Analysis and Results

The screen capture recordings of the high scorers from Study 5 were analyzed and Table 5.2 shows the comparison of the interaction of the high scorers from Study 5 and Study 3 which indicates that the flaws detected earlier have been corrected and the desired action is being performed by the student while interacting with the learning environment.

Table 5.2: Results of the Screen Capture Analysis from Cycle 2

Observations from qualitative analysis of Study 3 (N=10)	*Learning related problems located*	*Possible TEL environment design related problem (speculative)*	*Redesign step to address problem*	*Was the problem addressed? Study 5 (N= 10)*
No. of visits to Prediction Question feature: 132. No. of visits to Justification feature: 62. Making an informed choice of prediction: 11 Attempts to establish a micro-macro link while writing justification: 26.	Struggle in establishing a micro-macro link in first/second attempt, making an informed prediction and phrasing a justification.	Disjoint activities-detailed question prompts and scaffolds i.e. assertion and reasoning questions are included in the revision phase only.	Incorporating the assertion and reasoning questions at two stages: when a choice of graph is made and justification is written. Testing indicates incorrect prediction. Option to take notes.	No. of visits to Prediction Question feature: 89 No. of visits to Justification feature: 50 Making an informed choice of prediction: 37 Attempts to establish a micro-macro link while writing justification: 40
No. of visits to Simulation of micro world: 88. No. of visits to Assertion and reasoning questions: 34 Attempts to follow pointers and indulge in sense making: 20	While number of observations in the simulation was high, the number of times feedback from the assertion and reasoning questions was followed was much lower.	Overload on memory to recollect pointers from feedback while interacting with simulation of microscopic model.	Simultaneous display of simulation of micro world and rest of the features including assertion and reasoning questions. Including a pedagogical agent and providing feedback as a dialogue.	No. of visits to simulation of micro world: 64 No. of visits to assertion and reasoning questions: 32 Attempts to follow pointers and indulge in sense making: 35
No. of visits to assertion and reasoning questions: 34 Attempts to follow pointers and indulge in sense making: 20	Leaving task half way after getting multiple answers incorrect.	Perceiving assertion and reasoning questions as assessment.	Including a pedagogical agent and providing feedback as a dialogue.	No. of visits to assertion and reasoning questions: 32 Attempts to follow pointers and indulge in sense making: 35
Number of visits to each feature is very high in comparison with the action taken i.e. attempts to view/edit their previous choice/answer written.	Navigation difficulty while interacting with the environment.	Features are included in a linear manner and in order to view the first features you had to compulsorily visit all other features. On coming back /previous choices/answers were erased.	Back tracing the path and retaining users action such as choices selected and text entry. Scroll bars, reset and back button and retention of answers/choices included.	Number of visits to each feature and the actions taken seem to be on par considering the instances of action taken.

There exist a higher number of attempts in establishing a micro-macro link, in following the pointers given in the feedback of the assertion and reasoning questions, and the navigation difficulty appears to have eased out due to enabling path tracing and retention of the choices and text entered by the student. We can say this by comparing the number of visits to each feature and the corresponding action taken. For example: in DBR cycle 1, attempts to establish a micro-macro link while writing a justification were 26 but the student visited the features of Prediction Questions and Justification Box 132 and 62 times respectively. In the revised version, attempts to establish a micro-macro link while writing a justification were 40 but the student visited the features of Prediction Questions and Justification Box 89 and 95 times respectively. The attempts towards the correct action have increased and number of visits towards other features have reduced (Eg: Prediction question).

5.3.4.3 Discussion of Study – 5

In order to answer RQ 2 c: What was the effect of the improvised design on students' interaction with the various features of the learning environment? The data from Study 5 has been compared with Study 3. Post a rigorous analysis, we can say that using both the versions of the MIC-O-MAP TEL environment, students are able to develop the skills of Observe-Predict-Test-Revise but the improvisation undertaken in the design structure for DBR cycle-2 reduce the learning based problems which had arisen earlier. Students are now able to perform the desired actions for each skill. While making observations in the microscopic world, they use the animation of the microscopic picture and the assertion and reasoning questions as scaffolds in order to identify key areas where changes are taking place, for eg: knee voltage. A dialogue with the pedagogical agent erases the look and feel of assessment, instead, provides an aspect of mentoring and providing feedback when necessary. When posed with prediction questions, students are found to make an informed choice in their prediction option since they choose a graph and also phrase a justification for the same using a micro-macro link. Establishment of a micro-macro link takes place since students are using the assertion and reasoning questions as pointers towards making more careful observations, also for sense making between the unseen dynamics and the visible manipulative outcomes. They perform all these actions when they choose a macroscopic I-V graph and then phrase a justification for choosing that graph.

Similar to Study 3, students are found to develop the skill of testing their answer with respect to experimental outcomes. Students go back and forth between all the features of the TEL environment but the instances of the expected actions are higher in comparison with the earlier version MIC-O-MAP in DBR cycle-1. Revision of their prediction or justification happens throughout in this revised learning environment.

We display the features of the animation of the microscopic picture along with the rest of the features and the agent simultaneously. This is done to reduce the load on memory and keep the focus on development of the skills and sense making. Usability changes such as allowing the user to trace his/her path has helped in navigation and students need not restart each time that they wish to go back to a certain area of interaction. Retention of their answers and choices has also aided in focusing on improvisation of the answers instead of rewriting them for the sake of moving back and forth. We have also provided a section for taking down their own notes which students generally have a habit of during their learning process. These notes are retained for each session of interaction. Lastly, we have allowed students to reset the entire environment and start like a clean slate in case they feel like beginning from scratch. This option will erase all the data entered by them.

Owing to the results from Study 4 and Study 5 we claim that the pedagogical features identified by us for designing a learning environment can be used for developing the skills of Observation-Prediction-Testing Predictions against real world outcomes-Revising Predictions. A limitation of this study is that the entire on screen activity keeps getting recorded unless the students says that he/she has finished interaction with MIC-O-MAP, a maximum time of 1 hour has been allotted but by viewing each other's peers there exists a chance that students take more rounds of interaction until their friends/peers finish interaction. Every students pace of interaction and understanding the content is unique which can get affected by this.

5.4 Overall Discussion and Summary

After completing two DBR cycles we find that MIC-O-MAP features are effective in developing micro-macro thinking skills. With reference to the Scaffolding Design Framework [Quitana et.al., 2004], we segregate the MIC-O-MAP features into the strands of sense making, which involves the basic operations of testing hypotheses and interpreting data; process management which involves the strategic decisions involved in controlling the inquiry process; and articulation and reflection, which is the process of constructing, evaluating, and articulating what has been learned [Quitana et.al., 2004]. The following image reflects how each feature of MIC-O-MAP is mapped to the Scaffolding Design Framework.

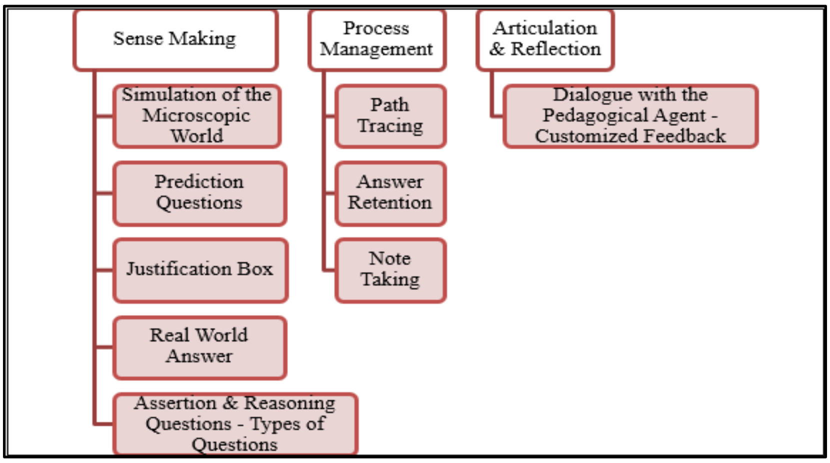


Figure 5.4: MIC-O-MAP mapped to the Scaffolding Design Framework

The features mentioned under the strand of sense making help the students in going through an inquiry cycle which includes making observations in the micro world, devising explanations based on the observations, predicting a macroscopic outcome and testing it against a real world answer. The assertion and reasoning questions are prompts towards identifying key areas of the micro world which may need further observations, or in establishing a link between the ongoing processes in the micro world and the graphical options presented in the macro world prediction questions. The features mentioned under process management aid completion of each task of MIC-O-MAP without any struggle. The option to trace paths helps in reaching any area visited previously, unique for every learner and answer retention helping in quick improvisation of previous choices. Note Taking makes following feedback and comprehension of onscreen information easier by providing students with a scratchpad where they can write down text in their own worlds. This scratch pad can be enlarged and moved around the screen so as to utilize the screen space effectively. Lastly, articulation and reflection of what has been learnt takes place by indulging into a dialogue with a pedagogical agent who guides the learner through the entire inquiry cycle. It not only gives instructions for proceeding through the learning environment but also provides customized feedback for every question answered by the learner.

The learning materials used in the studies in both DBR cycles were based on the same topic of PN Junctions- Forward Biased from Basic Analog Electronics. We now wanted to examine if the MIC-O-MAP design features that have been evaluated, refined and re-evaluated in the two iterations can be used for the development of new modules. In order to do this, we first created an Instructional Design Document and identified various topics suitable for the learning of micro-macro thinking skill. This as well as their evaluation of the various modules will be discussed in Chapter 6.

Chapter 6

Development & Evaluation of MIC-O-MAP modules in topics in analog electronics

6.1 Design learnings from two DBR cycles

The pedagogical goals of the MIC-O-MAP learning environment are to promote students' skills of establishing, strengthening and integrating micro-macro thinking skills. The features and learning activities in MIC-O-MAP supports students as they learn to explain reasoning, justify conclusions, analyze outcomes of an experiment, get immediate feedback, test their predictions against experimental outcomes and revise their predictions. A link gets established between the microscopic and macroscopic worlds as students vary the parameters and observe its immediate effect in both the worlds. After undertaking careful observations, this link gets strengthened when they predict the functionality of the system based on the micro-macro link. Towards completing interacting with MIC-O-MAP, students are asked to vary parameters and observe its effects on dynamically linked multiple representations of the topic which helps integrate the micro-macro link.

Two design based research cycles have been detailed out and described in Chapters 4 and 5 respectively. After confirming that the challenges faced by students are addressed in the revised version of MIC-O-MAP (Study 5, Chapter 5, Section 5.3.4), we arrived at an instructional design template for creating MIC-O-MAP modules in various topics. This template provides teachers/researchers guidance on choosing a topic suitable for developing micro-macro thinking skills, placement and positioning of the micro and macro worlds on screen, ways of writing instructions such that a programmer can easily distinguish between instructions for coding and content to be displayed on screen and writing assertion and reasoning questions which are observation or inference based. The instructional design template of MIC-O-MAP provides instructions with regards to the placement and position of both the worlds as well as the facility of tracing one's learning path in order to improvise or reattempt the choice of answer. This is discussed in detail in Section 6.3.

6.2 Choice of Topics

An important decision to be taken was the choice of the topic to develop MIC-O-MAP modules. The process of the development of the first MIC-O-MAP module was initiated by comparing the syllabi of theory as well as laboratory experiments for the subject of Analog Electronics within the domain of Physics for the first year of undergraduate study. The topics chosen were such that they were covered as an experiment in the laboratory as well as were to be taught in theory courses. The second filter applied was that the topics formed the basic building blocks of the higher complex topics such as transistor or FETs/MOSFETs. Lastly, we ensured that the modules of MIC-O-MAP which we have covered complete 60% of the integrated syllabus of Electronics.

The process for selecting topics is started by taking note of the levels across which learning of the topic takes place. Topics which have concepts consisting of multiple levels (i.e. a micro and macro level) are best suited for learning using MIC-O-MAP. In such topics, there are important variables at the macroscopic level (i.e. observable/ measurable) and corresponding variables at a microscopic level (often invisible) which explain the mechanism for the macroscopic variable behaviour. The above criteria were applied to the syllabus of 1st year Analog Electronics. The topic of forward biased PN junction was chosen for the development of the first MIC-O-MAP module. Five further modules of MIC-O-MAP in the following topics were created:

- Conductivity in Intrinsic Semiconductors
- Formation of Extrinsic Semiconductors
- Conductivity in Extrinsic Semiconductors
- Thermistors
- Light Dependent Resistors (LDR)

For all of these topics, there are variables/parameters which can be manipulated in a real-world laboratory and its corresponding readings can be obtained simultaneously. When these parameter values are varied, there exists an effect on elements at the microscopic level. For example: For the first topic of PN Junctions, when the voltage is varied, there is an effect on the electron motion at the microscopic level which further reflects a change in the ammeter reading which depicts current flowing in the circuit. As the voltage is varied further, the electrons are able to cross the barrier potential and there exists a rise in the current post this voltage value. This voltage value is referred to as knee voltage. These values of current and voltage can be measured in a laboratory and when plotted as a graphical outcome, it depicts the functionality of the system. The current versus voltage graph for the PN junction diode is exponential when the battery voltage exceeds the value of the knee voltage. Here, we have elements such as electrons, barrier potential which are present in the microscopic world or are invisible in the real world where as there are variables which can be manipulated in a laboratory such as current and graph. The readings obtained from the current and voltage meters are used for plotting an I-V curve which depicts the behaviours of the electrical component of the diode.

Similar cases exist for the rest of the topics where in, for the module of a thermistor, the real world/macroscopic variable which can be manipulated is temperature which affects the electron excitation from the valence band to the conduction band, giving rise to a value of resistance in an ohm meter. This enables the plotting of a resistance versus temperature curve which depicts the functioning of the component of ‘thermistor’. For the module of formation of extrinsic semiconductors, the variable which can be manipulated in the real world is the doping of the semiconductor and its effect on the rise number of electrons getting excited from the valence band to the conduction band can be noted. This is further used to plot the graph of conductivity versus doping. For the module of conductivity in intrinsic and extrinsic semiconductors, the variable to be manipulated in the real world is the temperature and its corresponding effect on the excitation of the electrons can be observed in the micro world. Simultaneously, the readings for the current and voltage can be measured which can be further used for the calculation of the resistance. Following this, the conductivity is calculated and a graph of conductivity versus temperature is plotted to depict the functionality of the component. Lastly, for the module of the Light Dependent Resistor (LDR), the distance of the LDR from the light source is varied and its effect on the electron excitation is observed in the micro world. Simultaneously the reading of the resistance is measured in the real world which is further used to plot a graph of resistance versus distance from the light source.

6.3 Instructional design template to develop MIC-O-MAP modules

On the basis of the findings from the two DBR cycles, we have created a template of MIC-O-MAP which can be filled out for various topics. Appendix A has this template filled out for the first module of PN Junctions. The brief look and feel of the entries in the template can be gathered Fig. 6.1.

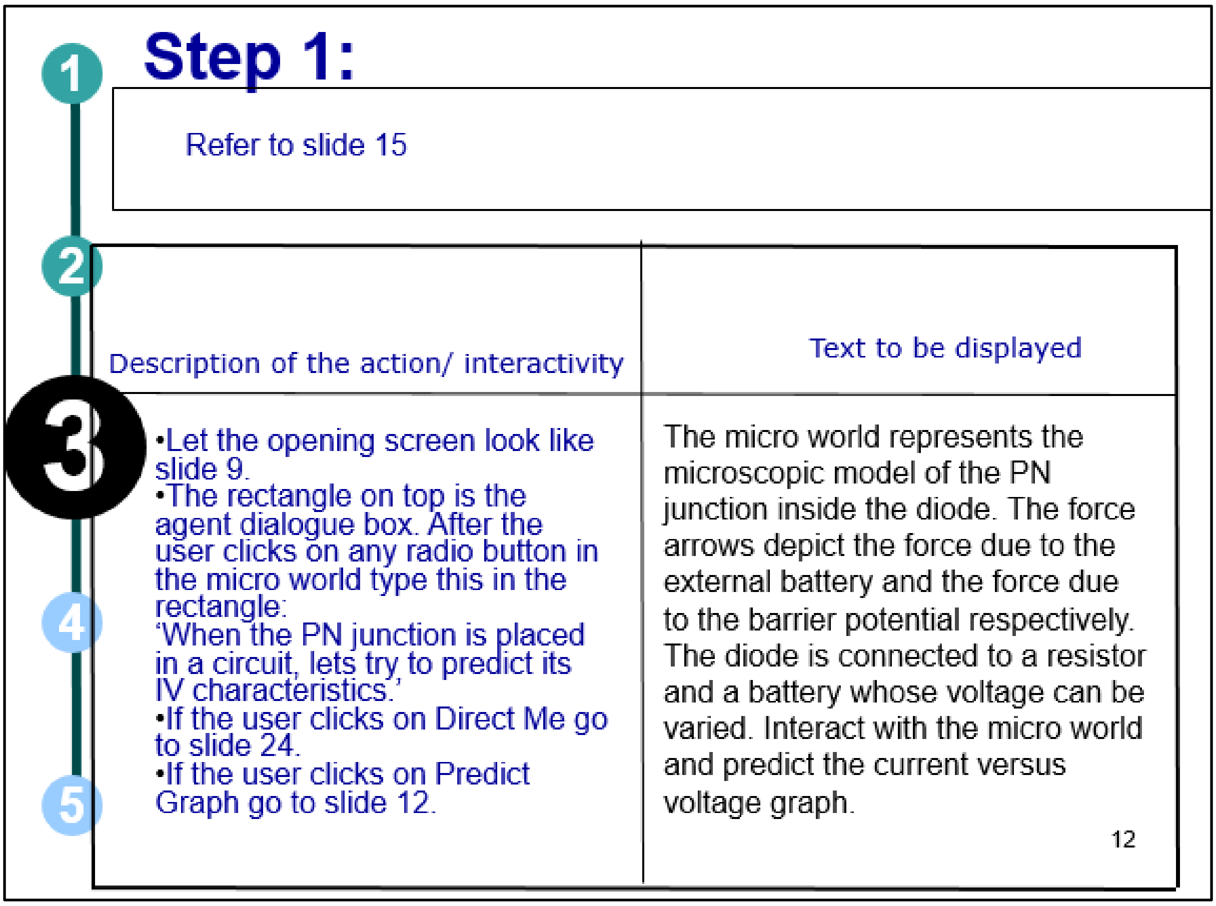


Figure 6.1. MIC-O-MAP template entries

The template has a colour coding to separate the instructions to the programmer from the text to be displayed on screen. This can be seen in Fig 6.1. The entire screen when coded gets separated into two parts where one side depicts the micro world and the other half depicts the macro world of the chosen phenomenon. This is shown in Fig. 6.2.

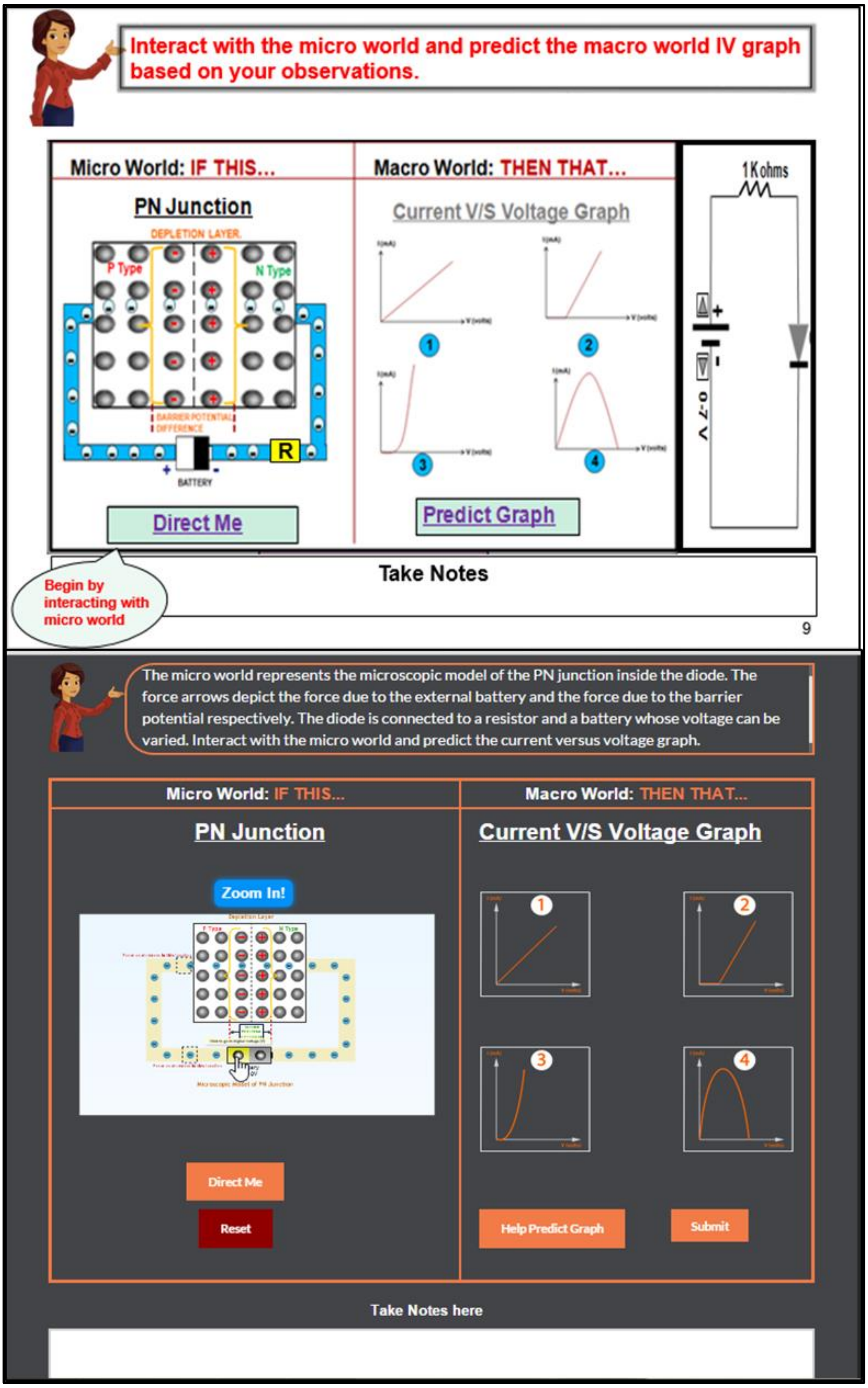


Figure 6.2. Demarcation of the micro and macro world in the instructional design document template mapped to the MIC-O-MAP module

The pedagogical agent is to be displayed on the top of the screen where the instructions to the learner as well as the feedback will be displayed. At all times, the micro world be available for interaction on left side of the screen and the other half depicting the macro world will get replaced with the assertion and reasoning questions in case the learner clicks on the icon of ‘Direct Me’ or ‘Help to Predict’. Here customized feedback will be provided to the learner mediated by the pedagogical agent based on the answer chosen. This is shown in Fig. 6.3.

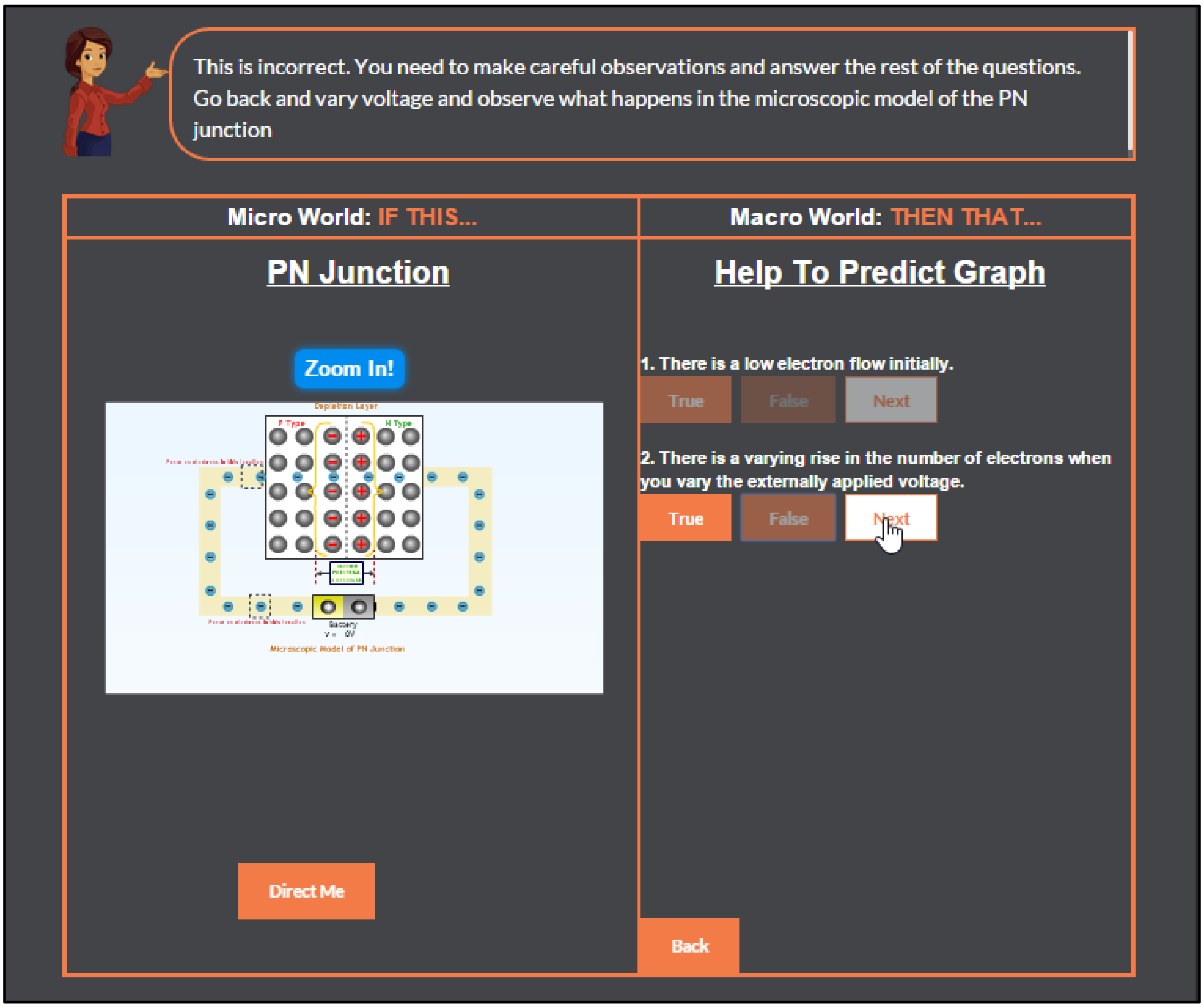


Figure 6.3. Assertion and reasoning questions mediated by the pedagogical agent

The Prediction Questions along with an entry for justification will also be present in the area demarcated for the macro world as these are all the instances which can take place in a real world setting and will be visible to the learner as shown in Fg.6.4.

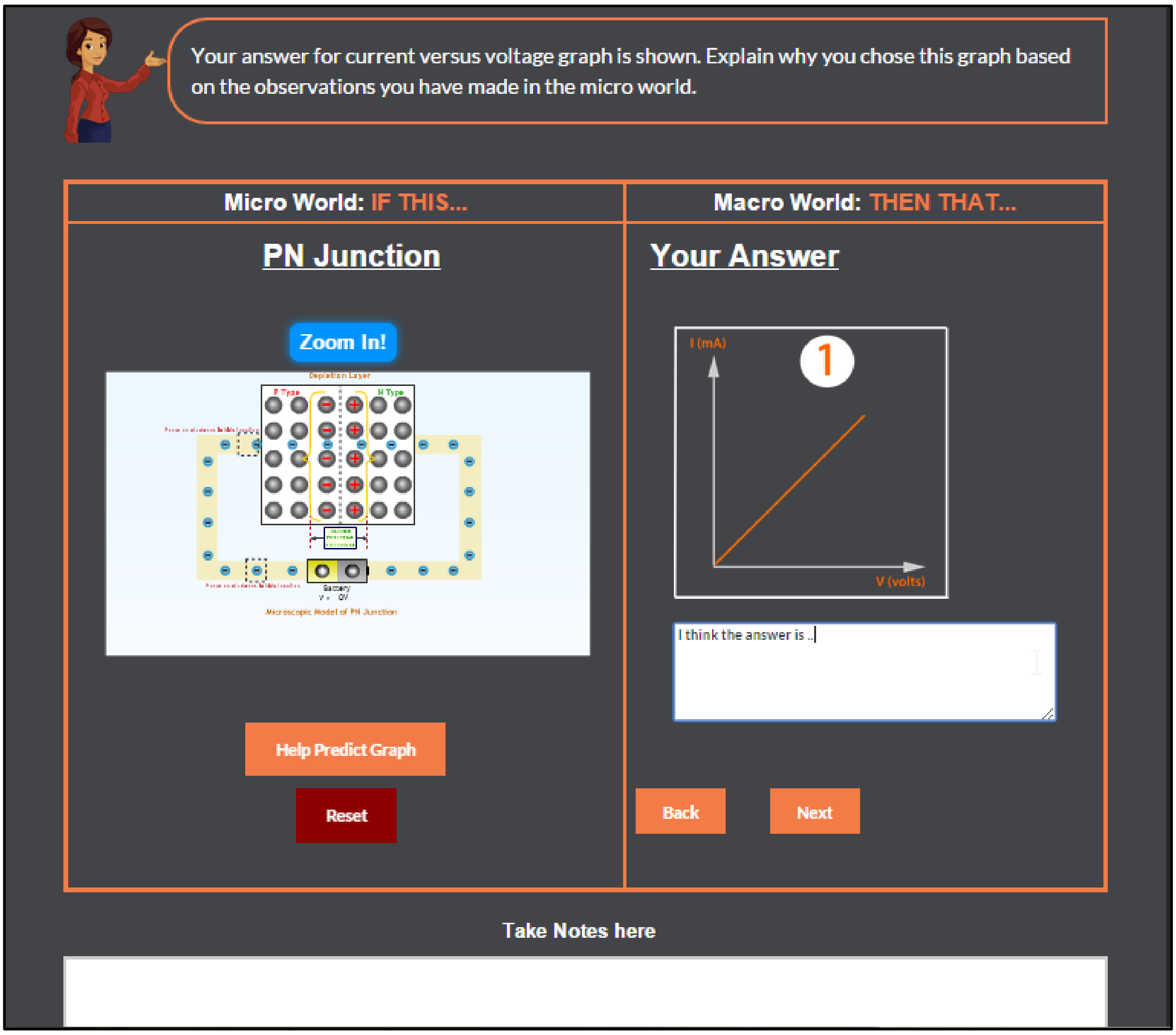


Figure 6.4. Prediction Choice with Justification written

There are also two options of note taking as well as path tracing which are affordances provided to the learner from the system. Either the learners path can be traced dynamically and provided to him/her by the 'Back' and 'Next' button or have a separate area demarcated for the path traced out. We suggest the inclusion of the two buttons which smooths out this process of reaching an area which they have interacted with. The note taking section can either be segregated out and placed below the micro and macro worlds or a learning from student interactions is that a text box which can be opened and closed as well as moved around the screen is more appreciated as well as user friendly. At all times an option to reset the screen is present in case the learner wishes to start the entire learning process afresh. So also, the choices made by the learner (for example: an option of a graph) are always retained unless and until the user chooses to reset the screen.

6.4 MIC-O-MAP modules

In this section, we describe the details of the six MIC-O-MAP modules we developed. We discuss the content in each topic, specifically the microscopic and macroscopic levels and how they are linked. We provide details of how we developed the module, and describe the evaluation study we performed with each module.

6.4.1 Module 1: PN Junctions (Diode Theory)

Content: A PN junction is a device with a junction between a p-type and an n-type semiconducting material. Students are expected to observe the microscopic phenomenon like electron motion as they vary macroscopic parameters like voltages. Further they are expected to predict the voltage versus current characteristics based on these observations and justify this characteristic curve by establishing a link between the microscopic and macroscopic worlds.

***Development and Evaluation*:** PN Junctions has been taken as the topic for the development of the learning environment of MIC-O-MAP. The learning activities and results of the studies conducted in the DBR cycles have been reported in detail in Chapters 4 and 5.

6.4.2 Module 2: Thermistors

Content: A Thermistor is an electrical resistor whose resistance varies based on changes in temperature. Students are expected to observe the changes in the electrons getting excited from the valence band to the conduction band in the microscopic world as they make changes in the temperature in the macroscopic world. Further they are expected to predict the temperature versus resistance curve based on these observations and justify this characteristic curve by establishing a link between the microscopic and macroscopic worlds.

***Development*:** The design template explained in section 6.3, was used for the topic of thermistors based on the content mentioned above. In the microscopic picture of the thermistors, students were allowed to vary the temperature and observed its effect on the rise number of electrons getting excited from the valence band to the conduction band for a thermistor. In the graph, they were asked to predict a relationship between resistance and the temperature. Four different options of resistance versus temperature were provided under the features of 'Prediction Questions'. Students were asked to predict the correct graphical outcome based on the based on the observations recorded by them in the microscopic world of the thermistor. This is shown in Fig. 6.5.

If students were unable to make a prediction, then they were asked observation based questions such as 'Did you notice that before increasing the temperature no electrons existed in the conduction band’ OR ‘Did you notice that the electrons started getting excited to the conduction band only when the temperature is varied?’. Based upon their responses to the above questions they were provided with feedback such as ‘Observe the number of electrons in the conduction band before you start varying the temperature’ OR ‘Vary the temperature and observe the number of electrons in the conduction band.’

If students needed assistance in establishing a link between the microscopic and macroscopic worlds, then they were provided with link establishing questions. These questions were also of two types – Link Establishment -Observation based, for example, ‘In the simulation what happens to the number of electrons getting excited to the conduction band as there was a rise in the thermal energy?

a) More number of electrons get excited to the conduction band
b) Less number of electrons get excited to the conduction band’

Based upon the student response, they were provided with feedback such as ‘Observe the number of electrons in the conduction band for each temperature value. Note that a rise in temperature indicates a rise in thermal energy.’ The second type of questions provided were for Link Establishment – Inference based, for example, ‘Which of the following is related to concept of resistance? Thermal Energy or Excitement of electrons to the conduction band’ If the option of Thermal Energy was chosen, then feedback provided was, ‘Recollect that Thermal energy increases when you increase the temperature. It is not related to the concept of temperature’. It asks the learner to recollect the definition of thermal energy and helps them correlate it to the observations made by them in the micro world i.e. the number of electrons getting excited from the valence band to the conduction band as the temperature is increased. In contrast to this, if the option chosen by the student is excitement of electrons to the conduction band, then the feedback provided was, ‘You are Right! Go ahead and answer the remaining questions.’ It informs the learner that their thought process is correct and encourages them to answer the next question. This is shown in Fig. 6.6.

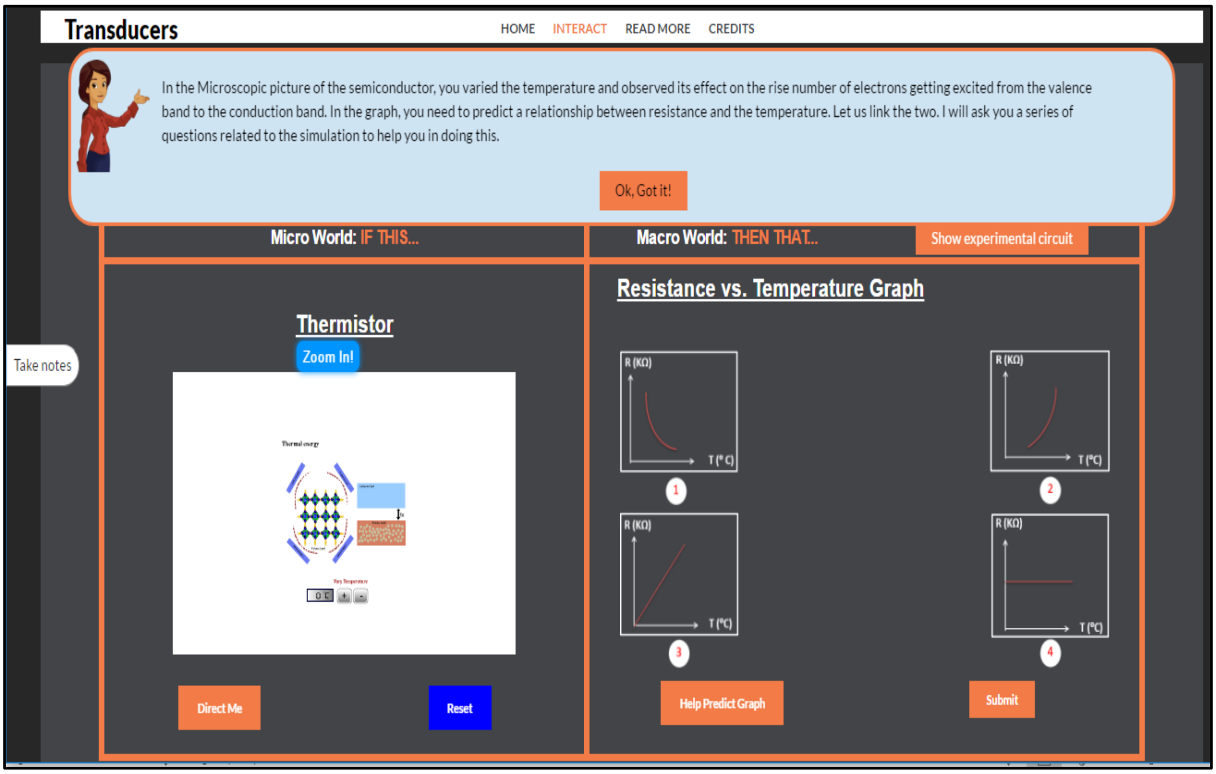


Figure 6.5. Screenshot of module on Thermistor

Figure 6.6. Observation and Inference based Questions- Thermistors

<u>Evaluation and Findings:</u> *Research Design and Sampling*: A single group pre-post test research design was adopted. Participants were undergraduate students from colleges affiliated to Mumbai University. Students were familiar with the domain content in the topics, but they were not explicitly exposed to micro-macro thinking process before this study. The sampling procedure consisted of the following steps: students with a knowledge of higher secondary level and studying in the first year of graduation were randomly chosen as participants in the study. Randomized sampling ensured that students with varying prior knowledge were allowed to participate. The total number of participants were 30.

Procedure: Before interacting with MIC-O-MAP, physical phenomenon was presented to the student by means of a simulation depicting its microscopic explanation. Students were asked to interact with a simulation depicting the working of a light dependent resistor. They had to later answer pre-test questions related to this phenomenon. These pre-test questions tested the student's skills of making observations, predictions, testing the prediction by comparing with given experimental results, and revising the prediction if necessary. Post this the students were allowed to interact with MIC-O-MAP and a total time period of 1 hour was allotted to the students for learning the topic of thermistors. At the end of the hour, students had to view the earlier simulation once again and answer a post-test having the same questions testing students' skills of making observations, predicting outcomes, testing them and revising when necessary. The post-test questions on the topic of an LDR are given in Appendix B.3.

Instruments and Data Analysis: The scientific abilities rubrics explained in Chapter 4 have been used for the grading of the tests. There existed one question per criterion in the tests answered by students. A prior inter-rater reliability analysis of the rubric has shown that Cohen's $\kappa=0.839$ with $p<0.001$.

The Wilcoxon signed-rank test was used to determine differences in the pre-test and post-test scores on observation-prediction-testing-explanation skills. It is the nonparametric test equivalent to the dependent t-test. This test is used to compare two sets of scores that come from the same participants. This can occur when we wish to investigate any change in scores from one time point to another, or when individuals are subjected to more than one condition. It is only appropriate to use a Wilcoxon signed-rank test if your data "passes" three assumptions that are required for a Wilcoxon signed-rank test to give you a valid result. The first assumption is that the dependent variable should be measured at the ordinal or continuous level. In our case, the dependent variable is ordinal as it is measured using a Likert Scale. The second assumption is that the independent variable should consist of two categorical, "related groups" or "matched pairs". "Related groups" indicates that the same subjects are present in both groups. This assumption also holds in our case as the same group of students answer the pre-test as well as the post-test. The last assumption is that the distribution of the differences between the two related groups is symmetrical in shape.

***Findings*:** The average learning time was 41.2 minutes. A Wilcoxon signed-rank test showed that a statistically significant change in pre-test and post-test scores for all of the sub skills of micro-macro thinking with $p < 0.01$. Table 6.1 shows the mean rubrics scores of students' pre-test and post-test performance related to the skills of describing observations, devising explanations for observed patterns, making predictions and deciding whether the prediction matches experimental.

Table 6.1 Wilcoxon signed-rank test results-Thermistors

Ability to	**Z Value**	**Pre-test Mean** (out of 3)	**S.D.**	**Post-test Mean** (out of 3)	**S.D.**	**p-value**
Describe observations	-4.428	1.53	0.681	2.80	0.406	0.000
Devise a micro-world explanation for observed pattern	-4.802	1.73	0.583	3.00	0.00	0.000
Make prediction of macro-world based on micro-world explanation	-4.617	1.10	0.607	2.50	0.508	0.000
Decide whether the prediction and the experimental outcome agree	-4.820	0.93	0.583	2.50	0.508	0.002

6.4.3 Module 3: Light Dependent Resistors

Content: A Light Dependent Resistor (LDR) is a resistor whose resistance varies based on changes in light incident on it. Students are expected to observe the changes in the electrons getting excited from the valence band to the conduction band in the microscopic world as they make changes in the amount of light incident on the LDR in the macroscopic world. This is done by varying the distance at which the LDR is placed form the light source. Further they are expected to predict the resistance versus distance curve based on these observations and justify this characteristic curve by establishing a link between the microscopic and macroscopic worlds.

***Development*:** The design template explained in section 6.3, was used for the topic of light dependent resistors based on the content mentioned above. In the microscopic picture of the light dependent resistors, students were allowed to vary the distance between the LDR and the light source i.e. the bulb and observed its effect on the rise number of electrons getting excited from the valence band to the conduction band for a light dependent resistor. In the graph, they were asked to predict a relationship between resistance and the distance. Four different options of resistance versus distance were provided under the features of 'Prediction Questions'. Students were asked to predict the correct graphical outcome based on the based on the observations recorded by them in the microscopic world of the light dependent resistors.

If the students faced a difficulty in predicting the graphical outcome or establishing a micro-macro link, they were provided with questions based on their observations and link establishment as explained for the module of thermistors in section 6.4.2. An example of such a question is as follows: Observation based questions: ‘What happens to the number of electrons getting excited to the conduction band when the distance between the LDR and light source is increased? Increases, Decreases or remains same’ with a feedback of ‘Vary the distance between LDR and light source and observe the number of electrons in the conduction band’ in order to direct them to next appropriate action. Inference based question example: ‘What is the co-relation between the distance between the LDR and light source varied by you and the value of resistance measured of the LDR?’ with options of ‘As the distance between the LDR and the light source increases, the resistance of the LDR decreases’ OR ‘As the distance between the LDR and the light source increases, the resistance of the LDR increases’. The feedback given is ‘Recollect that the number of incident photons increases when you decrease the distance between the LDR and light source. A rise in the number of incident photons is responsible for more number of electrons to be excited to the conduction band further leading to high current and low resistance. Consider this and rethink your options.’

Screenshots of the module on light dependent resistors as well as the questions related to observations and micro-macro linkages are shown in Fig. 6.7 and Fig.6.8.

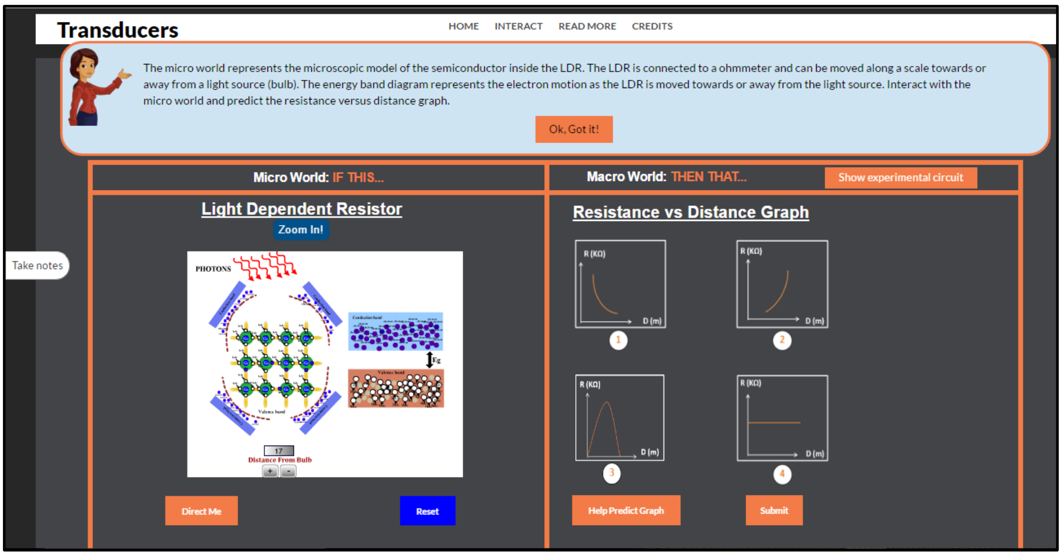


Figure 6.7. Screenshot of module on Light Dependent Resistor (LDR)

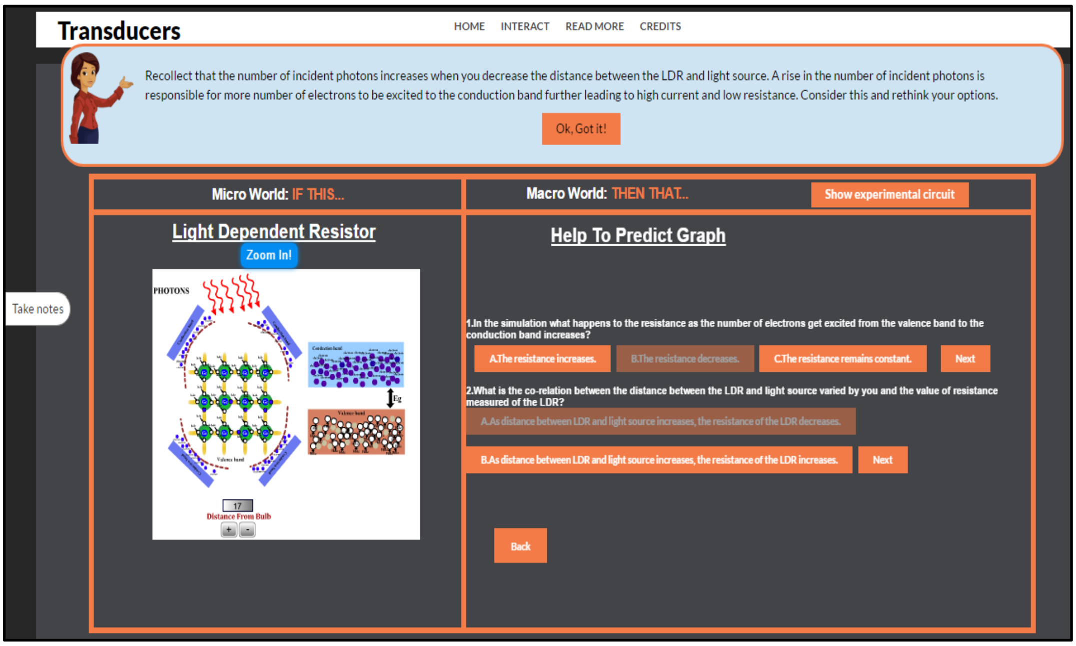


Figure 6.8. Observation and Inference based Questions- LDR

Evaluation and Findings: The research design, sampling method, instruments as well as data analysis method is same as that carried out for the module on thermistors and detailed out in section 6.4.2. The total number of participants were 29.

Procedure: Before interacting with MIC-O-MAP, physical phenomenon was presented to the student by means of a simulation depicting its microscopic explanation. Students were asked to interact with a simulation depicting the working of an extrinsic semiconductor. They had to later answer pre-test questions related to this phenomenon. These pre-test questions tested the student's skills of making observations, predictions, testing the prediction by comparing with given experimental results, and revising the prediction if necessary. Post this the students were allowed to interact with MIC-O-MAP and a total time period of 1 hour was allotted to the students for learning the topic of thermistors. At the end of the hour, students had to view the earlier simulation once again and answer a post-test having the same questions testing students' skills of making observations, predicting outcomes, testing them and revising when necessary. The post-test questions on the topic of conductivity in an extrinsic semiconductor are given in Appendix B.5.

Findings: The average learning time was 43 minutes. A Wilcoxon signed-rank test showed that a statistically significant change in pre-test and post-test scores for all of the sub skills of micro-macro thinking with $p < 0.01$. Table 6.2 shows the mean rubrics scores of students' pre-test and post-test performance related to the skills of describing observations, devising explanations for observed patterns, making predictions and deciding whether the prediction matches experimental.

Table 6.2. Wilcoxon signed-rank test results- Light Dependent Resistors

Ability to	Z Value	Pre-test Mean (out of 3)	S.D.	Post-test Mean (out of 3)	S.D.	p-value
Describe observations	-4.078	1.58	0.682	2.65	0.483	0.000
Devise a micro-world explanation for observed pattern	-4.179	1.8	0.539	2.79	0.412	0.000
Make prediction of macro-world based on micro-world explanation	-3.788	1.55	0.827	2.55	0.506	0.000
Decide whether the prediction and the experimental outcome agree	-3.798	1.68	0.849	2.65	0.483	0.000

6.4.4 Module 4: Conductivity in Extrinsic Semiconductors

Content: An extrinsic semiconductor is a doped semiconductor whose conductivity is enhanced by adding impurities. Students are expected to observe the changes in the electrons getting excited from the valence band to the conduction band in the microscopic world as they make changes in the temperature in the macroscopic world. Further they are expected to predict the conductivity versus temperature curve based on these observations and justify this characteristic curve by establishing a link between the microscopic and macroscopic worlds.

***Development*:** The design template explained in section 6.3, was used for the topic of conductivity in extrinsic semiconductors based on the content mentioned above. In the microscopic picture of the extrinsic semiconductors, students were allowed to vary the doping in the extrinsic semiconductor and observe its effect on the rise number of electrons in the conduction band. In the graph, they were asked to predict a relationship between conductivity and doping in the extrinsic semiconductor. Four different options of conductivity versus doping were provided under the features of 'Prediction Questions'. Students were asked to predict the correct graphical outcome based on the based on the observations recorded by them in the microscopic world of the extrinsic semiconductors.

If the students faced a difficulty in predicting the graphical outcome or establishing a micro-macro link, they were provided with questions based on their observations and link establishment as explained for the module of thermistors in section 6.4.2. An example of such a question is as follows: Observation based question example: 'Did you notice that the bulb glows brighter as you increase the amount of Temperature?' with options of Yes or No and a feedback of 'Vary the doping and carefully observe the brightness of the bulb at each value'. Inference based question example: 'What do you think is the nature of the relation between conductivity and temperature?' with options of 'conductivity increases as the temperature is increased' OR 'conductivity decreases as the temperature is increased' OR ''conductivity stays the same as the temperature is increased'. The feedback given is 'Recollect the definition of conductivity i.e it is a measure of the amount of electrical current a material can carry. And a rise in temperature increases the current flowing through the circuit.’ Screenshots of the module on conductivity in extrinsic semiconductors as well as the questions related to observations and micro-macro linkages are shown in Fig. 6.9 and Fig. 6.10.

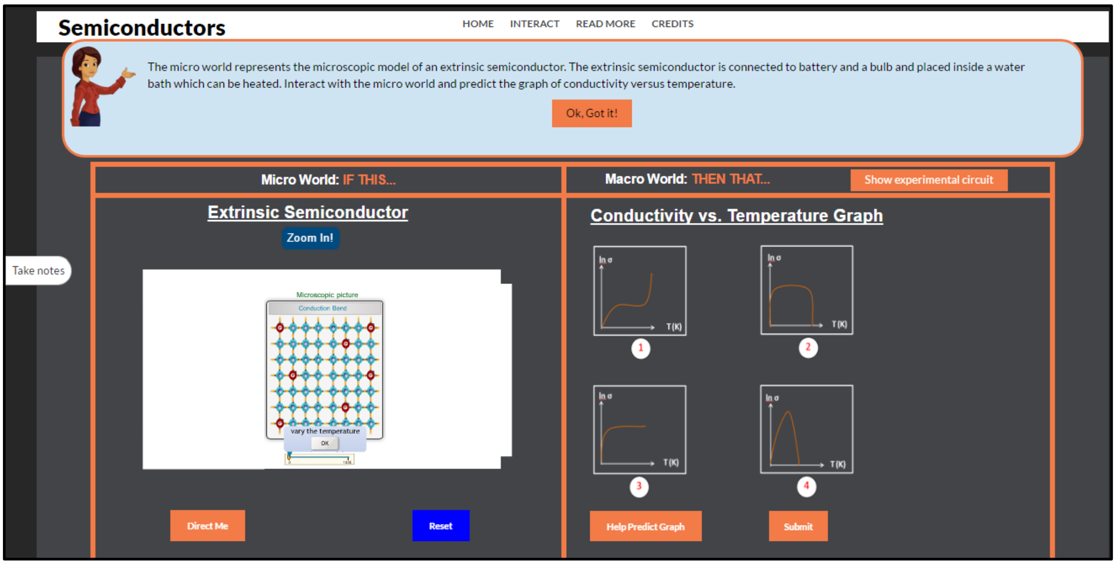


Figure 6.9. Screenshot of module on Conductivity in Extrinsic Semiconductors

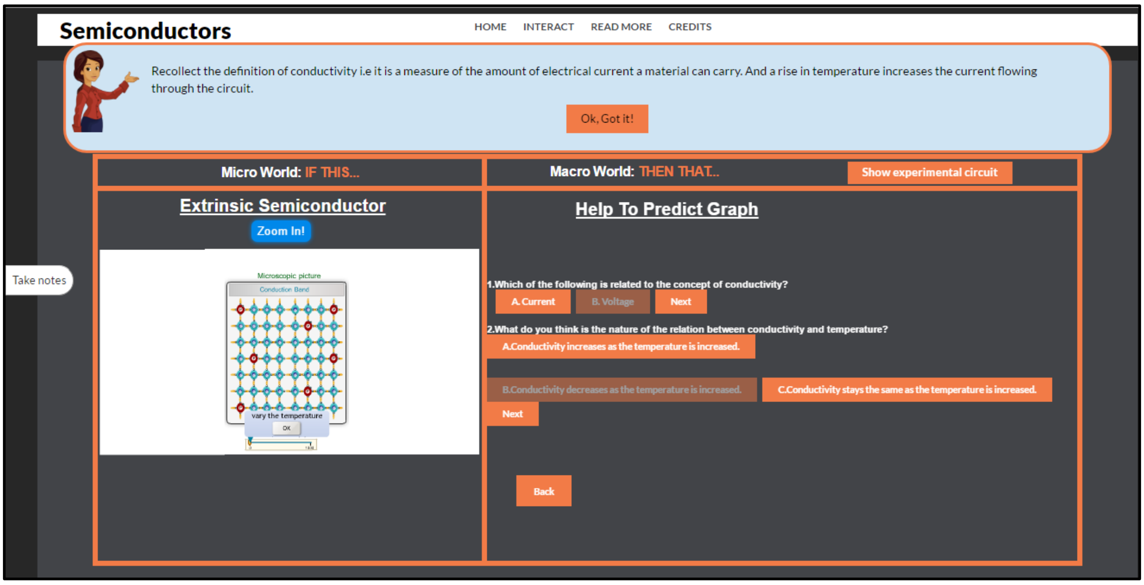


Figure 6.10. Observation and Inference based Questions- Conductivity in Extrinsic Semiconductors

Evaluation and Findings: The research design, sampling method, instruments as well as data analysis method is same as that carried out for the module on thermistors and detailed out in section 6.4.2. The total number of participants were 30. The post-test questions on the topic of a thermistor are given in Appendix B.2.

***Findings*:** The average learning time was 42.5 minutes. A Wilcoxon signed-rank test showed that a statistically significant change in pre-test and post-test scores for all of the sub skills of micro-macro thinking with $p < 0.01$. Table 6.3 shows the mean rubrics scores of students' pre-test and post-test performance related to the skills of describing observations, devising explanations for observed patterns, making predictions and deciding whether the prediction matches experimental.

Table 6.3. Wilcoxon signed-rank test results- Conductivity in Extrinsic Semiconductors

Ability to	**Z Value**	**Pre-test Mean** (out of 3)	**S.D.**	**Post-test Mean** (out of 3)	**S.D.**	**p-value**
Describe observations	-3.504	1.7	0.651	2.4	0.498	0.000
Devise a micro-world explanation for observed pattern	-4.021	1.83	0.530	2.63	0.490	0.000
Make prediction of macro-world based on micro-world explanation	-3.522	1.93	0.583	2.53	0.507	0.000
Decide whether the prediction and the experimental outcome agree	-3.051	2.26	0.639	2.63	0.490	0.002

6.4.5 Module 5: Conductivity in Intrinsic Semiconductors

***Content*:** Intrinsic Semiconductors are undoped semiconductors and conduct weakly at room temperature. Students are expected to observe the changes in the electrons getting excited from the valence band to the conduction band in the microscopic world as they make changes in the temperature in the macroscopic world. Further they are expected to predict the conductivity versus temperature curve based on these observations and justify this characteristic curve by establishing a link between the microscopic and macroscopic worlds.

***Development*:** The design template explained in section 6.3, was used for the topic of Conductivity in Intrinsic Semiconductors based on the content mentioned above. In the microscopic picture of the semiconductor, students were allowed to vary the temperature and observed its effect on the rise number of electrons getting excited from the valence band to the conduction band for an intrinsic semiconductor. In the graph, they were asked to predict a relationship between conductivity and the temperature. Four different options of conductivity versus temperature were provided under the features of 'Prediction Questions'. Students were asked to predict the correct graphical outcome based on the based on the observations recorded by them in the microscopic world of the Intrinsic Semiconductor. This is shown in Fig. 6.8

If the students faced a difficulty in predicting the graphical outcome or establishing a micro-macro link, they were provided with questions based on their observations and link establishment as explained for the module of thermistors in section 6.4.2. An example of such a question is as follows: If students were unable to make a prediction, then they were asked observation based questions such as ‘Did you notice that the bulb glows brighter as you increase the amount of temperature?’ OR ‘Did you observe that there exist more number of free electrons in the conduction band as the temperature is increased?’. Based upon their responses to the above questions they were provided with feedback such as ‘Vary the temperature and carefully observe the brightness of the bulb at each value.’ OR ‘Vary the temperature and carefully observe the number of electrons in conduction band.’

If students needed assistance in establishing a link between the microscopic and macroscopic worlds, then they were provided with link establishing questions. These questions were also of two types – Link Establishment -Observation based, for example, ‘In the simulation what is the effect of increasing the temperature?

a) A rise in the number of electrons in the conduction band.
b) A fall in the number of electrons in the conduction band.’

Based upon the student response, they were provided with feedback such as ‘Carefully observe the number of electrons getting excited as you increase the temperature.’ The second type of questions provided were for Link Establishment – Inference based, for example, ‘Which of the following is related to the concept of conductivity? Current or Voltage’. If the option of current was chosen, then feedback provided was, ‘You are right! Electrical conductivity is a measure of the amount of electrical current a material can carry.’ It informs the learner that their thought process is correct and also helps them recollect the definition of electrical conductivity. In contrast to this, if the option chosen by the student is voltage, then the feedback provided was, ‘Recollect the definition of conductivity and notice the number of electrons in the conduction band as you increase the temperature. Hence it is directly related to the current.’ It asks the learner to recollect the definition of conductivity and helps them correlate it to the observations made by them in the micro world i.e. the number of electrons getting excited from the valence band to the conduction band as the temperature is increased. This is shown in Fig. 6.11 and Fig. 6.12.

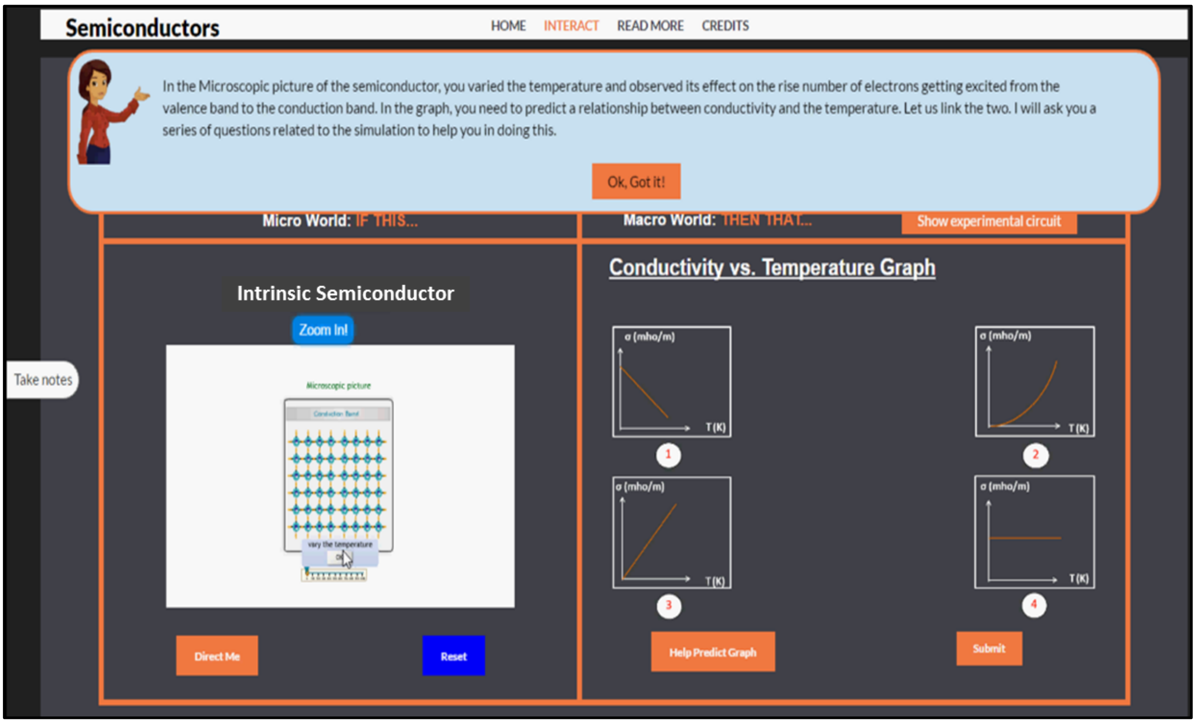


Figure 6.11. Screenshot of module on Conductivity in Intrinsic Semiconductors

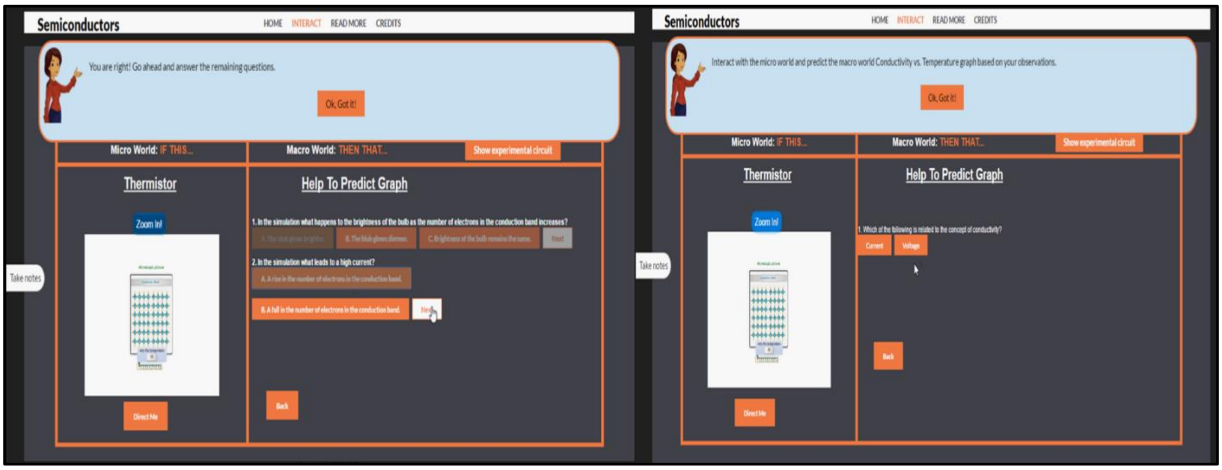


Figure 6.12. Observation and Inference based Questions- Conductivity in Intrinsic Semiconductors

6.4.6 Module 6: Formation of Extrinsic Semiconductors

Content: An extrinsic semiconductor is one in which impurities contribute a significant fraction of the conduction band electrons and/or holes. Students are expected to observe the microscopic phenomenon like rise/fall in the number of conduction band electrons as they vary macroscopic parameters like doping. Further they are expected to predict the conductivity versus doping characteristics based on these observations and justify this characteristic curve by establishing a link between the microscopic and macroscopic worlds.

Development: The design template explained in section 6.3, was used for the topic of Formation of Extrinsic Semiconductors based on the content mentioned above. In the microscopic picture of the extrinsic semiconductor, students were allowed to vary the doping and observed its effect on the rise in the number of in the conduction band for an extrinsic semiconductor. In the graph, they were asked to predict a relationship between conductivity and the doping. Four different options of conductivity versus doping were provided under the features of 'Prediction Questions'. Students were asked to predict the correct graphical outcome based on the based on the observations recorded by them in the microscopic world of the extrinsic semiconductor. This is shown in Fig. 6.10.

If the students faced a difficulty in predicting the graphical outcome or establishing a micro-macro link, they were provided with questions based on their observations and link establishment as explained for the module of thermistors in section 6.4.2. An example of an observation based question is 'Did you notice that the donor impurity atoms have free electrons in the conduction band?' with the options of Yes or No. The feedback provided is 'Vary the doping and carefully observe the free electrons in doped atoms in the atomic structure.' An inference based question example is 'In the simulation what leads to a high current?' with the options of 'A rise in the number of electrons in the conduction band' OR 'A fall in the number of electrons in the conduction band' with the feedback of 'Recollect the definition of current and notice the number of electrons in the conduction band as you increase the doping.' Screenshots of the module on formation of extrinsic semiconductors as well as the questions related to observations and micro-macro linkages are shown in Fig. 6.13 and Fig. 6.14.

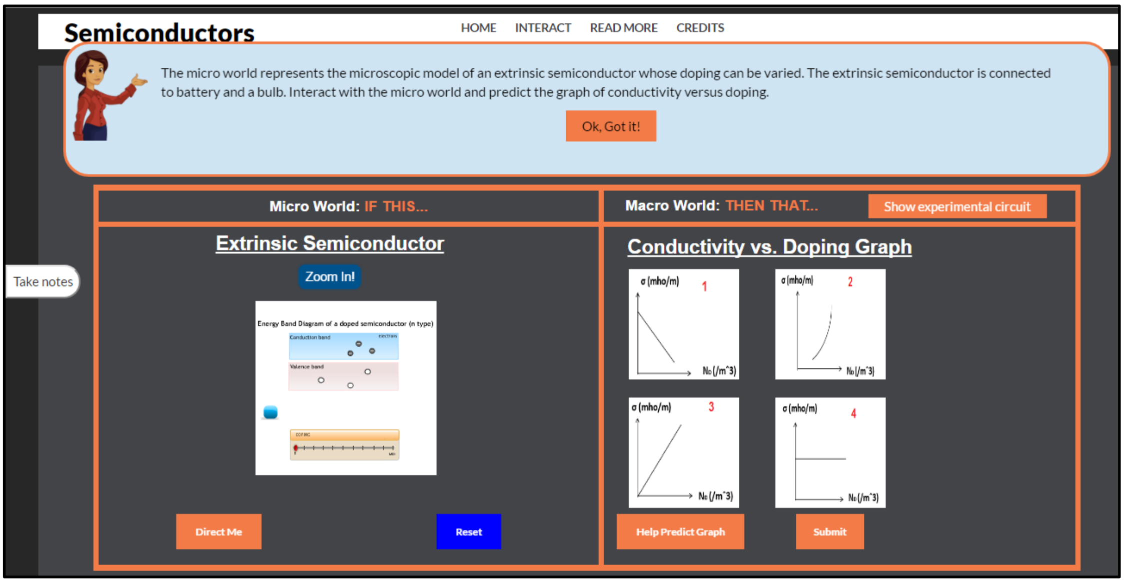


Figure 6.13. Screenshot of module on Formation of Extrinsic Semiconductors

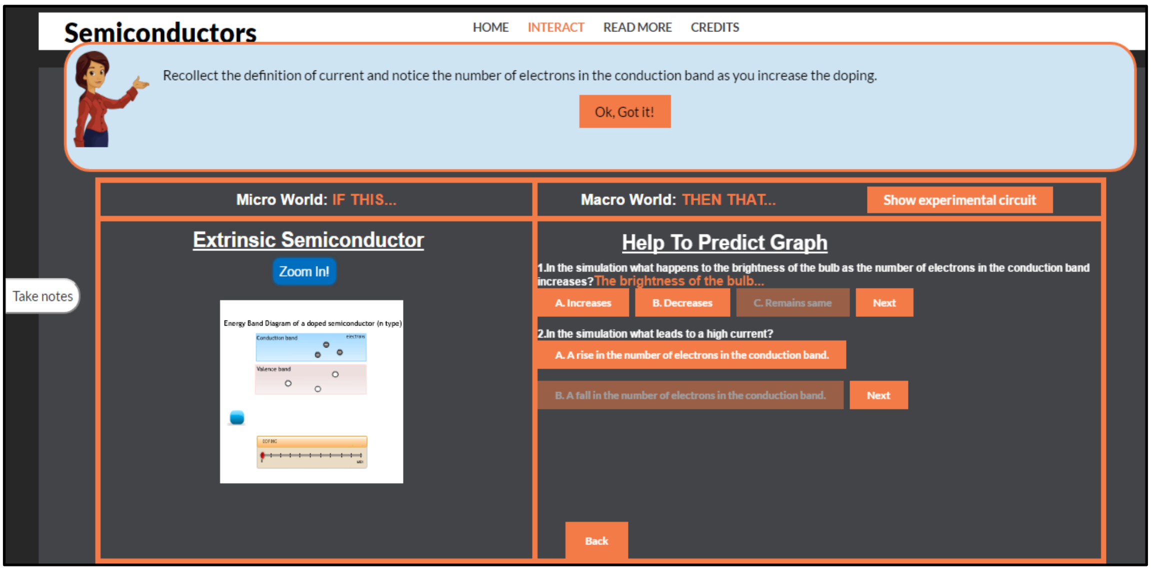


Figure 6.14. Observation and Inference based Questions- Formation of Extrinsic Semiconductors

6.5 Repeated Measures Study

This section reports a study to evaluate effect of the effect of increased interaction with MIC-O-MAP modules on micro-macro thinking skill development. Increased interaction is operationalized in terms of the sessions of interaction with MIC-O-MAP modules in different topics, and micro-macro thinking skill development is operationalized in terms of the score on the micro-macro thinking skill test.

6.5.1 Research Design

A repeated measure is a variable measured two or more times, usually before, during and/or after an intervention or treatment. After evaluating student responses to each module, student responses to the micro-macro thinking skill test on more than one occasion were examined. ‘Repeated measurement may occur due to measuring the participant at successive times (pre, post and follow-up) or under more than one experimental condition (i.e., participants are exposed to both treatment conditions sequentially). A distinction is made among independent variables (factors) composed of separate groups of participants (called between-subjects or independent groups factors) and independent variables in which the same participant is in more than one group or condition (called repeated or within-subjects factors)’ [Ellis, p. 554, 1999]. We will be following the within-subjects or repeated measurement for the group of participants. The response of a participant to the treatment can be measured either as a part of a group or catered to each individual. These are known as group designs and single subject research design respectively. A group research design will be followed in this study wherein we will be analysing group averages instead of responses at the individual participant level of analysis and within subject's factor will be considered since the sample remains the same across interaction with all modules.

6.5.2 Participants

Students from first year graduation, affiliated to Mumbai University, India were chosen as the participants. These students had a prior knowledge of subject domain of physics from standard 12th examination. We had opted for convenience sampling and sent an invitation to the college which had sent maximum number of participants during vacation period. This was done because we wanted a large number of students to participate in this study and wanted them to sincerely attend all the sessions involved in the workshop. Total number of students who were present throughout the study was 29. We had tried to maintain a zero attrition rate by keeping the presence of the college teachers throughout the workshop and also awarding the participation certificates to those who complete the entire workshop.

6.5.3 Procedure

The students (N= 29) who arrived at the experiment venue given MIC-O-MAP as the learning material. A one-and-a-half-day workshop was held wherein the same set of students were asked to interact with 2 modules of MIC-O-MAP on the first day and the third module on the second day. On the first day, Students were asked to interact with Module 1 of MIC-O-MAP for the topic of PN junctions-forward biased, for a maximum time period of 1 hour. At the end of the hour, students had to view a simulation of the microscopic world for a new topic - PN Junctions reverse biased and answer a post-test having questions testing students' skills of making observations, predicting outcomes, testing them and revising when necessary.

Same procedure was repeated for session 2 where Module 2 of MIC-O-MAP was presented to the students as the learning material. The topic for Module 2 was conductivity in intrinsic semiconductors and the topic for the post-test was thermistors, i.e. students were presented with a simulation of the microscopic world of thermistors and were asked to answer micro-macro thinking skill based questions for this topic. Lastly, on day-2, Module 3 was allotted as the learning material. The topic for Module 3 was formation of extrinsic semiconductors and the topic for the post-test was light dependent resistors i.e. LDR. students were presented with a simulation of the microscopic world of an LDR and were asked to answer micro-macro thinking skill based questions for this topic. Module 2 and 3, described in section

6.4 have been used as the learning material for this study. The post-test questions are given in Appendix B. The schedule for the 3-day workshop was as follows:

Table 6.4. Mapping Sessions to the Test Numbers

Session Number	Micro-Macro Thinking Skill Test
---------	0 – Pre-test – PN junction reverse biased
1 - PN Junctions forward biased	1 – Post-test 1- PN Junction reverse biased
2 - Conductivity in Intrinsic SC	2 – Post-test 2- Thermistors
3 - Formation of Extrinsic SC	3 – Post-test 3- LDR

6.5.4 Instrument and Data Analysis

Scientific abilities rubrics have been used for grading the tests in this study and a Friedman test will be calculated since there is no control group and the test scores have been evaluated post each session and for the same sample.

The Friedman test is the non-parametric alternative to the one-way ANOVA with repeated measures. It is used to test for differences between groups when the dependent variable being measured is ordinal. This test can be used if one group that is measured on three or more different occasions. Also, the participating group of students have to be a random sample from the population. Lastly, the dependent variable should be measured at the ordinal or continuous level. The micro-macro thinking skill has been scored using a Likert scale which is ordinal data. In our study the responses to the micro-macro thinking skill test has been measured after on 4 occasions for the same set of students. To examine where the differences actually occur, we will run a post hoc Wilcoxon signed-rank tests on the different test combinations of related groups. We will be doing a pair wise comparison of the pre-test and the first post-test which the students will be answering after interacting with the first MIC-O-MAP module, the first post-test and the second post-test which the students will be answering after interacting with the second MIC-O-MAP module, the second post-test and the third post-test which the students will be answering after interacting with the third MIC-O-MAP module and lastly we will also be comparing the test scores on the pre-test and the last post-test, which to examine their performance after interacting with three MIC-O-MAP modules.

6.5.5 Findings

<u>For the skill of Observe:</u>

Fig. 6.15 depicts the variation of the mean scores with each test answered by the students for the skill of ‘Observe’. It can be noted that after interacting with the first module, there is minimal variation in the scores and the value lies between the second highest and highest rubric score. In Fig. 6.15, the test numbers correspond to the tests answered by the students as given in Table 6.4.

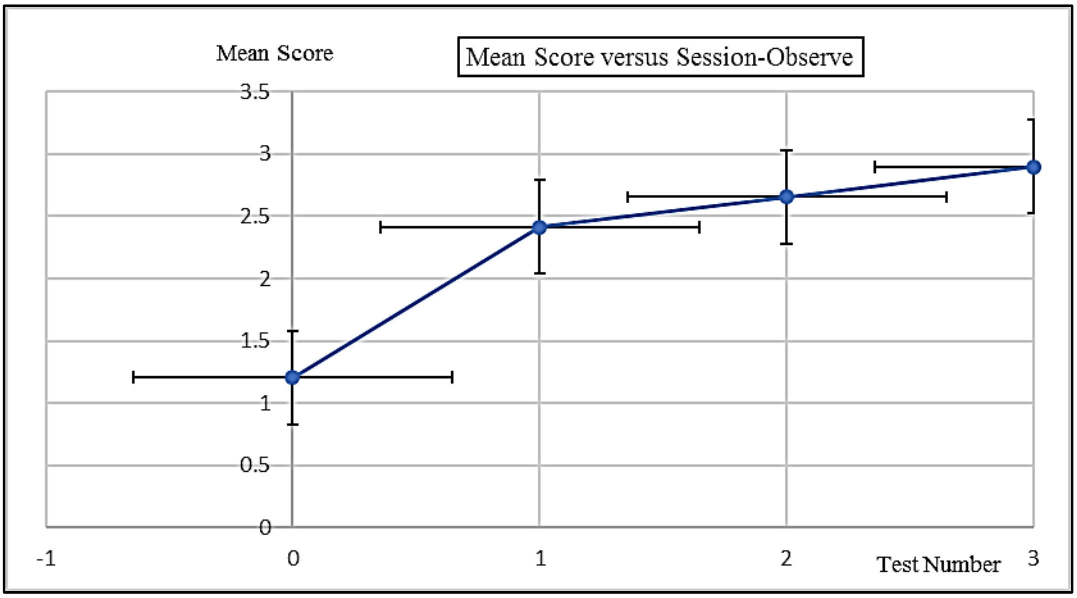


Figure 6.15. Mean Score Variation across tests-Observe

The Friedman test indicates that there was a statistically significant difference in the test scores for the sub skill of 'Observe' depending upon the MIC-O-MAP module used as the learning material, $\chi2$ (3) = 56.868, p = 0.000.

The mean scores of students before and after interacting with each session are shown in Table 6.5. The post hoc Wilcoxon signed-rank test indicates that there exists a statistical significant difference in the scores of the post-test 1 compared to the pre-test and in the scores of post-test 3 compared to the pre-test. But there is no statistical significant difference in the scores of post-test 2 compared to post-test 1 and post-test 3 compared to post-test 2.

Table 6.5. Pair wise comparison of Mean Scores- Sub Skill of Observe

Pair Wise Tests	**Z value**	**Mean Score-before**	**S.D.**	**Mean Score-After**	**S.D.**	**P value**
Pre-test & Post-test 1	-4.202	1.206	0.675	2.413	0.501	0.000
Post-test 1 & Post-test 2	-1.698	2.413	0.501	2.655	0.483	0.090
Post-test 2 & Post-test 3	-1.941	2.655	0.483	2.896	0.309	0.052
Pre-test & Post-test 3	-4.640	1.206	0.675	2.896	0.309	0.000

For the skill of Explain:

Fig. 6.16 depicts the variation of the mean scores with each test answered by the students for the skill of 'Explain'. It can be noted that post interacting with 3 MIC-O-MAP modules, students are found to receive the highest rubric score. There exists a rise and a fall in the test scores however, they are not found to be significant. In Fig. 6.16, the test numbers correspond to the tests answered by the students as given in Table 6.4.

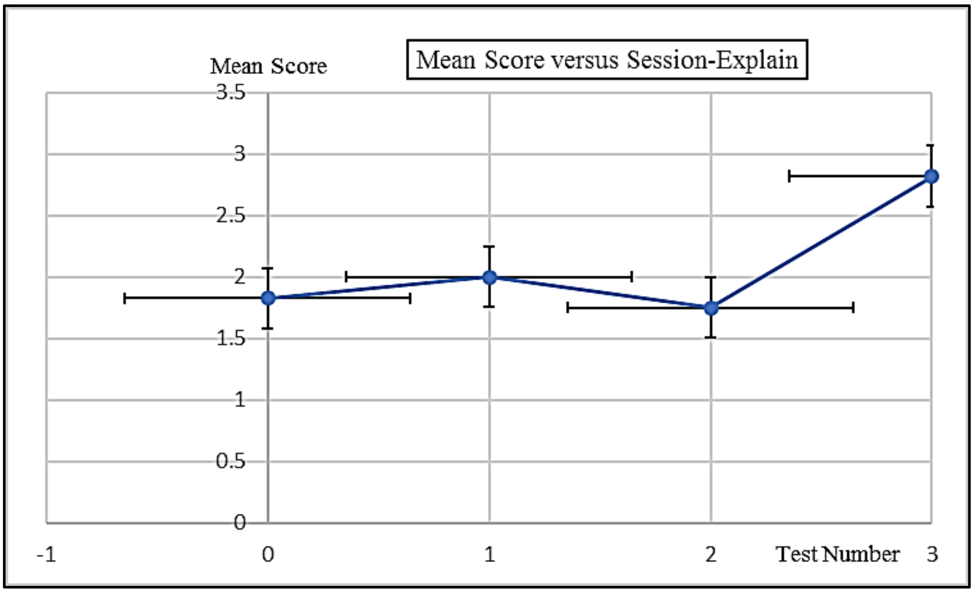


Figure 6.16. Mean Score Variation across tests-Explain

The Friedman test indicates that there was a statistically significant difference in the test scores for the sub skill of 'Explain' depending upon the MIC-O-MAP module used as the learning material, $\chi2$ (3) = 36.411, p = 0.000.

The mean scores of students before and after interacting with each session are shown in Table 6.6. The post hoc Wilcoxon signed-rank test indicates that there exists a statistical significant difference in the scores of the post-test 3 compared to the post-test 2 and in the scores of post-test 3 compared to the pre-test. But there is no statistical significant difference in the scores of post-test 1 compared to pre-test and post-test 2 compared to post-test 1.

Table 6.6. Pair wise comparison of Mean Scores- Sub Skill of Explain

Pair Wise Tests	**Z value**	**Mean Score-before**	**S.D.**	**Mean Score-After**	**S.D.**	**P value**
Pre-test & Post-test 1	-0.912	1.827	0.658	2.000	0.654	0.362
Post-test 1 & Post-test 2	-1.444	2.000	0.654	1.758	0.689	0.149
Post-test 2 & Post-test 3	-4.137	1.75	0.689	2.82	0.384	0.000
Pre-test & Post-test 3	-4.221	1.827	0.658	2.82	0.384	0.000

For the skill of Predict:

Fig. 6.17 depicts the variation of the mean scores with each test answered by the students for the skill of 'Predict'. It can be noted that initially there is improvement in the scores of students and only in the last test, there is no difference observed. In Fig. 6.17, the test numbers correspond to the tests answered by the students as given in Table 6.4.

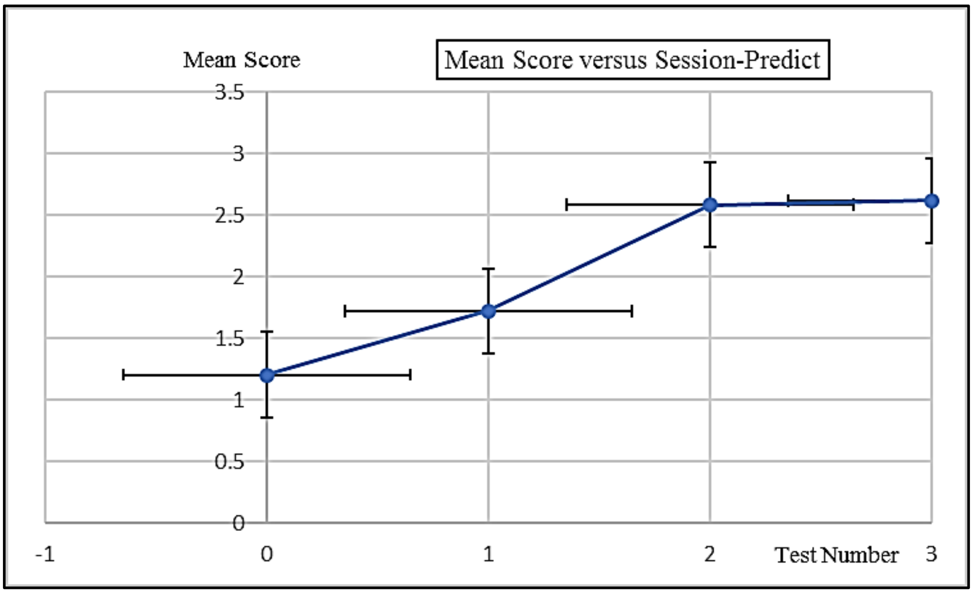


Figure 6.17. Mean Score Variation across tests-Predict

The Friedman test indicates that there was a statistically significant difference in the test scores for the sub skill of ‘Predict’ depending upon the MIC-O-MAP module used as the learning material, $\chi 2$ (3) = 58.803, p = 0.000.

The mean scores of students after interacting with each session are shown in Table 6.7. The post hoc Wilcoxon signed-rank test indicates that there is a statistical significant difference in the scores of post-test 1 and the pre-test, post-test 2 and post-test 1and post-test 3 and the pre-test. Where as there is no statistical significant difference in the scores of post-test 3 and post-test 2.

Table 6.7. Pair wise comparison of Mean Scores- Sub Skill of Predict

Pair Wise Tests	**Z value**	**Mean Score-before**	**S.D.**	**Mean Score-After**	**S.D.**	**P value**
Pre-test & Post-test 1	-3.638	1.206	0.491	1.724	0.454	0.000
Post-test 1 & Post-test 2	-3.987	1.724	0.454	2.586	0.501	0.000
Post-test 2 & Post-test 3	-0.190	2.586	0.501	2.620	0.727	0.850
Pre-test & Post-test 3	-4.490	1.206	0.491	2.620	0.727	0.000

For the skill of Test:

Fig. 6.18 depicts the variation of the mean scores with each test answered by the students for the skill of 'Test'. Initially there is no improvement in the scores but after interaction with the second module of MIC-O-MAP, there is a constant improvement noticed. In Fig. 6.18, the test numbers correspond to the tests answered by the students as given in Table 6.4.

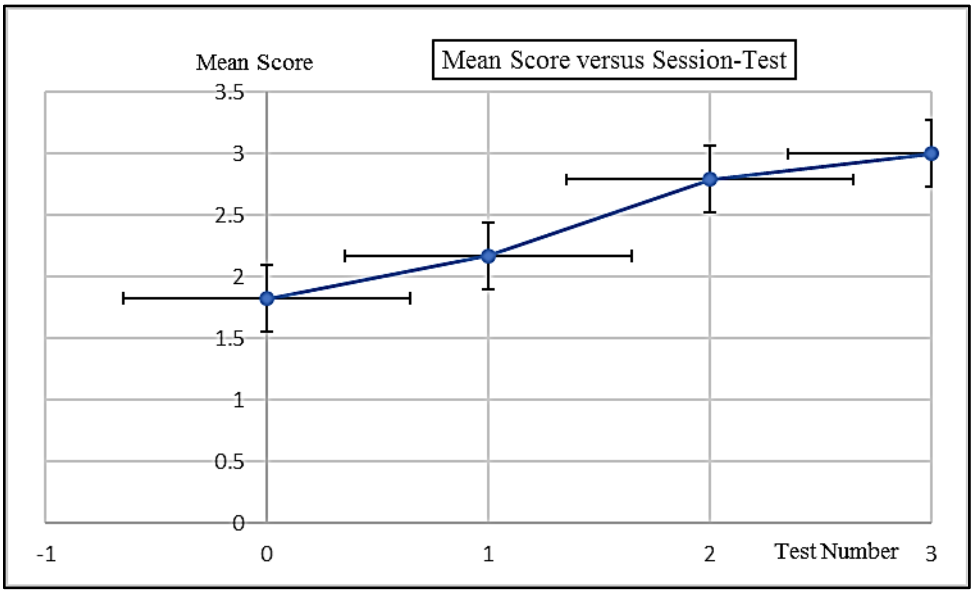


Figure 6.18. Mean Score Variation across sessions-Test

The Friedman test indicates that there was a statistically significant difference in the test scores for the sub skill of 'Test' depending upon the MIC-O-MAP module used as the learning material, $\chi2$ (3) = 36.686, p = 0.000.

The mean scores of students after interacting with each session are shown in Table 6.8. The post hoc Wilcoxon signed-rank test indicates that there is a statistical significant difference in the scores of post-test 3 and post-test 2, post-test 2 and post-test 1 and post-test 3 and the pre-test. Where as there is no statistical significant difference in the scores of post-test 1 and pre-test.

Table 6.8. Pair wise comparison of Mean Scores- Sub Skill of Test

Pair Wise Tests	**Z value**	**Mean Score-before**	**Std. Deviation**	**Mean Score-After**	**Std. Deviation**	**P value**
Pre-test & Post-test 1	-1.389	1.827	0.848	2.172	1.071	0.165
Post-test 1 & Post-test 2	-2.623	2.172	1.071	2.793	0.412	0.009
Post-test 2 & Post-test 3	-2.449	2.793	0.412	3.000	0.000	0.014
Pre-test & Post-test 3	-4.327	1.827	0.848	3.000	0.000	0.000

6.5.6 Discussion

After analysing the findings for all the subskills of micro-macro thinking for the three sessions, overall it can be noted that there is a statistical difference in the test scores after students interact with each module of MIC-O-MAP for all the subskills but there exists a variation when a pairwise comparison of each test is undertaken for statistical significance.

Post analysing the variation of the mean scores with each session, the following inferences can be made: For the subskill of 'Observe' there is a rise in the scores across all tests and the test score reaches the second highest rubric value immediately after the first session. For the subskill of 'Explain' there exists a drop followed by a rise in the test scores wherein the drop in the scores after the second session. For the subskill of 'Predict' initially there is a rise in the scores which later remains constant. Lastly, for the subskill of 'Test' there is a continuous rise in the test scores across all sessions.

In section 6.4.5, we have also analysed the pair wise comparison of mean scores on the micro-macro thinking skill test for each sub skill. For the sub skill of observe, It was found that after interacting with the first module, there is minimal variation in the scores and the value lies between the second highest and highest rubric score. This is an indication that students are able to make careful observations after exposure to one module of MIC-O-MAP and further interaction with MIC-O-MAP modules are a practise for them. For the sub skill of Explain, post interacting with 3 MIC-O-MAP modules, students are found to receive the highest rubric score. Based on this finding it can be inferred that students might need more exposure and practise in order to be able to establish a micro-macro link when faced with a new situation. For the sub skill of predict, initially there is improvement in the scores of students and only in the last test, there is no difference observed. But, a good point to be noted is that the score is on the second highest value of the rubric scale. For the sub skill of Test, initially there is no improvement in the scores but after interaction with the second module of MIC-O-MAP, there is a constant improvement noticed.

Even though MIC-O-MAP modules are found to help students in developing each subskill of micro-macro thinking, a serious and sustained commitment is required while working with them. There are multiple limitations of this study such as: the difficulty level of the topics chosen for this study is the same. This could be a reason due to which attainment of a score which remains between the second highest and highest score is seen to be possible. The time gap between interaction with each MIC-O-MAP module is very less i.e. when they complete interaction with one module, answer the test questions and begin interaction with the next module. There is also a time gap between the second and third module which can lead to students being prepared beforehand for topics in basic electronics. A maturity effect can also take place as students interact with MIC-O-MAP modules multiple number of times and for a longer period of time. So also, inter-participant variability is largely ignored in group based analysis and contributes to weak effects (statistical insignificance for the subskill of explanation). Some participants improve and some get worse in response to the learning material resulting in a weak effect for the group.

Overall, we can conclude that development of the skill keeps on improving as students interact with multiple modules and for longer time periods.

6.6 Summary and Implications

In this chapter, the choice of topics, development and evaluation of MIC-O-MAP modules has been discussed. Six modules have been developed within the domain of basic analog electronics out of which three modules for the topics of thermistors, light dependent resistors and conductivity in extrinsic semiconductors have been evaluated by means of single group pre-post test research designs. A repeated measures design research study has also been carried out wherein student responses to micro-macro thinking skill tests has been examined post interacting with three modules for the time period of one and a half day. It is found that overall there is a statistical significance in their test scores even though there is a variability in the significance when a pair wise comparison is calculated. The mean plots for the different sessions are an indication of improvement in the skill development as the frequency of interaction with modules increases.

Towards an effort in enabling students to develop explanations and reasoning linkages which deepens their understanding, the next study to be undertaken will be a qualitative study examining their thought process while interacting with MIC-O-MAP.

Chapter 7

Student Interaction with MIC-O-MAP

7.1 Introduction

7.1.1 Motivation

The evaluation studies in Chapters 5 and 6 showed that learner interaction with MIC-O-MAP modules in various topics helps in their development of micro-macro thinking. The interaction path followed by a student reflects the learning process that the student takes while as they develop micro-macro thinking skill. Our goal now is to examine the learning process behind the development of micro-macro thinking skill. The reason behind investigating this learning process is that in spite of having a similar academic background, technology familiarity and interaction time, there is a variation in students' post-test scores which evaluates the extent to which they have acquired micro-macro thinking skill. Also, students who get a high score on the micro-macro thinking skill test follow a similar pattern of interaction while navigating through MIC-O-MAP in section 4.7.4 while this pattern of interaction is different compared to students who score low on the micro-macro thinking post-test.

Investigating a scientific phenomenon without the presence of a mentor can give rise to difficulties as there is no one for doubt solving or for providing guidance when stuck. In many existing TEL environments, there exists a facilitator to guide the students throughout the learning session or suggest alternative interaction paths when required. On the other hand, MIC-O-MAP is used primarily in the context of self-regulated learning. Thus, it is important to investigate the learning process of students as they interact with MIC-O-MAP. To do this, we have analysed the screen recordings of learners' interaction with MIC-O-MAP as well as the responses from follow-up semi-structured interviews. This qualitative analysis will provide an insight into the thought processes of students while interacting with MIC-O-MAP. Thus, our study will provide guidelines for prospective designers of TEL environments on how to promote actions considered 'productive' so as to maximize learning benefit of MIC-O-MAP learning environment.

7.1.2 Developing a Description of Students 'Productive Actions'

While considering any educational setting, it is important to stress the dual aspects of both (a) accomplishing the task and (b) learning from one's efforts, that is, improving one's performance on the future tasks in the process [Reiser, 2004]. In problem solving using heuristics, students learn to monitor and direct their own progress, asking questions such as, "What am I doing now," "Is it getting me anywhere," "What else could I be doing instead?" This metacognitive level helps students to avoid perseverating in unproductive approaches, to remember to check candidate answers, and so on [Schoenfeld, 1982].

Wertheimer has used the term productive thinking to denote insightful learning based on an understanding of the underlying nature of the problem [Wertheimer, 1959]. According to this view, learning occurs as the learner gains insight into the problem. Learning based on understanding is called productive thinking [Bower & Hilgard, 1981]. Also, a more holistic emerging view of learning is captured in Schoenfeld's definition: '… coming to understand things and developing increased capacities to do what one wants or needs to do …' [Schoenfeld, 1999]. If there exists a difficulty in managing investigations then it leads to insufficient attention devoted to reflection and re-evaluation [Loh, 2003; Loh et al., 2001]. For learning through investigation to succeed, it is needed to develop a process which articulates a generalization of students' ongoing understanding. Learners should be able to "see" the core meaning rather than getting bogged down in translating from a representation to its underlying meaning. Simplifying this translation can reduce the complexity of the task, minimize errors possible with the tool [Norman, 1993; Reiser, 2004].

The "process of learning" is exhibited by what the student does in order to learn something and it is defined in terms of the student's focus of attention. This process of learning is investigated through a student's report of what he is doing, and this can be related to the outcome, which is exhibited by his performance in tests [Laurillard, 1979]. A synthesis of the above ideas wherein we understand what makes a process of learning productive i.e. which type of actions performed by students while learning can be considered productive. A student should be performing an action which makes an active contribution to what he is doing rather than simply reproducing what can be recalled from lectures [Laurillard, 1979].

We define students' actions as 'productive' when they intentionally use a combination of MIC-O-MAP features for establishment of a micro-macro link. While we try to encourage all students interacting with MIC-O-MAP to complete attempting all the tasks presented to them, it is also crucial to gather insight into the manner in which they complete the task and try to find an underlying common set of actions performed by students who score high on the micro-macro thinking skill test. The following study using a case study approach provides us with the richness of exploring patterns in qualitative data through screen captures and the logical explanations behind student choices while interacting with MIC-O-MAP.

7.2 Research Design

The research question to be investigated in this study is as follows:

RQ 3: *How does student interaction with MIC-O-MAP lead to development of micro-macro thinking skills?*

This research question is mapped to the third theme, which is, process of acquiring micro-macro thinking.

7.2.1 Participants

Participants were students from the 1st year undergraduate science and engineering programs from various colleges under Mumbai University, India. Formal invitations were sent to 5 colleges and students were asked to formally register with us for the study. We chose 1st year students since we wanted students to have prior knowledge of XII standard science, but we wanted them learn the topic for the first time using the learning environment. The sample size was of 12 students out of which 10 students scored high on the test measuring micro-macro thinking skills. Purposive sampling was adopted to focus on the thought process of high scoring students. These students who scored high (N=10) were asked to explore the learning environment- MIC-O-MAP, and try to attempt every task in it.

7.2.2 Procedure, Data Sources and Instruments

A total time period of 1 hour was allotted to the students for learning the topic. The topic being learnt using the learning environment was P-N Junctions (forward biased) from the subject domain of physics. While they were learning, the topic using MIC-O-MAP, their screen captures were recorded and post end of the session, the recording was replayed and semi structured interviews were conducted. Students were asked to explain in detail the reason behind viewing every feature and the manner in which it did/did not help them in developing micro-macro thinking. These sub-skills were mentioned in MIC-O-MAP as learning objectives, hence students were aware of the learning outcomes expected from them. The maximum time duration for which the interviews lasted were 10-15 minutes.

In order to record the on screen activities, My Screen Recorder software, screen-recording software was used. All these screen capturers were analyzed and later coded in accordance with the interaction pattern observed. This is known as Clickstream Analysis i.e. analyzing the record of screens or pages that user clicks on and sees, as they use a site or software product [Taniguchi, 2009]. Semi structured interviews were conducted post this analysis in order to gather an understanding into the thought process behind the choice of a particular interaction path. Semi structured interviews contained questions such as, "Can you elaborate why you have opted to go back to this feature?", "In what manner is this feature helpful for finishing this task?", "Can you explain how are you phrasing this justification your prediction? Can you detail out how you have managed to establish the micro-macro link?".

7.2.3 Data Analysis

The recordings of the screen captures and interviews were transcribed leading to a complete interleaved transcript of interviews and screen captures of each of the 10 students, amounting to 5-6 pages' worth data per student. Focusing on the screen capture recording, we took note of which feature was viewed in order, one after another. Analysis of this provided us with the interaction path taken by students as they interact with MIC-O-MAP. The unit of analysis was one question by the interviewer and a corresponding answer by the student. Codes were allotted to each unit of analysis depending upon what was being reported- usability, purpose of visit and time spent. Initially new codes were allotted till saturation of these codes was reached, after 4-5 students transcript.

Two raters coded the transcripts. Inter-rater reliability for the raters was calculated and the value of Cohen's Kappa was found to be 0.839 ($p<0.001$). Students reported the usage of a particular feature of MIC-O-MAP for various learning goals. The interviewer at the same time took notes of the actual actions of the students while interacting with the learning environment in the recordings. Analysis of a mapping between the codes allocated and the interaction path taken by students gave rise to the actions considered productive when students learn with rich technology enhanced environments such as MIC-O-MAP. Three illustrative case studies have been detailed out in section 7.4 which contrast the thought processes of high and low scoring students.

7.2.4 Results

Frequencies of the responses given by students were noted and are tabulated in Table 7.1. The three main categories arising for these codes are: Usability, Purpose for which features have been used and Reason behind time spent. The number of times a code appears under the categories of purpose of visit and reason behind time spent is shown in Fig. 7.1 and Fig.7.2 respectively. There were a few codes associated with the usability of MIC-O-MAP which got addressed immediately post the interviews. These changes are mentioned in Fig.7.3.

Table 7.1: Frequency of Student Responses for the Codes

Codes	Frequency
Good navigation-buttons self-explanatory	11
Bad navigation-too much scrolling	12
Not noticeable (notes taken and feedback)	15
Zooming in for closer view	8
Micro world Simulation & Assertion and Reasoning Questions - Improving conceptual understanding	3
Micro world Simulation & Assertion and Reasoning Questions - Improving reasoning & prediction	10
Viewing Micro world Simulation, Experimental Setup and Assertion and Reasoning Questions to phrase justification	10
Viewing Micro World Simulation and Experimental Setup together to improve prediction.	15
Correlating representations for sense making- Multiple representations	15
Title of button (direct me) – Useful for finding guidelines/instructions	4
Tracing path for curiosity.	1
Tracing path to check earlier answers	5
Tracing path to change answer	2
Experimental Setup- Linkage to real world lab	4
Glossary- Gathering/recollecting information	7
Notes to reduce memory load	4

Missed a task hence gone back	1
Navigation for finding a task	4
View features multiple times to decide what has to done	3
Multiple attempts for Sense making (reading and trying to understand)	3
No of attempts (attempting again) i.e. restarting	3

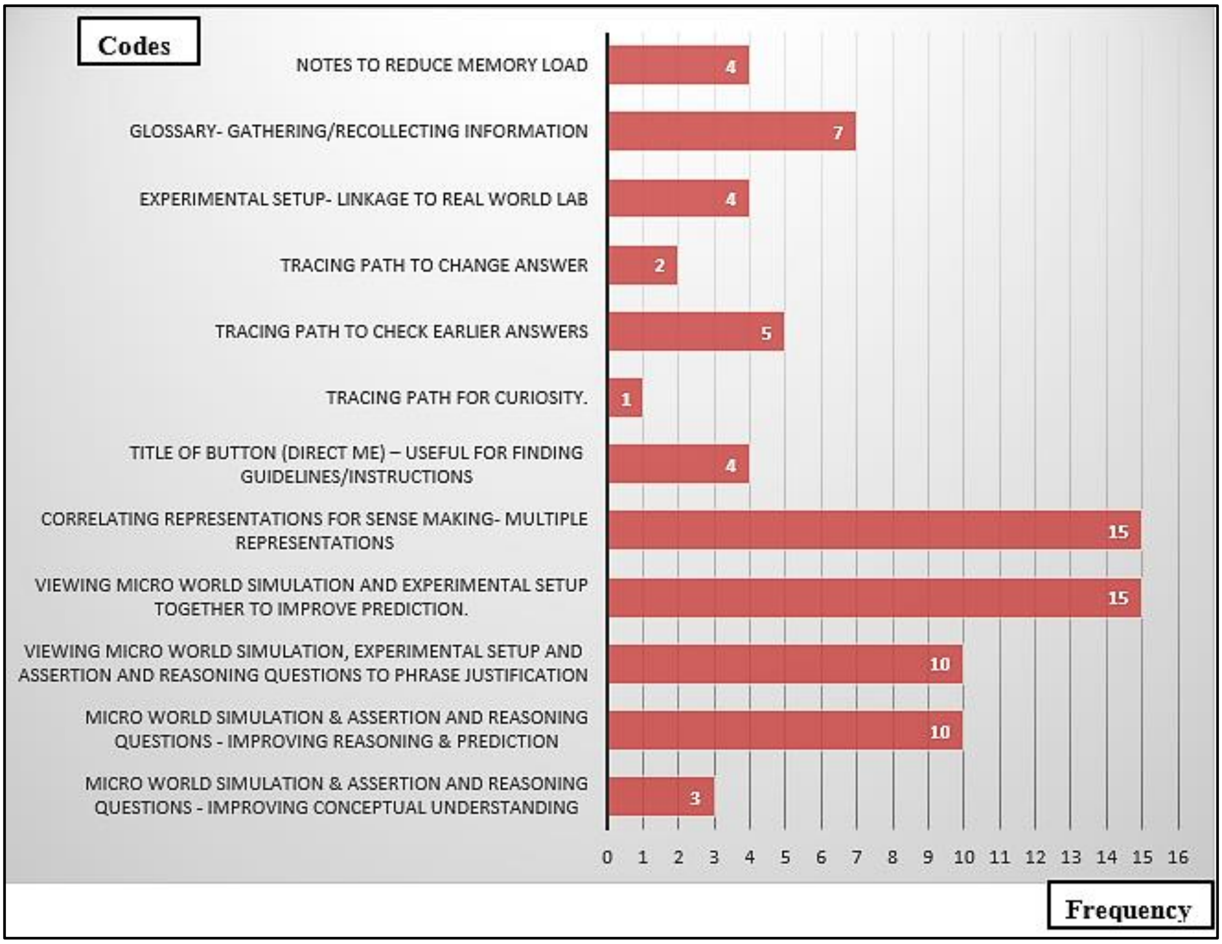


Figure 7.1: Frequency of codes arising for Purpose of using MIC-O-MAP Features

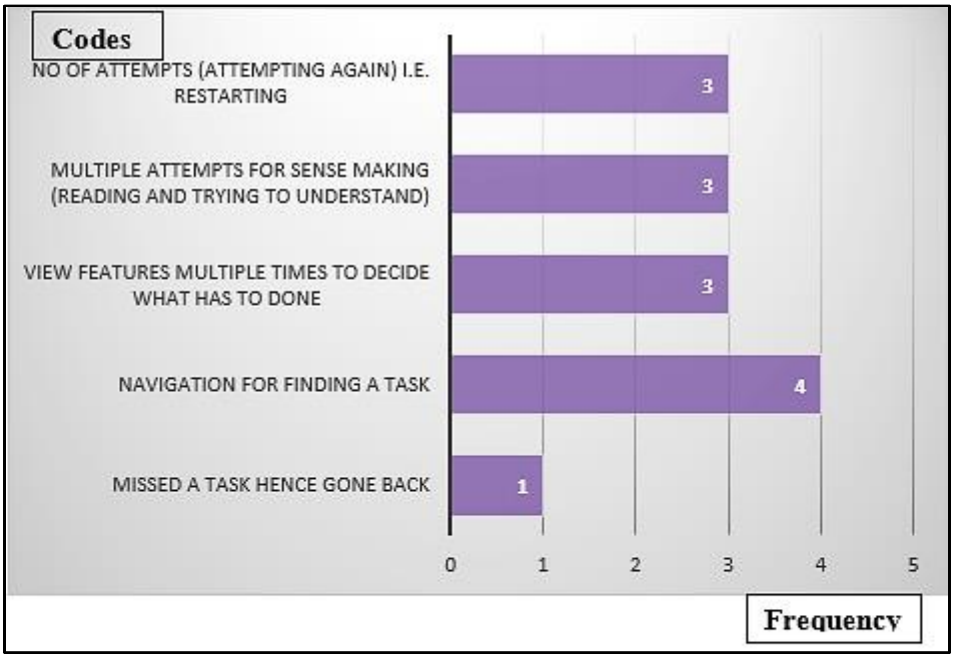


Figure 7.2: Frequency of codes arising for Multiple Attempts

For the responses associated with the categories of usability and time spent, we addressed them in the following manner: Scrolling was stopped in totality and it was ensured that students need not view a scroll bar leading to distraction. The usability of the entire screen was improvised by generating the dialogue with the pedagogical agent in the form of a pop up which can also be closed if not needed for assistance. The response received from participants that the feedback was not noticeable got addressed due to this. Similarly, for the note taking section, we ensured that the scratch pad for writing down notes could be enlarged and moved all over the screen and could also be closed with the information retained when not needed. Fig. 7.4 brings out the difference between these two screen images.

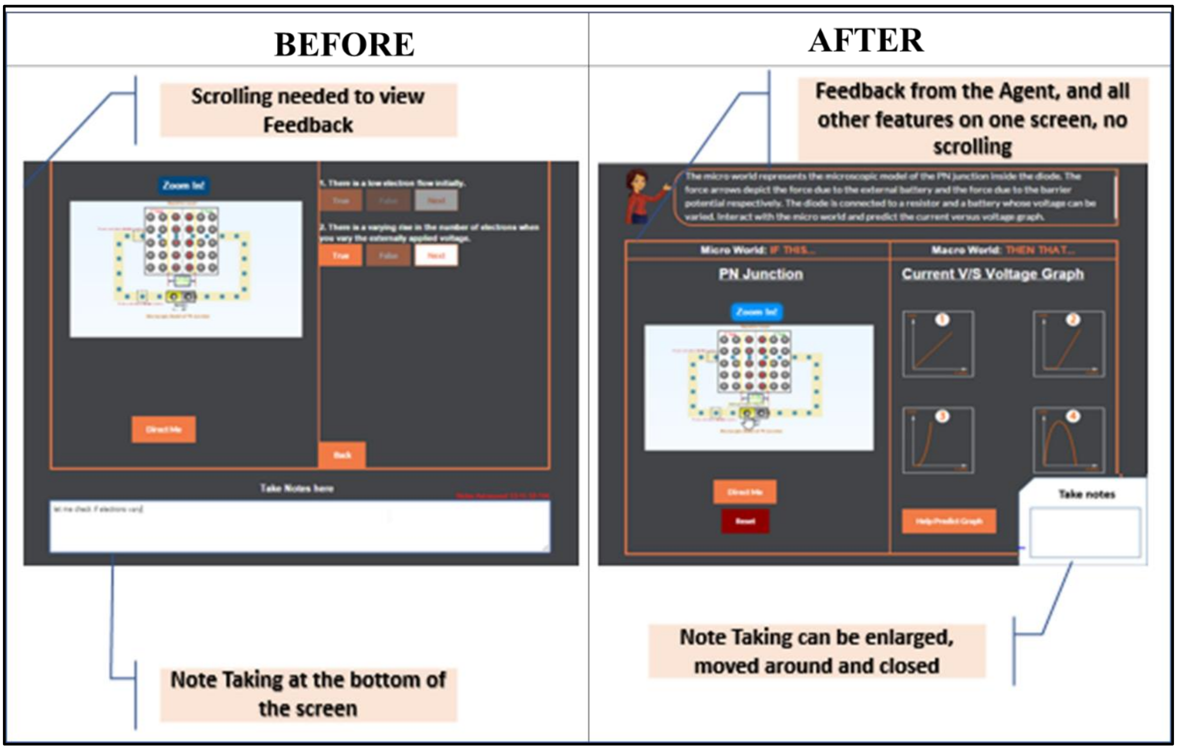


Figure 7.3: Usability based Changes

7.2.5 Findings

On the basis of the results reported in section 7.2.4, it can be inferred that students vary the micro world simulation parameters in order to view its corresponding effect on the elements and processes in the micro world. They are found to be using the assertion and reasoning questions- observation based for improving conceptual understanding. This same combination of features, i.e. interaction with the micro world and answering the assertion and reasoning questions (in this case, observation as well as inference based) has also been used for prediction of a macroscopic outcome and establishing a micro-macro link. Students interact with only the simulation of the microscopic world and its corresponding experimental setup explicitly for predicting an outcome of a macroscopic phenomenon.

Another combination of features being extensively used by students is that of the simulation of the microscopic world, the experimental setup along with the assertion and reasoning questions (observation and inference based questions) for the purpose of phrasing a justification i.e. to strengthen the micro-macro link. A combination three dynamically linked representations i.e. the simulation of the microscopic simulation, the experimental set up and the dynamic graph plotting has been used for a coherent summarization of the concept towards the end of the module when students have completed interacting with all the other features of MIC-O-MAP. In addition to this, the titles of the MIC-O-MAP features have been effectively and aptly used as we had hoped for while students interact with this TEL environment. For example, tracing one's path to check or revise an answer or writing down notes and later using these notes for phrasing a justification for a graphical prediction.

Students are also found to undertake multiple attempts to complete the interaction with MIC-O-MAP. One of the reasons noticed through the screen capture data has been to reach a particular choice of feature. The option of path tracing present in MIC-O-MAP has been used by students for this purpose. The next two instances for which multiple attempts of interaction with MIC-O-MAP have been undertaken by students is for restarting the entire process and going through all of the tasks once again. Overall, we have seen students making a genuine attempt at trying to develop all the subskills of micro-macro thinking using MIC-O-MAP.

7.2.6 Case Studies

We present three illustrative cases of student actions and behaviours as they interact with MIC-O-MAP. The first two cases reported here are those students who developed the micro-macro thinking skill whereas the last case is of a student who did not develop this skill in spite working with the same environment of MIC-O-MAP. An indication of the development of micro-macro thinking skill is their scores on the post-tests. Also, the interview transcript analysis for these chosen students are representative of actions considered to be productive for students while using MIC-O-MAP. The specific interaction paths of the first two learners are different, yet each of these learners was seen to display productive underlying actions to develop micro-macro thinking. One case representative of a typical path undertaken by low scorers is also presented in end. The key point to be noted is that the last student who is a low scoring student, does not perform the productive actions undertaken by the high scoring students. This stands out as evidence for establishing a relation between the productive actions performed by a learner and their development of micro-macro thinking skill.

Case 1: High Scoring Student

Student-1 begins by interacting with the simulation of the micro-world and almost immediately goes to the prediction task. In the prediction task, in which he has to choose one correct graph out of four shown graphs, his cursor moves over and pauses on the graph in each option, however he does not commit to the prediction. He then goes back to the simulation of the micro-world and makes more minute and careful observations. After this, he commits to one graph. He then tries to phrase a justification, comes back to take a look at other options in prediction task, does not change initial answer and continues phrasing the justification. Then he comes to the testing phase, notices that the prediction is incorrect and goes to scaffolding questions. He reads all the options and feedback, deliberately moving and pausing between the words, indicating careful reading. He once again goes back and watches each and every part of the previous screen (as indicated by the cursor movement and corroborated in the interview). He varies all voltage values in the simulation and reads corresponding screen text. Later he comes back and reads the scaffolding questions second time. He repeats the action of going back and forth between the simulation of the micro-world, the prediction question and the scaffolding questions. He then makes a second attempt at predicting a graph and justifying it. This brings him to the summary phase where he writes a correct description of how the different representations are linked to each other. He also reads assumptions listed before stopping.

Given below is his corresponding interaction path:

SIM	PQ	SIM	PQ	SIM	PQ	SIM	PQ	SIM	PQ	JUS	PQ	JUS	RWA	SQ	PQ	SIM	PQ	SIM	PQ	JUS	RWA	SUM	ASM

Here, SIM- Simulation of the micro world, PQ- Prediction Questions, JUS- Justification of Prediction, RWA- Real World Answer, SQ- Assertion and Reasoning Questions i.e. Scaffolding Questions, SUM- Summarization, ASM- Assumptions.

Summarized below is an excerpt from the interview transcript for Student-1*:*

Question by Researcher: Please share your entire experience while interacting with this module.

Answer by Student-1: Understanding improved using MIC-O-MAP as opposed to what is taught in class.

Q: Can you elaborate how you have made a choice of the graph?

A: I have followed whatever was suggested on top [*by the mentor agent in the system*]. It was told that we should observe what happens when the voltage is varied. That is why I clicked on the button indicating + and -. I interacted this for quite some time and saw how the electrons moved. Then I saw that four graph options are given and submit is written, it means that I should choose one of these. So I went ahead and chose one.

Q: On what basis did you chose a graph? You have selected option2, so what was your thought process behind this?

A: When I was playing with this, for starting few values of voltages not many electrons flow. Later they start increasing and move faster with each voltage value.

Q: You have clicked on the help button in after the task of testing your prediction.

A: Yes I was answering each question, combining the feedback with what I observed in the animation and then chose another graph and wrote my answer.

<u>Case 2: High Scoring Student</u>

Student-2 similarly begins by interacting with the simulation of micro-world, varies different voltages and observes the output electron motion for each value. She then comes to the prediction question task. When she realizes that a graph is to be predicted, she goes back and interacts with the simulation of micro-world for a longer time repeating the voltage values and observing onscreen action. After this she goes the scaffolding questions. Her cursor moves along each option of the scaffolding questions, and then she answers each question. She then goes back to the simulation of micro-world as per the suggestions in the feedback obtained in the scaffolding questions. Later she tries to attempt the prediction question once again and chooses one graph. In the justification task, she writes a detailed justification: "… as the voltage is increased step by step, the current increases but after the knee voltage is crossed, the current increased rapidly". Then she goes back to the simulation of micro-world and rapidly varies the voltage and checks what is happening. She returns to the justification task, and she writes an even more detailed justification, noting that when the voltage is zero no electrons are flowing. She also writes that when the knee voltage is crossed, there is a large electron flow for small increases in voltage. She tests her answer with the real world answer, when found correct proceeds to summary and assumptions. After reading the assumptions she comes back to the given real-world experimental view, goes over the graph and goes through the summary once more.

Given below is her corresponding interaction path:

SIM	PQ	SIM	PQ	SIM	PQ	SQ	PQ	GLO	SIM	PQ	JUS	SIM	PQ	SIM	PQ	JUS	RWA	SUM	ASM	RWA	SUM

Summarized below is an excerpt from the interview transcript for case 2:

Question by Researcher: Can you share what you were thinking while the cursor is moving around?

Answer by Student-2: Yes I am trying to decide what I should be clicking on first. I have clicked on PN junction animation.

Q: Please explain why.

A: Because everything is dependent on this, including graphs.

Q: Now before choosing a graph you have clicked on help to predict graph.

A: Yes the graphs were voltage versus current and I am trying to see which one depicts the fact that current increases after a certain value.

Q: Can you elaborate that based on your choice of option how did you decide your answer of the graph?

A: Because I realized after reading the third point that when we increase the voltage of the external battery, that at certain voltage current increases. That's how I decided my choice of a graph.

Case 3: Low Scoring Student

Student 3 begins by interacting with the simulation presented in the micro-world. He proceeds to the prediction question but is unable to make a choice and returns to make more observations in the micro-world. He repeats the action of choosing one graph and going back to the simulation of the micro-word. He tries to proceed without making a prediction. When not allowed to proceed he commits to one choice of graph but is unable to phrase a justification. He goes back and forth between the scaffolding questions and the simulation in an attempt to copy the on screen text. Finally, post reaching the testing phase, notices that the prediction is incorrect but instead of attempting a revision proceeds to the summary and stops.

Given below is his corresponding interaction path:

SIM	PQ	SIM	PQ	demo	PQ	JUS	PQ	JUS	SQ	JUS	SQ	SIM	JUS	RWA	SUM

Summarized below is an excerpt from the interview transcript for case 3:

Question by Researcher: Can you explain the reason behind alternating between the simulation and the prediction questions?

Answer by Student-3: I am trying to think which is the correct option from the four graphs presented.

Q: How did you arrive at your final choice of graph.

A: Actually I wanted to go ahead to the next task, which is why I picked one of the graphs.

Q: Okay, after making your choice how did you phrase the justification? You seem to viewing the features of scaffolding questions and the simulation.

A: I had not thought much before choosing the graph which is why I have copied the on screen text from the scaffolding questions to proceed.

Q: You seem to be choosing one of the options in order to proceed to the next task, am I right?

A: Yes, I wanted to see what is there next. My graph which I had chosen did not match with the real world answer so I went ahead to view the summary.

7.2.7 Discussion

On the surface level it seems like the paths taken by Student-1 and Student-2 are different. Student-1 attempted the task of making a prediction almost right after starting the activity, got the prediction wrong, and interacted with the micro-world simulation and scaffolding questions multiple times for revising his prediction as well as for phrasing a justification. In contrast, Student-2 spent a lot of time initially interacting with the simulation to make careful observations in the micro-world, then used a combination of the simulation results and scaffolding questions in order to make the prediction and improvise the justification. Student-2 got the prediction correct in the first attempt. However, each of these learners displayed common productive actions in which they intentionally used MIC-O-MAP features to establish a micro-macro link. These actions were not noticed in the interaction undertaken by the low scoring student. Below we show some instances of our codes and analysis of the interleaved transcript for high scoring students. This was done to extract out productive actions of the high scoring students.

i) From the screen-captures, we found that students interacted with the micro-world simulation multiple times and with greater detail in successive visits. Visits to the simulation alternated with spending time on the prediction question and graphs of current-voltage readings (macro-world). During the interview, students corroborated that the reason for multiple visits and large time spent on the micro-world simulation was to reason through the predictions of the macro-world processes. For example, Student-2 reported that "*I clicked on PN junction animation. Because everything is dependent on this including graphs"* We gave a code of 'micro-macro together to improve prediction and reasoning'. We infer that students interact with the micro-world simulation in a more detailed manner in order to make an informed prediction of the macro-world process.

ii) The screen-captures showed that students alternated between the scaffolding questions that led them towards the reasoning behind the prediction and the micro-world simulation. The interviews provided quotes such as *"I wanted to see what is mentioned in Help to predict with respect to the graphs mentioned here […] the mentor (agent) suggested that we interact with the simulation while answering the scaffolding questions."* We gave a code of 'Simulation and scaffolding questions – to help reason and predict'. We infer that students use the scaffolding questions as prompts when they are unable to make a prediction and the types of scaffolding questions with links to the micro-world simulation are designed so that to be able to provide students guidelines for helping them solve the complex task.

iii) Screen-capture data showed that students revisited the micro-world simulation multiple times during the process of writing the justification for their prediction. After each interaction with the simulation, the justification was refined and improved. In the interviews students reported that "*I realized that when we increase the voltage of the external battery, that at certain voltage current sharply increases. That's why the graph is what I chose."* We infer that when students write a justification after making more careful observations to phrase it and later repeat this exercise to improvise or ensure that justification written is correct.

iv) The screen-captures showed that students spend time on the integrated summary which contains both the micro-world simulation and the macro-world processes. A code of 'co-relating representations for sense making' is given when students report that *"Yes this view of having all three together is much better, with the diagram and graph. I'm trying to write whatever I have understood till now. Having the three representations on top is useful so I can relate them to each other."* We infer that co-relating the multiple representations in the summary task for sense making and improving their understanding of the topic.

Table 7.2 summarizes the actions of learners considered to be productive as they interact with MIC-O-MAP learning environment to establish micro-macro links, and connects the design of the learning environment that may have supported these actions.

Table 7.2: Student Actions which are considered to be 'Productive'

Learner productive actions	**How does the learner action help establish a micro-macro link?**	**MIC-O-MAP design supporting micro-macro link**
When unable to make in informed prediction, learners undergo multiple rounds of interaction with all features of learning environment.	The various types of scaffolds are well designed to be able to provide students specific guidelines for helping them get unstuck. Further these scaffolds lead students to do productive actions while exploring micro world. Scaffolds not just leading students to correct answer but to act like scientists and practice thinking skills.	Scaffolding questions aid in identifying key areas in the micro-world and use these observations in predicting the graph in the macro world.
In order to establish a micro-macro link while phrasing justification, learners manipulate variables in the micro-world simulation and establish correlation with graphical outcome in the macro-world.	When asked to write a justification for the macro-world prediction, students make more careful observations in the micro-world simulation, and later repeat this exercise multiple times to improvise or ensure that justification written is correct.	The pedagogical agent in MIC-O-MAP encourages learners to make careful observations in the micro-world simulation while constructing the justification for the macro-world prediction.
For a complete understanding of the topic, learners simultaneously interact with the dynamically linked multiple representations to summarize understanding.	Students correlate the multiple representations in the summary task for sense making and improving their understanding of the topic.	The summary section of MIC-O-MAP encourages learners to integrate various representations and write the summary of the physical process, after varying parameters and correlating multiple linked representations.

7.3 Summary and Implications

We wanted to identify productive actions undertaken by students because enactment of these actions are found to be aiding in establishing a micro-macro linking by using the design features of MIC-O-MAP for the precise goals for which they had been incorporated into the learning environment. Table 7.2 establishes these connections between the action of the learner, manner in which the action helps in developing a micro-macro link and how the design of MIC-O-MAP supports establishment of this link. The productive actions identified enable learners to effectively use the rich features and scaffolds of the learning environment in order to achieve the learning objectives of establishing connections between the micro-world dynamics and the macro-world processes of physical phenomena. As an answer to RQ 3, we highlight the connection between learners' productive actions and the design of MIC-O-MAP. These provide an insight into the process of acquiring micro-macro thinking:

- Guided Investigation and wayfinding

When a learner is stuck in navigation or thought process enabling an informed choice of prediction, the constructive dialogue with the pedagogical agent aids in locating key areas to be observed in the simulation of the micro-world. A combination of these features is being used by learners for carrying out a scientific investigation in MIC-O-MAP and locating a path leading to the goal of micro-macro skill development.

- Accurate articulation and establishment of micro-macro link

Learners use the conceptual scaffolds for establishing or strengthening the micro-macro link after committing to a graphical prediction in the macro-world. This is done via a dialogue with the pedagogical agent who provides scaffolds. Control is given to the learner who is able to decide how to use the scaffolds present in MIC-O-MAP in order to analyze the graphical curves and observations in the micro-world and later link the two. This is done when they justify their commitment to a certain graphical outcome. Students are able to take pauses in between their learning curve and reflect on their choices as well as the link establishment between the two worlds.

- Activities based on dynamic linked representation for holistic sense making

After interacting with various activities in the learning environment, a complete summary is written by learner post interacting with all representations present on the screen. Students are allowed to control the pace of the dynamically linked representations while interacting with MIC-O-MAP. While they do this, they are able to understand the on-going process in the micro world and the tangible outcomes in the macro world. Establishment of this correlation is essential for their conceptual understanding as well as transfer of this knowledge in future learning.

The analysis of this study is focused only on students who did develop micro-macro thinking skills, i.e. those who scored high on the post-test that included questions on relating micro- and macro- worlds in a new topic. Our rationale was to attempt to identify if there were any common behaviours and actions of such students which may have led to increased learning. We have also noted that these actions were absent in low scoring students, the case study from section 7.5 providing an example of the contrasting behavioral patterns. We found a common set of actions in the behavior of high scoring students useful in the micro-macro thinking skill development, i.e. the set of productive actions. Post extracting out the actions found to be productive while working with MIC-O-MAP, we will now be providing an overall discussion of the thesis work and recommendations for interaction and working with MIC-O-MAP in chapter 8.

Chapter 8

Overall Discussion & Future Work

In this thesis, we reported two design-based research (DBR) cycles of design, implementation and evaluation to develop a TEL environment, MIC-O-MAP, to develop micro-macro thinking skills in undergraduate science and engineering students. This DBR approach helped us identify features and learning activities in MIC-O-MAP that led to productive learning, such as, multi-level linked representations and conflict resolution questions with customized feedback which aid students in establishing a link between the microscopic and macroscopic worlds. Findings from the study gave rise to specific learnings for example, the role of the pedagogical agent to ease assessment anxiety related to MIC-O-MAP question prompts, and instead transform it into a mentoring process. The iterative and closely-linked process involving the design (and redesign) of MIC-O-MAP and its evaluation formed the backbone of our research process. The detailed qualitative interaction analysis led to insights in terms of the productive actions taken by students who achieved micro-macro thinking after interacting with MIC-O-MAP.

8.1 Answering the Research Questions

The first research question, which was under Theme 1: Learning of micro-macro thinking using MIC-O-MAP was **RQ1: Do students who interact with MIC-O-MAP develop micro-macro thinking abilities?**

RQ1 was answered in both the DBR cycles. Overall, we find that students who learn using MIC-O-MAP are found to develop micro-macro thinking skills. This has been evaluated multiple number of times. Initially, In DBR cycle 1, a controlled study (Study 1) was carried out where MIC-O-MAP was tested against a traditional simulation which did not have scaffolds present in MIC-O-MAP and there was statistically significant improvement in the scores of students learning with MIC-O-MAP. In the next DBR cycle, when the features of MIC-O-MAP were revised, a single group pre-post test study was carried out (Study 4) to find that the difference between the pre-test and post-test scores of students learning with MIC-O-MAP are statistically significant with the post-test scores higher than the pre-test scores. This strengthened the finding that students learning with MIC-O-MAP develop micro-macro thinking skills. The same research design was carried out to test 3 more MIC-O-MAP modules (Study 6) with the result also turning out to be same i.e. the difference between the pre-test and post-test scores were statistically significant with the post-test scores higher than the pre-test scores. The students participating in these studies were different each time but the difficulty of the topic was on par for all of the modules being tested. Similar results have been reported in research which says that micro-macro thinking skill is developed is when learners understand and to use relations between observed phenomena at the macroscopic level and the models of invisible particles such as atoms or molecules at as microscopic level (Meijer, 2011).

A repeated measures study was also carried out (Study 7) to examine the student performance on the micro-macro thinking skill test post exposure to multiple modules of MIC-O-MAP. Once again, it was found that over all there is a difference in the pre-test and post-test scores of these students post interaction with each module. When a pair wise examination was carried out, we found that even if there exists a variation in the test scores, it lays between the second highest and highest value on the rubric. There is never a fall to the lowest score. This is an implication for the fact that over a period of time students go on improving in their micro-macro thinking skills. A possible reason for this finding could be that there is a ceiling effect since the difficulty level remains the same.

Now that we knew that students learning with MIC-O-MAP develop micro-macro thinking skills, we also wanted to ensure that students are able to interact with MIC-O-MAP with high degree of usability. The reason for this is that MIC-O-MAP is a semi open ended environment and students are provided with instructions but the path of interaction to be undertaken is at the discourse of the learner. In order to do this, under Theme 2: Interaction of learner with MIC-O-MAP, we aimed to find an answer to **RQ 2a: What interaction paths do students follow as they learn with MIC-O-MAP?** A qualitative study was undertaken (Study 2) wherein their screen capture log was analysed using the method of clickstream analysis. Our goal was to examine the interaction paths of students who scored high versus those students who scored low on the post-test for RQ1. A subset of the sample from Study 1 was chosen for this study. We found that there existed a difference in the learning paths of high scoring and low scoring students. It was found that high scoring students have an underlying purpose whenever they visit any feature of MIC-O-MAP, based on this purpose, for example: if the purpose is to strengthen a micro-macro link, they undertake a combination of features such as the simulation of the microscopic world, the experimental setup along with the assertion and reasoning questions (observation and inference based questions) for the purpose of phrasing a justification i.e. to strengthen the micro-macro link. These students undertake multiple iterations of interacting with MIC-O-MAP features due to which they interaction path depicts a back and forth interaction activity. In contrast to this, students who score low are found to be keen on completing any given task rather than indulging in sense making and combining features for the same. These students interact with one feature after another until they finish interaction with the entire module. They are also found to treat the assertion and reasoning questions as a summative evaluation instead of scaffolds for improvisation of their predictions and answers. They interaction path in very linear with each feature of MIC-O-MAP viewed one after another. This aspect of finding a path which is beneficial for all learners is also termed important by adaptive navigation support (ANS) which is aimed to help students to find an "optimal path" through any learning material [Brusilovsky, Eklund, & Schwarz, 1998].

After gathering insight into the interaction paths, we aimed at going on level deeper in this interaction path taken by students and undertook purposive sampling of the high scoring students (N = 10) and transcribed the entire on screen activity (Study 3). This was done in order to answer **RQ 2.b: What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?** under Theme 2: Interaction of learner with MIC-O-MAP. The entire transcript was later coded and categorized in order to find the difference in the time spent on each activity present in MIC-O-MAP and the frequency of features visits – analysed in accordance with purpose of visit. It was found that on an average, all the students spent around 30 minutes interacting with all the features of MIC-O-MAP. However, when the time spent on activities by high scorers versus low scorer was compared, it was found that there was a statistically significant difference in the time spent for activities like prediction questions, usage of experimental results for comparison and judgment and assertion and reasoning questions. To understand possible reasons for the different time spent by students, we compared the interaction behaviour of students from the low and high scoring groups respectively i.e. a frequency analysis of each code related action being performed in the screen capture recording. We found a stark difference in the reasoning method of these two types of students- high scorers and low scorers. Examples include: Attempts to predict based on micro-macro link –High scorers: 5 times more than low scorers OR Attempts to follow question prompts- High scorers: twice more than low scorers.

Research says that it takes a good design to make good technology based instruction [Dempsey & Van Eck, 2002] which is why we wanted to gather more deep insight into the way in which MIC-O-MAP features are being used for developing micro-macro thinking skills. Students from the same academic background and having the same familiarity with technology were present in the experimental group and all of them received MIC-O-MAP as the learning material. Inspite of this, some of these students are receiving high scores where as some are receiving low scores. Hence, we focus our attention on high scoring students and try to make explicit the reasoning behind their decisions as they undertake an interaction path. We analysed the number of visits to each feature of MIC-O-MAP and the action performed on visiting a particular feature (Study 3). For example, even though the number of visits to Prediction Question feature was 132, an informed choice of prediction was made only 11 times. This calculation was executed for all crucial features of MIC-O-MAP and it was found that there exist learning related problems while interacting with MIC-O-MAP. Possible reasons based on the design perspective were found for these learning problems.

Under Theme 2: Interaction of learner with MIC-O-MAP, RQ 2.c: What was the effect of the improvised design on students' interaction with the various features of the learning environment? was investigated by analysing the screen capture log of the high scoring students who have interacted with the second version of MIC-O-MAP (Study 5)**.** We wanted to check if the frequency analysis of the purpose of visit versus feature visit are mapping to each other. It was found that for high scorers who interacted with the revised version of MIC-O-MAP, the number of visits to a feature was quite close to the number of visits to a feature based on a purpose. Example: Number of visits to Prediction Question feature: 89 and Making an informed choice of prediction: 37 times. This is to say that students visited the feature of ‘Prediction Question’ 89 times but made an informed choice of prediction 37 times. This was now contrasted with this analysis from cycle 1. For the same feature, earlier analysis showed the following finding: Number of visits to Prediction Question feature: 132 and Making an informed choice of prediction: 11. Based on this, it can be said that there exists a higher number of attempts in establishing a micro-macro link, in following the pointers given in the feedback of the assertion and reasoning questions, and the navigation difficulty appears to have eased out due to enabling path tracing and retention of the choices and text entered by the student. On the basis of this comparison and analysis, it can be confidently claimed that the pedagogical features identified by us for designing the learning environment of MIC-O-MAP can be used for developing micro-macro thinking skills.

The last study of undertaken in this thesis was a qualitative study (Study 8) with 12 students as the sample, under Theme 3: Process of acquiring micro-macro thinking and in an attempt to answer **RQ 3: How does student interaction with MIC-O-MAP lead to development of micro-macro thinking skills?** Purposive sampling (N=10) was carried out to identify the high scoring students and semi structured interviews were carried out which were further transcribed and coded in order to identify the thought process behind the actions performed by students while interacting with MIC-O-MAP. These actions performed by high scoring students are titled ‘Productive actions’. Productive actions are actions which enable learners to effectively use the features of MIC-O-MAP for achieving the objective of connecting the micro-world dynamics and the macro-world processes of physical phenomena. Examples of the actions are: undertaking multiple rounds of attempting all tasks when unable to predict, interacting with the micro world parameters when asked to establish a micro-macro link and simultaneous interaction with dynamically linked multiple representations. High scoring students perform these where as they are absent in the interaction process of low scorers.

8.2 Claims

Based on the results and findings from the different experiments carried out with MIC-O-MAP, we claim the following:

1. Students who work with MIC-O-MAP develop micro macro thinking skills.

Evidence: Two DBR cycles were undertaken before finalizing the instructional design document template for the development of future modules. In the first cycle, a statistical difference in post-test scores of the experimental and control group wherein the experimental group performed better than the control group on the test measuring the micro-macro thinking skills. Post examining the results from qualitative studies about the interaction path followed by students while working with MIC-O-MAP, a revised version of MIC-O-MAP was designed and a single group pre-post research study was conducted. A statistical difference in the pre-test and post-test scores measuring micro-macro thinking was found. 3 modules of MIC-O-MAP were tested using the single group pre-post test research design and each time the post-test scores were statistically significantly higher than the pre-test scores.

A repeated measures design was also conducted in order to analyse student responses to the MIC-O-MAP modules over a period of time. Over a period of 1.5 days, students interacted with 3 modules and a statistical difference in pre-post test scores was found in the results. Although, a variability was also detected in the statistical differences in the pair wise mean scores. The sub skills of Observe and Testing showed a constant increase in the scores as students interacted with more number of modules where as for the sub skills of Explain and Predict, at certain instances a dip was found in the scores. The good sign inspite of this finding was that the variation in the scores remained in the range of 2 -3 on the scale of the rubrics. An indication of the skill development can be confirmed because the scores remain either on the second highest or the highest score.

2. There exists a difference in the learning paths of high scoring and low scoring students- with the high scoring students using MIC-O-MAP feature combinations for sense making and skill development leading to them going back and forth between these features. In contrast to this the path of low scorers is linear where they interact with one feature after another till the end of the module.

Evidence: Learning paths plotted for high as well as low scoring students. It was found that the students who score high on the micro-macro thinking skill test are found to repeat interaction cycles with a combination of MIC-O-MAP features depending upon the goal. For instance, they read the learning objective and then proceed to varying parameters in the micro world and making careful observations, if unable to determine which area to direct their focus on, then they answer the observation based assertion and reasoning questions and then repeat an interaction with the simulation of the micro world. When the observations are complete, they finally attempt the prediction question after they are sure about the observations recorded by them. Similarly, they repeat cycles of feature combinations in MIC-O-MAP depending on whether they want to establish the micro-macro link, strengthen it or integrate this link.

In contrast to this, students who score low on the test measuring micro-macro thinking are found to follow a linear path and answer each task one after the other in an attempt to complete every task and finish interacting with the MIC-O-MAP module. Too much of an effort is not seen in instilling thought into the interaction path, instead the feature presented to them is answered in the order in which it comes. On account of this, at times these students miss answering the answering the assertion and reasoning questions which could have helped them in developing each sub skill of micro-macro thinking.

3. High Scoring students build their reasoning and predict an outcome using the conceptual scaffolds and dynamically linked representations.

Evidence: Semi structured interviews were conducted with high scoring students and they were asked to mention, rather defend each choice made by them. While interacting with MIC-O-MAP the on screen activity was recorded and later replayed in front of them. Students were asked to explain the entire thought process behind the interaction path followed by them, the goal which they had in mind and how the feature chosen by them would aid in achieving the said goal. The same process was repeated for the low scorers and case studies of 2 high scorers and 1 low scorer were elaborated to depict the contrast in the thinking process. We inferred 3 productive actions which can be followed by students while interacting with MIC-O-MAP. Examples of the actions are: undertaking multiple rounds of attempting all tasks when unable to predict, interacting with the micro world parameters when asked to establish a micro-macro link and simultaneous interaction with dynamically linked multiple representations.

8.3 Generalizability

8.3.1 Generalizability of Domain

Topics which have concepts consisting of multiple levels (ie a micro and macro level) are suitable for learning micro-macro thinking using MIC-O-MAP. In such topics there will be important variables at the macroscopic level (ie observable/ measurable) and corresponding variables at a microscopic level (often invisible) which explain the mechanism for the macroscopic variable behaviour. Example of such a topic in biology is to study the effect of different temperatures and pH on the activity of salivary content, amylase on starch. The macroscopic parameters which can be measured are temperature and pH level and its effect can be observed on an enzyme called salivary amylase which hydrolyses starch into maltose. In chemistry, qualitative analysis of carbohydrates can be conducted by performing different tests. For example, in a Benedict's test, in a test tube, 1-2 ml of Benedict's reagent is added to 1-2 ml of aqueous solution of the sample and this test tube is kept in a boiling water bath. A reddish precipitate indicates the presence of a reducing sugar. This the experiment to be performed and observations to be recorded in the macroscopic world where as the reason for getting a reddish precipitate (establishing the micro-macro link) is carried by writing the chemical reaction of the Benedict's reagent with carbohydrates to form cuprous (copper (I) oxide which is red in colour and seen as a precipitate. An example in physics is to find the velocity of sound in air at room temperature using the resonance column by determining two resonance positions. Tuning forks on known frequency are used as the macroscopic parameter which can be varied and resonance can be explained using stationary waves at the microscopic level.

We have tested the MIC-O-MAP instructional design document template in one additional domain of biology. The topic is to study pollen germination on a slide. The macroscopic parameter which can be varied is the pollen germination medium. In the macro world, the pollen germination medium is present on screen. Ingredients are also mentioned i.e. 10 grams sucrose, 10 milligrams boric acid, 30 milligrams magnesium sulphate and 20 milligrams potassium nitrate in 100ml are dissolved in distilled water. Students are allowed to take this nutrient solution using a dropper and put two drops on a clean glass slide. They then have to take a mature flower and dust a few pollen grains from its stamen on to the drop on the slide. Then place the glass slide on the stage of the compound microscope and observe the slide through the microscope regularly. A clock is present for depicting the time.

In the microscopic world, what they observe is that the pollen grain is uninucleate (has one nucleus) in the beginning. At the time of liberation, it becomes 2 celled, with a small generative cell and a vegetative cell. In the nutrient medium, the pollen grain germinates. The tube cell enlarges and comes out of the pollen grain through one of the germ pores to form a pollen tube. The tube nucleus descends to the tip of the pollen tube. The generative cell also passes into it. It soon divides into two male gametes.

Students have to establish a micro-macro link in order to understand how a pollen germinates. In flowering plants, however, the ovules are contained within a hollow organ called the pistil, and the pollen is deposited on the pistil's receptive surface, the stigma. On the stigma, the germination of pollen grains begins by absorption of water and nutrients and the pollen grain produces a tiny pollen tube through the style to the ovary. The tube cell enlarges and comes out of the pollen grain through one of the germ pores to form a pollen tube. The tube nucleus descends to the tip of the pollen tube. The generative cell also passes into it. It soon divides into two male gametes. In an act of double fertilization, one of the two sperm cells within the pollen tube fuses with the egg cell of the ovule, making possible the development of an embryo, and the other cell combines with the two subsidiary sexual nuclei of the ovule, which initiates formation of a reserve food tissue, the endosperm. The growing ovule then transforms itself into a seed. We can stimulate pollen germination in vitro with the help of a nutrient medium.

8.3.2 Generalizability of Context

MIC-O-MAP has been designed for self-learning by a student but can also be used in an instructor led classroom or a laboratory. Students can interact with MIC-O-MAP and work through the modules in a classroom or lab where the topic is being discussed. The teacher can decide how to integrate an interaction with MIC-O-MAP into the lesson plan, for example, as a 30 min pre-lab activity, or during in-class problem solving. The teaching learning strategy would be similar to that discussed as a recommendation in section 8.3 (a). Either students can be given the TEL environment of MIC-O-MAP to interact with as a whole in the beginning or end of a class/lab session. Another way to integrate this to ask students to pause and interact with MIC-O-MAP at multiple instances decided by the teacher. The stages of establishing, strengthening and integrating the micro-macro link can also be explained to the students, enabling them to interact with MIC-O-MAP keeping a goal in mind.

8.3.3 Generalizability of Technology

MIC-O-MAP has been developed primarily using interactive simulations to depict the microscopic and macroscopic phenomena. But the pedagogical design template for MIC-O-MAP has also been tested with a solution based on Augmented Reality (AR) technology. Augmented Reality (AR) is a real-time device mediated perception of a real-world environment that is closely or seamlessly integrated with computer generated sensory objects [Camba, et.al., 2014]. It is a natural way of exploring 3D objects and data, as it brings virtual objects into the real world where we live. The possibilities of AR include information visualization, navigation in real-world environments, advertising, military, emergency services, art, games, architecture, sightseeing, education, entertainment, commerce, performance, translation and so on. Virtual objects used in Augmented Reality Systems may include text, still images, video clips, sounds, 3-dimensional models and animations. Ideally these virtual objects will be perceived as co-existing within a real world environment. The basic hardware requirements of an Augmented Reality System include [Azuma, 1997; Billinghurst et.al., 2001]:

- The presence of a video camera to capture live images
- Significant storage space for virtual objects
- A powerful processor to either composite virtual and real objects or display a 3d simulated environment in real-time
- An interface that allows the user to interact with both real and virtual objects.

Examples of AR include Wikitude [http://www.wikitude.com/] which allows information about sights, restaurants and events to display in a text layer on top of the camera viewport. More examples are MARS (Mobile Augmented Reality System) [Feiner et.al., 2001], CyberCode [Rekimoto & Ayatsuka, 2000] and games like ARQuake system [Piekarski & Thomas, 2002]. In engineering education, the development of spatial abilities has been acknowledged by many authors as a factor that is strongly related to higher-level reasoning skills, critical thinking, creativity, and success in STEM (science, technology, engineering, and mathematics) fields [Camba et.al., 2014]. Specific examples of Augmented Reality (AR) applications in this field include the development of a video game for assembling and analyzing structures using virtual LEGO blocks or an AR system to study graphic projection methods. Sometimes these two types of Augmented Reality are called "Marker and Markerless AR". "Marker AR" technology uses fiduciary markers as a point of reference that defines the position, orientation and scale of an AR object in the physical world, Eg: bar code, QR code. "Markerless tracking is where AR is used to track objects in the real world without using special markers, Eg: natural printed AR, a painting or real life marker like human face [Geroimenko, 2012]. Augmented Reality is the type of 'mixed reality' whereby digital content is infused into the real environment, as opposed to Augmented Virtuality where real world content is transplanted into a Virtual Environment. Thus Augmented Reality can be seen as a conduit for bringing together education in virtual environments and the real world [Milgram et.al., 1994].

A pilot study was conducted with three students to contrast the findings from the studies with the TEL environment of MIC-O-MAP with the technology of Augmented Reality. Students from first year graduation course were chosen are participants for this study. Initially students were provided with the simulation of a reversed biased PN junction and were asked to answer pre-test questions. They were then provided with the circuit diagram for the experiment of forward biased PN junctions. They were also provided with a bread board based circuit in a real world laboratory as shown in Fig. 8.1. along with QR coded stickers created using zap code software. Students were asked to download the applet of zap codes in their smartphones and focus the camera of the smart phone on the sticker after they have assembled the circuit using the bread board and other circuit components.

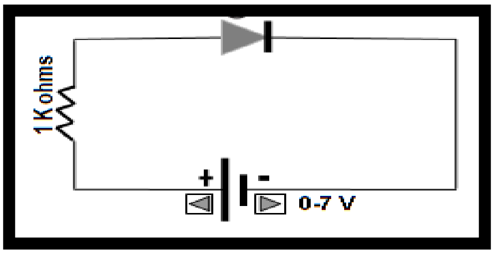


Figure 8.1: Circuit Diagram for PN Junctions topic

Once they set a voltage value using the battery they were able to note down live readings of voltage and current as well as watch the electron motion in the micro world simultaneously using the zap code software. Once they performed this exercise for all voltage values they were asked to interact with the MIC-O-MAP software in which they could directly procced to the feature of prediction questions. They were allotted a total time period of 2 hours to work with this entire set up. They were given no additional information, but their clarification questions were noted. Then they worked on the post-test and the average time required was noted. Finally, students were asked about their perceptions on the learning environment and if working with the laboratory based circuit and the MIC-O-MAP aided in improving their understanding. Questions such as, “Did watching the electron motion simultaneously with the meter readings help in predicting a graph? If yes in in what way?” “Did working with the laboratory based circuit in addition to the technology based environment improve your understanding?”

We found that the mean time taken by students to interact with the environment as well as the breadboard based circuit was 1 hour 45 minutes. The post-test scores were found to be higher than the pre-test scores. But these scores are on par with the results found with the studies of MIC-O-MAP. Findings from the short interviews suggested that watching the electron motion simultaneously with the meter readings enhanced their interest level but at the same time, one student reported that she spent more time in troubleshooting the circuit connections. Working with the TEL based environment was reported to be easier. One possible reason for this could be that students spent more time in troubleshooting the circuit than on keeping the focus on watching the microscopic world in parallel with the real world laboratory.

8.4 Limitations

MIC-O-MAP modules have been tested only with Urban students who are fluent with English. It will be a challenge for students from rural areas or students who are not fluent in English to use this learning environment. A reason for this being that MIC-O-MAP is an environment basically designed for the context of self-learning due to which clarification questions cannot be asked to any mentor/authority and peer learning was also not allowed in all of the studies with MIC-O-MAP. Another limitation of this research work is that students are assumed to be familiar with technology. We have not assessed every participants ease of use of a technology based environment. Students confidence levels and attempts to undertake multiple attempts can interaction can get affected by this aspect.

The sample chosen in all the empirical studies in this thesis is first year graduation students. Thus, the generalizability in student characteristics is restricted to undergraduate students who are novices in this chosen domain. Another limitation is that if students are not motivated or interested in self-learning then MIC-O-MAP may not be useful to learn micro-macro thinking.

In terms of methodology, we have used mixed methods wherein quantitative studies are followed by qualitative studies. While this research method allowed us to determine whether MIC-O-MAP is effective in developing micro-macro thinking skills, we have not explored the cognitive aspect of this skill development. Richer and deeper qualitative studies will be needed to understand how learners' interaction with the technology based learning environment affects their cognitive structures. This will help in understanding '*why'* MIC-O-MAP was effective in developing micro-macro thinking.

Another methodological limitation is that MIC-O-MAP was implemented only for short durations (1 hour). Students were allowed to stop interaction with MIC-O-MAP even before 1 hour if they felt satisfied and confident. Only for the repeated measures study students interacted with 3 modules for a period of 1.5 days. Further, the testing was done immediately after students interacted with MIC-O-MAP. There was no study in this thesis that can claim that students are able to apply micro-macro thinking after an elapsed time beyond their interaction with MIC-O-MAP. More implementation and evaluation is required to test for how long students need to initially interact with MIC-O-MAP and for how long they are able to retain the skill and further even apply it in other domains.

Even though we suggest that MIC-O-MAP can be used pre-lab activity, or during in-class problem solving, teacher training for the same purpose has not been carried out. Teachers will need to be trained in order to redesign their lesson plans and incorporate MIC-O-MAP into their strict time schedules.

All the MIC-O-MAP modules have been developed for topic that have a single link between the micro and macro world. But for complex topics such as transistors or MOSFETs, where multiple micro-macro links may be present, the development of these modules has not been attempted. There exists a possibility that the instructional design document template will need slight alteration depending upon the number of micro-macro links.

Ideally, the closest set up to develop micro-macro thinking would be to actually perform the experiment in a laboratory which has been briefly attempted in section 8.3.3 but extensive testing in this area will be more desirable wherein MIC-O-MAP can be integrated into a setup alongside a laboratory based experiment.

8.5 Recommendations

The detailed qualitative interaction analysis undertaken during this research work was invaluable, and hence we recommend such an analysis to be part of the evaluation of any TEL environment designed by researchers. Based on the findings from experiments and literature we propose the following guidelines for different stakeholders, namely: students interacting with MIC-O-MAP for micro-macro thinking skill development and teachers/researchers who would like to create more modules of MIC-O-MAP.

a) Recommendations for students interacting with MIC-O-MAP

While interacting with MIC-O-MAP, Fig. 8.2 shows an effective path which can be followed in order to ensure that they receive maximum benefit from the MIC-O-MAP TEL environment:

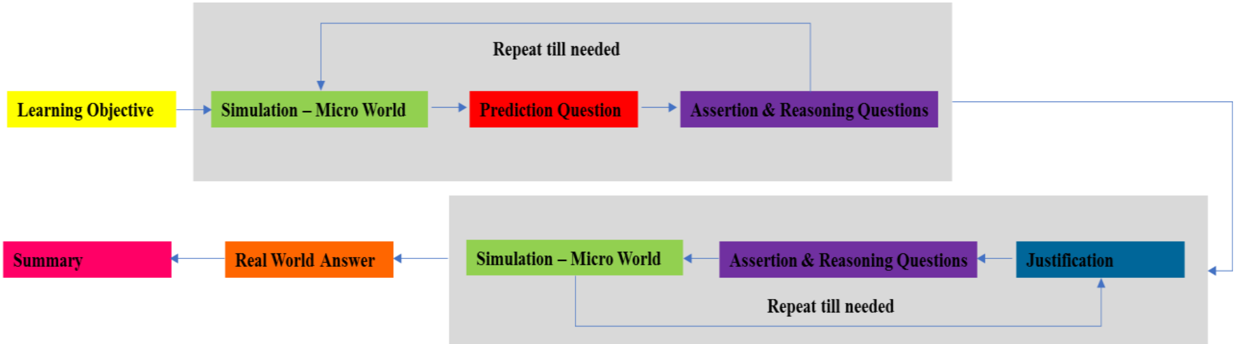


Figure 8.2: Effective Interaction Path

- In order to establish a micro-macro link, students should vary parameters in the simulation of the microscopic world and record their observations, attempt answering the prediction question of the macroscopic world, if unable to predict an outcome then answer the observation based questions under the tab of ‘Direct Me’ or ‘Help to Predict Graph’ i.e. the assertion and reasoning questions. Based on the feedback from the assertion and reasoning questions, students should identify the area pointed out and carefully observe that area of the simulation of the microscopic world. This cycle of interaction with the simulation of the micro world, attempting the prediction questions and answering the assertion and reasoning questions can be repeated until a prediction can be made based on the observations i.e. an informed choice.
- In order to strengthen the micro-macro link, students should justify their prediction by linking the macroscopic prediction of a graphical outcome to the observations recorded in the microscopic world of the elements and processes which are invisible in the real world. If unable to phrase a justification, students should answer the inference based

linking questions. Based on the feedback from the assertion and reasoning questions, a second round of interaction with the simulation of the microscopic world can be undertaken. These questions will aid in linking the microscopic observations to the macroscopic outcomes. This cycle of interaction with the justification box, attempting the prediction questions and answering the assertion and reasoning questions and interaction with the simulation of the micro world can be repeated until the graphical outcome chosen as an answer in the prediction questions can be justified based on a link between the microscopic and macroscopic world.

- Once the prediction question is answered and justified based on a micro-macro link, it can be tested against a real world experimental outcome to evaluate if the predicted outcomes matches with the answer obtained in a real-world laboratory. If it matches, then the student should proceed to the dynamically linked multiple representations for summarization of the concept.
- The entire cycle beginning from the learning objective ending on a summarization of the concept can be repeated as many times as required till the student is sure of learning the objective given.

b) Recommendations for researchers

In order to develop modules for micro-macro thinking, the following guidelines should be followed for choosing a topic:

- The topics need variables in the macro-world or real world that can be manipulated. This needs to be explained by relations in the micro-level variables.
- There needs to be a correlation in the manipulation of the variable in the real world/macro world and an effect on the action of a corresponding element associated in the microscopic world.
- The co-relation between the variable manipulation in the real world and its corresponding action in the micro world decides the functionality of the chosen system/component.

8.6 Design Guidelines

A set of design guidelines are derived based upon the technology affordance, learning activity and the interaction of the students with the TELE. The design guidelines mentioned below will aid in extending the findings from this study to other technology based learning systems. Let's begin with the mechanism of learning micro-macro thinking in general. This will be evaluated along three tangents: the technology feature, learning activity and interaction with the TELE.

Table 8.1: Design Guidelines

Stage of development of micro-macro thinking	Technology Feature	Learning Activity	Interaction with a TELE
Establishment of micro-macro thinking	Variable manipulation, text entry and simulation of any process. A multiple choice based question can also be included at this stage.	The variable manipulation should be a part of the simulation wherein the learner can change values and observe its effect on the different aspects of the simulation present on screen. A multiple choice question will account for options from which a prediction has to be made of the macroscopic real world phenomenon. Text entry can be allowed at all times so that learners can record any information that they think is crucial for their understanding.	In the TELE, this simulation mentioned as a technology feature can depict the processes at the microscopic level which a learner can interact with and use in order to predict an outcome at the macroscopic level.
Strengthening the micro-macro link	Scaffolding questions which provide the learner with hints towards the right course of action. At this stage as well, text entry should be allowed.	The learner will be expected to answer a series of linked questions which will help link the parameters varied and its corresponding processes at the microscopic level to the prediction expected to be made by the learner at the macroscopic level. The learner will also be expected to use this link in order to justify their choice of prediction by entering text post predicting an outcome.	A simultaneous display of the scaffolding questions along with customized feedback and the simulation of the microscopic processes will be provided and students are expected to use the feedback provided in order to locate the area of the simulation where detailed observations are expected. They are also expected to mention the link based on which they have arrived at their choice of answer. In short, how do their list of observations at the microscopic level lead

			to their choice of prediction at the macroscopic level. The learner is also expected to find the exact activity in the module which needs improvement and locate it in order to rework on it.
Integrating the micro-macro link	Dynamically linked multiple representations	Vary the parameters in the simulation of the microscopic processes and observe its effect on the rest of the representations provided.	The learner is expected to manipulate variables n the simulation of the microscopic processes and view the simultaneously linked animations of different representations of the given phenomenon.

<u>Guidelines for designing student/learner interaction aspects with the TELE:</u>

1. **Provide a simultaneous display of the scaffolding questions and feedback along with the simulation of the microscopic processes in order to lessen the cognitive load. This will also make the navigation throughout the module easier.**
    a. Supporting Evidence: Students who have decided to revise some of their responses and have come to the scaffolding questions in order to seek guidance are found to go to the incorrect area of the micro world simulation if the feedback and the simulation are presented on two separate pages.
2. **Provide multiple types of question prompts with customized feedback whenever a leaner asks for guidance. These questions should be catered to the need of the learner. A Micro-Macro Link based Question should be asked in order to help the student establish a link between the micro and macro worlds and justify their prediction of an outcome of the system. A Microscopic Observation based Question should be asked when students are unable to identify key areas which require observations in order to devise an explanation for a pattern. A Macroscopic Prediction based Question should be asked in order to lead students towards parameters of the macroscopic world which can be manipulated and are linked to elements of the microscopic world i.e a variation in these macroscopic parameters will lead to a corresponding change in the microscopic world. Confounding questions should direct the students to interact with the entire TELE from the**

beginning while making them realize that they have missed multiple aspects needed for the development of the micro-macro thinking skill.

a. Supporting Evidence: If the learner wants guidance before making a prediction with respect to the observations to be made in the micro world then a ‘microscopic only question’ is provided to them which aids in pointing out the key area which require a more detailed list of observations.

b. Supporting Evidence: If a learner has made a prediction but in unable to justify it based on a micro-macro link then they are provided with ‘micro-macro questions’ which aid in establishing a link between the processes at the micro level and its corresponding output at the macroscopic real world level.

c. Supporting Evidence: If a learner is unable to understand the real world manipulable variables then they are provided with a ‘macroscopic only question’ which aids in understanding which variables are relevant and needed to be varied in order to see an effect at the microscopic level.

3. **The feedback to the scaffolding questions can be mediated by an animated pedagogical agent so as to convert the task into a conversation and not give the feeling of an assessment.**

    a. Supporting Evidence: If the questions are provided one after another with a count of how many questions are correct or incorrect then the learners are found to leave the task halfway and proceed to the next task. They are lesser instances of students following the feedback because they treat the entire activity as an assessment.

4. **Maintain a simultaneous display of all the crucial features on a single screen without scrolling.**

    a. Supporting Evidence: Students are found to make an informed choice of a macroscopic prediction (i.e. a graph) based on a link between the macroscopic outcome and the explanation devised by them based on the microscopic observations. This establishment of the micro-macro link is strengthened by facilitating a simultaneous interaction with both these worlds and justifying the macroscopic prediction based on the explanation of the processes at the microscopic world.

b. Supporting Evidence: students are found to make lesser number of observations if there is one feature per page and have a tendency to lose track of revision if the entire sequence of tasks is linear and not together. Once a simultaneous display was included, students were found to follow the feedback given more meticulously and undertake multiple attempts at revising their answers.

c. Supporting Evidence: When scrolling was incorporated into this TELE, students were found to ignore the part of the screen which got left out due to the scroll bar not getting used.

5. **Provide the learner with a control of the visual display parameters so that they can take control of the speed at which the module proceeds and do ease out navigation.**

Supporting Evidence: The feedback provided has an option of making it hidden which aids in enlarging the other features of the environment and can be brought back on call by the learner using a single click. Leaners are also found to write down crucial/important points needed for a comprehensive understanding using the note taking section which can also be moved around the screen. The size of this section is also kept variable depending upon the text entered by the learner. Instead of resetting the entire module, multiple navigation paths are adopted by the learner to reach their choice of feature which they think needs more improvement. This has been found for most of the learners since each of them is unique and has a distinct learning path.

8.7 Thesis Contributions

The thesis makes contributions in the field of design and development of Technology Enhanced Learning Environments in terms of design guidelines, products and research knowledge based on the empirical studies conducted.

- The design of MIC-O-MAP TEL environment for developing micro-macro thinking skills

Features of MIC-O-MAP have been identified –crucial features such as simulation of the microscopic world, Prediction Questions, Justification Box, Real World Answer for comparison and judgement assertion and Reasoning questions and dynamically linked multiple representations. Features such as note taking, inclusion of a pedagogical agent for mediating the process of asking a question and presenting feedback by means of a dialogue, path tracing and answer retention are also included in MIC-O-MAP in order to ensure that interaction with MIC-O-MAP is smooth and struggle free.

- Development of MIC-O-MAP

MIC-O-MAP TEL environment has been developed and contains modules for analog electronics. It runs on a browser, and compatible with all browsers, screen sizes and operating systems. The website hosting all modules of MIC-O-MAP can be found under Project TELOTS (http://www.et.iitb.ac.in/telotsCompleted.html#). The modules can be directly downloaded by students/teachers. In addition the source code is available for researchers to build further new modules.

- Six modules for MIC-O-MAP have been developed and tested in the domain of Basic Analog Electronics. These accounts to a coverage of 60% of Basic Analog Electronics.
- Productive actions of students are identified which tell us the best practises while interacting with MIC-O-MAP. These have been provided as recommendations under section 8.3 (a) of chapter 8. Students are expected to follow these recommendations while interacting with MIC-O-MAP leading to optimizing the potential of features and activities in TEL environments.
- The instructional design template of MIC-O-MAP which can be used for the creation of further modules. For more complex topics such as transistors, JFETs or MOSFETs having more than one micro-macro link, further development of MIC-O-MAP modules can be undertaken by teachers or researchers, as required.
- Identification of learning paths of different types of students – Based on empirical evidence, an 'effective interaction path' is provided in section 8.3 (a) of chapter 8 which inform students about the most beneficial interaction path to be adopted while working with MIC-O-MAP. The combination and order of MIC-O-MAP features to be followed is provided as a recommendation so as to ensure that students are able to develop micro-macro thinking skills with ease.

These contributions are beneficial to multiple stakeholders. One of the stakeholders is **students** who can directly download the developed **MIC-O-MAP modules as a product** and use it in order to learn the concept as well as develop the skill of micro-macro thinking in the absence of a teacher. **Another product useful to teachers or researchers is the instructional design document template of MIC-O-MAP** which can be used for development of further modules in the domain of electronics or tweaking it for the development of micro-macro thinking in different domains.

The identification of the **design guidelines for the creation of the MIC-O-MAP** TEL environment is a **knowledge useful for researchers** who would be interested in creation of TEL environments for other higher order thinking skills.

The effective interaction path and the productive actions is knowledge useful for all three stake holders – students, teachers as well as researchers. Students can make use of these recommendations while interacting with MIC-O-MAP where as teachers can convert the recommendations into a teaching learning strategy while using MIC-O-MAP as an in class or pre lab activity. This knowledge is useful to researchers as it provides an insight into the thought process of students which is likely to repeat when they attempt learning any higher order thinking skill.

8.8 Future Work

One direction for future work in to include more recent learning analytics techniques. The analysis of scores on the test measuring micro-macro thinking has been completed manually throughout this thesis work. All of the screen captures had to be transcribed and coded for each qualitative study in order to claim a result. In order to make this TEL environment more valuable and effective, it can be coded and automated such that it can predict whether a student is following the interaction path of high scorer or low scorer and intervene accordingly so as to direct them towards the most effective interaction path. Building a TEL system which is predictive can be an extension of the MIC-O-MAP TEL environment.

Further analysis and behavioural patterns can be extracted out by carrying out more detailed repeated measures research studies. A mixture of exposure to topic complexity and time will help in understanding student behaviour as well as development of their level of expertise in micro-macro thinking as they interact with these modules over a long period of time. Collaboration in these studies can also be examined as a tangent in the dimension of context. The effect of collaboration on the development of micro-macro thinking skills can be investigated as part of future work.

Affective states such as motivation, interest and attention can also be considered as parameters which affect a student's learning process. These have not been covered as part of this research work but they could play a role within the context of self-regulated learning. The learning time is being measured and we conclude mastery or confusion based on this, whereas, the student could simply be distracted. As students are asked to participate in more number of studies their motivation could be restricted to receiving a certificate at the end of the study and low scores on the test could be due to lack of motivation. Variation in the data points as monitored over a period of time can possibly be explained using the students affective state at that point of time.

Lastly, difficulties in grasping and inferring graphs can lead to misconceptions and leave an impact on a student's capacity to test their prediction or even to draw/choose a graph. Including the feature of drawing a graph could also shed light in this direction because if the student is capable of understanding subtle differences in graphical curves only then will he/she be able to test these against an outcome presented to them as experimental evidence. Future work can include studies which will examine understanding and inferences of graphs as one of the parameters for investigation.

8.9 Final Reflection

This thesis work has been a continuous effort towards designing and creating a technology based learning environment for the development of a higher order skill of micro-macro thinking. It is hoped that continuous interaction with MIC-O-MAP modules will help students to bridge the gap between theory and experiment and aid in a transfer of this skill when posed with any situation having multiple levels. It was a challenge to identify and address struggles faced by students but at the same time it was interesting to view the same environment from multiple student perspectives. Apart from the thesis contribution, growth in oneself in terms of consistency, determination and real time troubleshooting has been a rewarding experience.

Appendix

Appendix A MIC-O-MAP instructional design document Template

PN Junctions

A device with a junction between a p-type and an n-type semiconducting material.

Course Name: **Diode characteristics**

Authors:
Anura.B.Kenkre

Learning Objectives

After interacting with this Learning Object, the learner will be able to:

- Predict the macroscopic IV characteristics of a diode based on the microscopic model of a PN junction.
- Test your prediction of the IV characteristic curve by comparing it with the outcome of a real world experiment.
- Revise your analysis of the microscopic model and then re attempt your prediction of the IV curve.

Definitions of the components/Keywords:

• An **n type semiconductor** is a semiconductor in which electrical conduction is due chiefly to the movement of electrons.
•A **p type semiconductor** is a semiconductor in which electrical conduction is due chiefly to the movement of positive holes.
•Current conduction in a semiconductor occurs via free electrons and "holes", collectively known as charge carriers.
•Adding impurity atoms to a semiconducting material, known as "doping", greatly increases the number of charge carriers within it.
•When a doped semiconductor contains excess holes it is called **"p-type",** and when it contains excess free electrons it is known as **"n-type".**
• A **p–n junction** is a boundary or interface between two types of semiconductor materials, p type and n type, inside a single crystal of semiconductor.

IMPORTANT NOTE TO THE ANIMATOR:

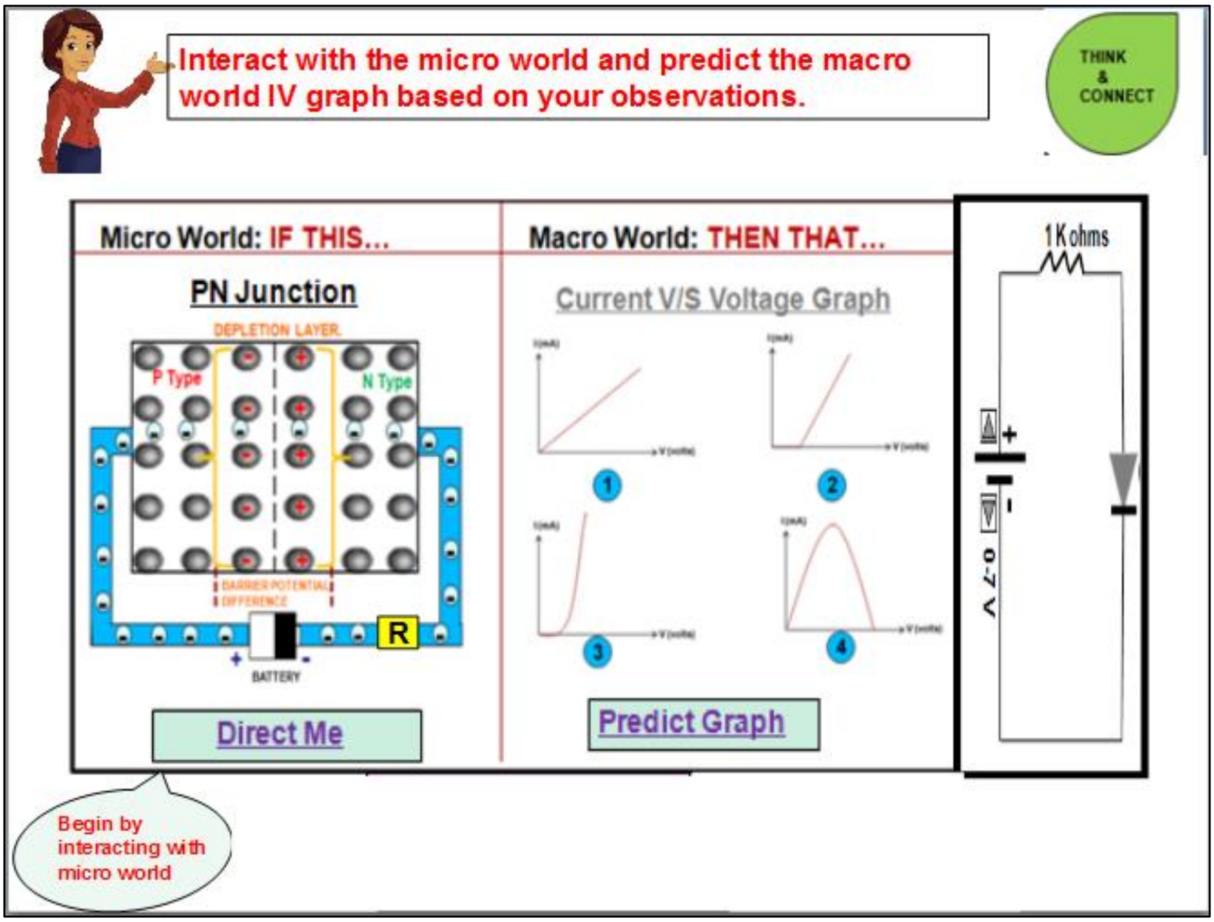
•All the instructions/labels or anything WRITTEN in blue are CONTENT NOT TO BE DISPLAYED!

•All the instructions WRITTEN in black are CONTENT TO BE DISPLAYED!

•This is not applicable for images as there can be overlapping of these colours there. This should be followed for all the instructions, labels,etc…

•

Kindly keep a note of this while displaying text in the animation.



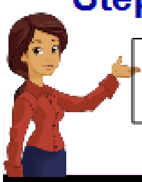
Step 1:

Refer to slide 15

Description of the action/ interactivity	Text to be displayed
•Let the opening screen look like slide 9. •The rectangle on top is the agent dialogue box. After the user clicks on any radio button in the micro world type this in the rectangle: 'When the PN junction is placed in a circuit, lets try to predict its IV characteristics.' •If the user clicks on Direct Me go to slide 24. •If the user clicks on Predict Graph go to slide 15. •If the user clicks on Think & Connect go to slide 25.	The micro world represents the microscopic model of the PN junction inside the diode. The force arrows depict the force due to the external battery and the force due to the barrier potential respectively. The diode is connected to a resistor and a battery whose voltage can be varied. Interact with the micro world and predict the current versus voltage graph.

12

Step 1contd

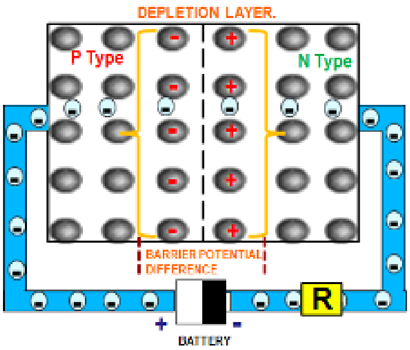


Did you notice? The electron flow goes on increasing linearly with respect to the externally applied voltage.

THINK & CONNECT

Micro World: IF THIS…

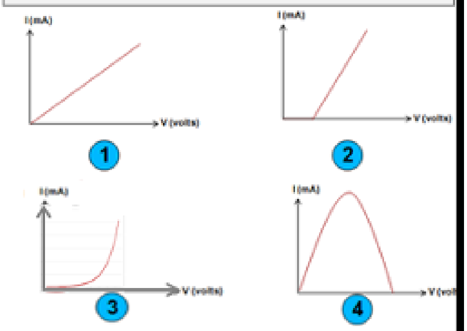
Micro World of a Diode



Help to Predict Graph

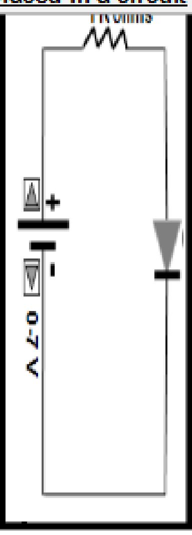
Macro World: THEN THAT…

Current versus voltage graph of a diode



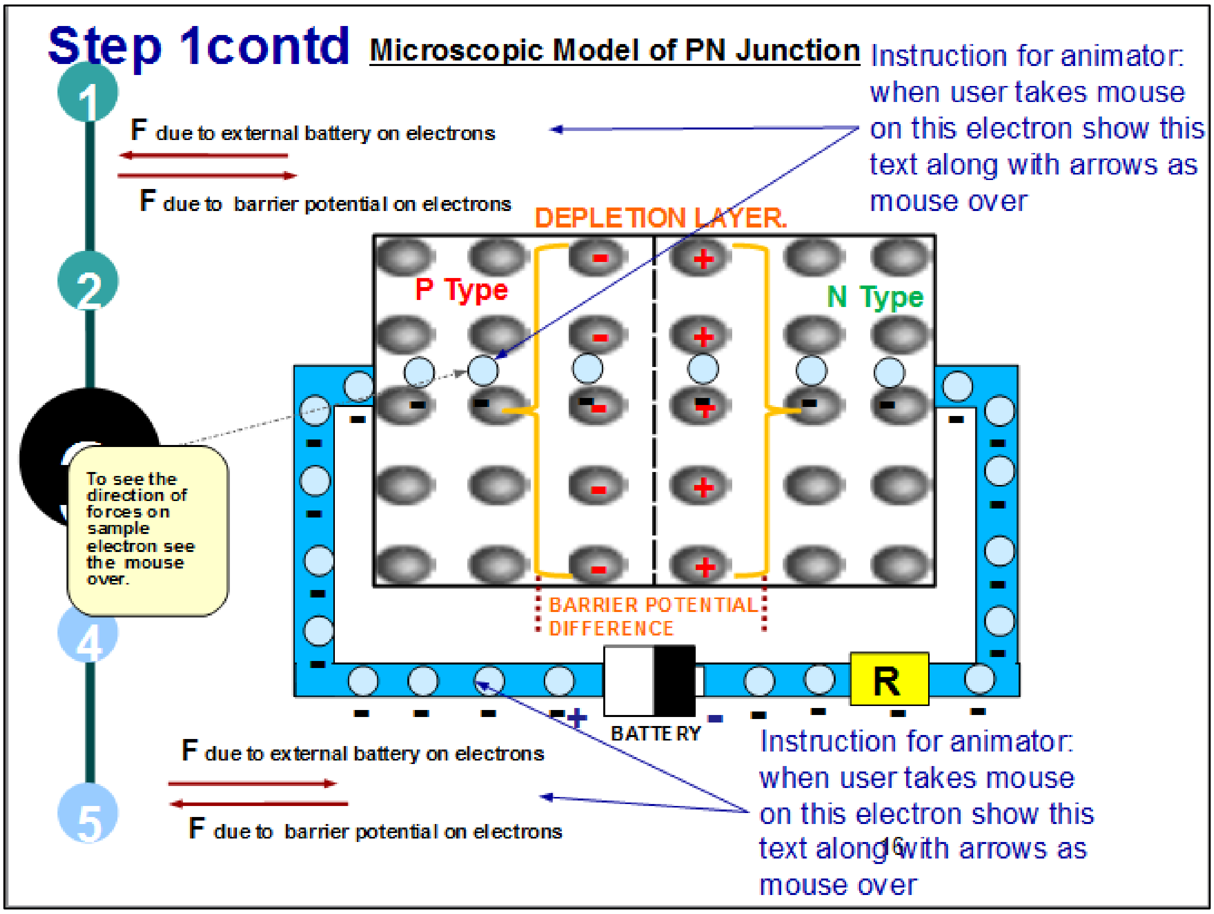
My Prediction

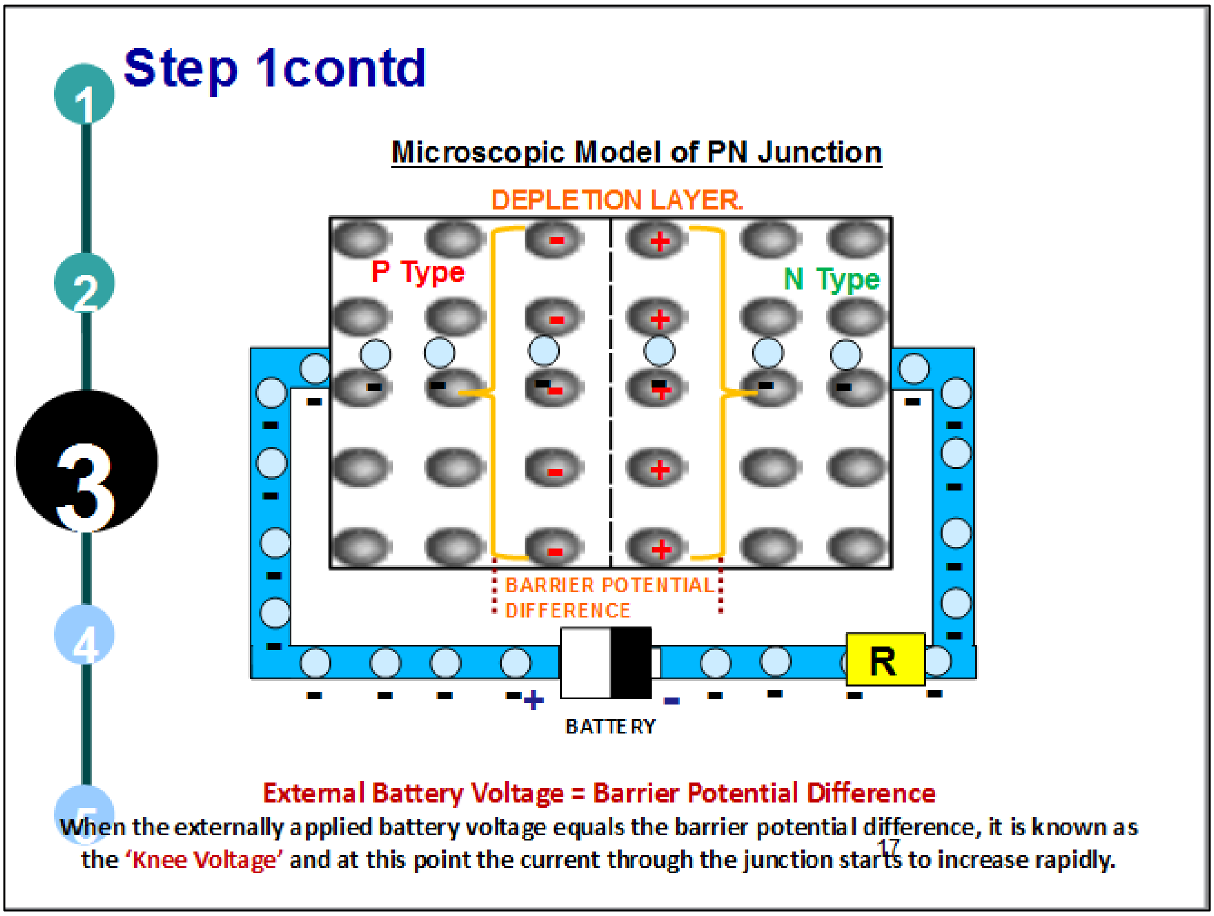
Diode placed in a circuit



Begin by interacting with micro world

15


Step 1contd
Microscopic Model of PN Junction
Instruction for animator: when user takes mouse on this electron show this text along with arrows as mouse over
F due to external battery on electrons
F due to barrier potential on electrons
DEPLETION LAYER.
P Type
N Type
To see the direction of forces on sample electron see the mouse over.
BARRIER POTENTIAL DIFFERENCE
R
BATTERY
F due to external battery on electrons
F due to barrier potential on electrons
Instruction for animator: when user takes mouse on this electron show this text along with arrows as mouse over
1
2
4
5
16


Step 1contd
Microscopic Model of PN Junction
DEPLETION LAYER.
P Type
N Type
BARRIER POTENTIAL DIFFERENCE
R
BATTERY
External Battery Voltage = Barrier Potential Difference
When the externally applied battery voltage equals the barrier potential difference, it is known as the 'Knee Voltage' and at this point the current through the junction starts to increase rapidly.
1
2
3
4
5
17

Description of the action/ interactivity

•Always keep the size of the atoms of the lattice a lot larger than the size of the electrons. Move the electrons along the path shown in the above figure. And do not let the electrons pass through the atoms of the lattice or through each other while moving in their respective paths.
•Allow the students to vary the voltage values of the battery between steps of 0.4, 0.52, 0.58, 0.6 and 0.64. Given below is a voltage versus speed table which you can use to create this animation.
•As the user increases the voltage slowly and gradually increase the speed of the electrons. Let the speed be fastest at 0.64.
•At the start let the arrow for 'F due to barrier potential on electrons' be longest and let only the head of the arrow for 'F due to external battery on electrons' be seen. As the voltage is increased, let the arrow for 'F due to barrier potential on electrons' reduce and that for the 'F due to external battery on electrons' increase until at voltage equal to 0.6 they are equal and after that show the arrow for 'F due to external battery on electrons' longer and that for 'F due to barrier potential on electrons' shorter.
•The electron should complete a square path (shown for one) from left to the right end of the battery and they should move one after another. Let them start moving from the + end and come and end on the – end of the battery.
•Then keep repeating this cycle till the user changes the voltage value.
•When the user clicks on the voltage value of 0.6V replace the text ' Barrier Potential Difference' by the text ' External Battery Voltage = Barrier Potential Difference'. This is shown in the figure on slide 17. Also display the definition of knee voltage as shown.
•If the user clicks on the button displaying 'To see the direction of forces on sample electron see mouse over on the left most end of the wire.' show the text along with the arrows for the electrons indicated by the blue arrows. This is shown on slide 16.
•

Voltage	Speed
0	0 cm/second
0.4	0.1 cm/second
0.52	0.3 cm/second
0.58	0.5 cm/second
0.6	1.2 cm/second
0.64	2 cm/second

18

Step 2:

1

Refer to slide 15

2

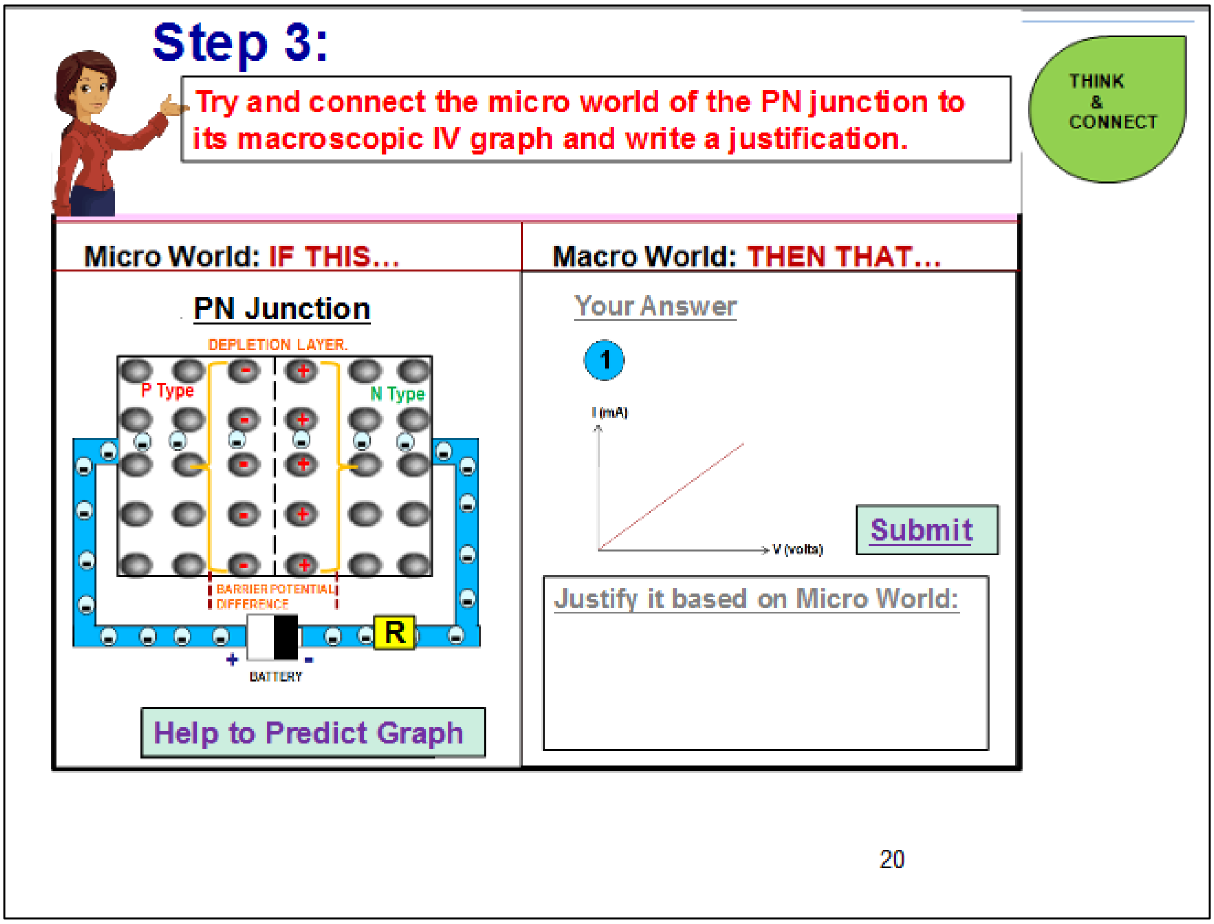
Description of the action/ interactivity	Text to be displayed
•Let the call out keep blinking until the user clicks on a radio button within the rectangle of micro world. •If the user clicks on Direct Me Insert the series of questions as shown on slide 24 in the rectangle titled 'Did You Notice' on the top as shown on slide 15. •If the user clicks on Predict Graph allow the user to choose any one of the four options and replace the radio button of 'Predict Graph' by 'Submit'. •When the user clicks on Submit go to slide 20 •If the user clicks on Think & Connect go to slide 25. • •	

3

4

5

19

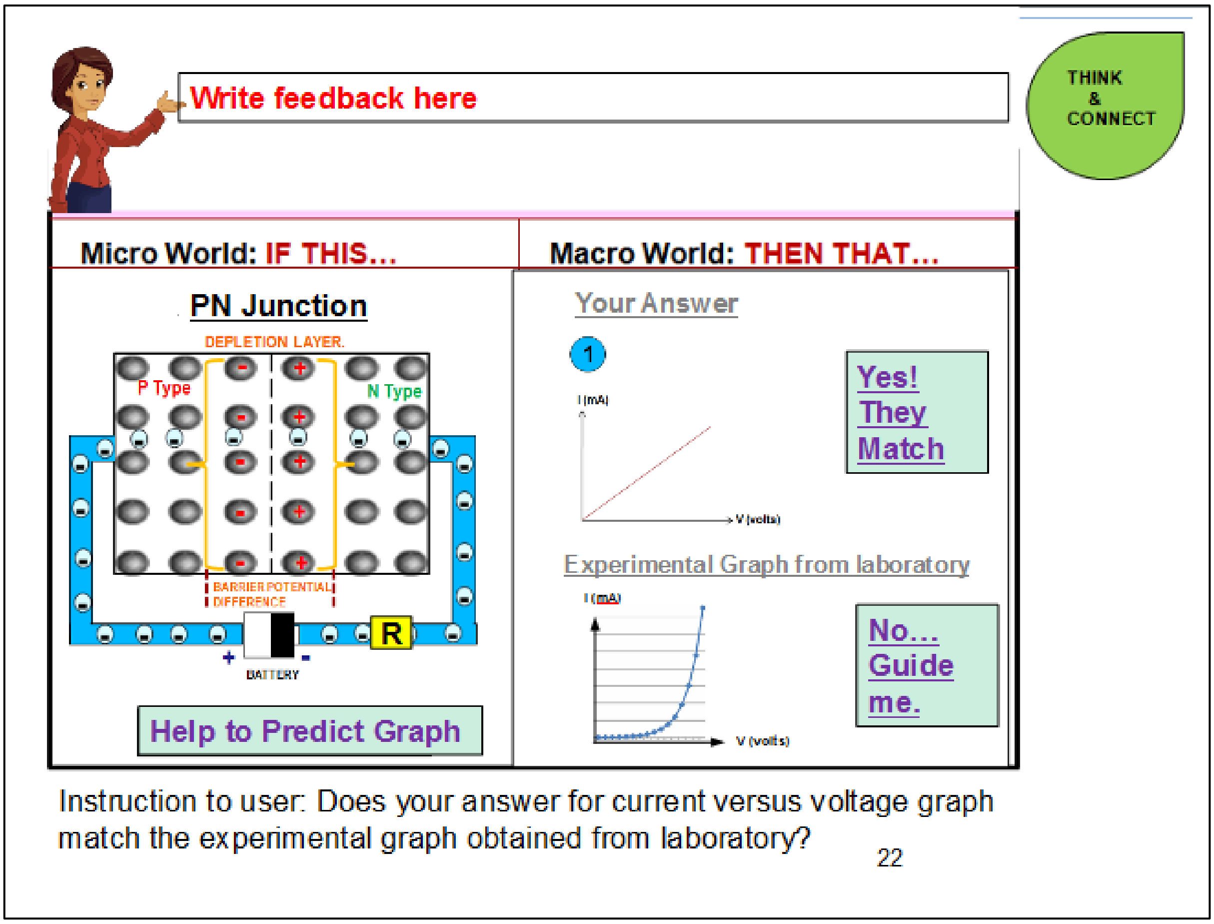


Step 3:

Refer to slide 20

Description of the action/ interactivity	Text to be displayed
•Display the answer chosen by user in the right hand side space and allow text entry in the box where 'Justify it based on micro world' is written. •When the user clicks on Submit go to slide 22 •If the user clicks on Think & Connect go to slide 25.	Your answer for current versus voltage graph is shown. Explain why you chose this graph based on the observations you have made in the micro world.

21



1

Step 4:

Refer to slide 22

2

Description of the action/ interactivity

3

•Display the Real World answer and the graph below it under the answer chosen by user and let 2 radio buttons pop up.
If user selects 'Yes! They Match' then display this under in the rectangle where currently 'Write feedback here' is written: "That's Good! You have correctly predicted the I-V characteristics of a PN junction diode. Now let us summarize the working of a PN junction by relating the microscopic model to the IV characteristics of the PN junction." Also let Proceed come up. When user clicks on this go to slide 33.

4

•If the user selects 'No..Guide me' then display "You need to make more careful observations and establish a link between the microscopic model of the PN junction and its macroscopic IV characteristics. Would like to try again?" Let a Radio button pop up saying 'Observe Micro World' When user clicks on that go to slide 15. If the user clicks on Direct Me go to slide 24.If the user clicks on Think & Connect go to slide 25.

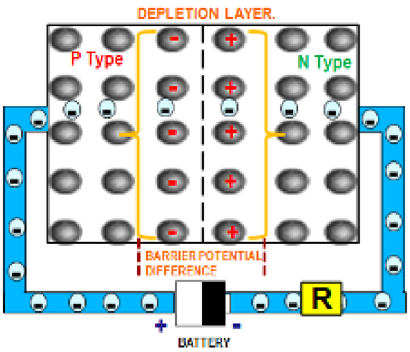
5

23

THINK
&
CONNECT

Let us analyze why the prediction is not matching with the real world answer.

Micro World: IF THIS…	Conflict Resolution
PN Junction	For the Questions to be displayed here go to slide 27. Here display: Take notes you might need it to write summary.



Help to Predict Graph

Predict Graph Again

Here, if user clicks on 'Predict Graph Again' then go to slide 15.

24

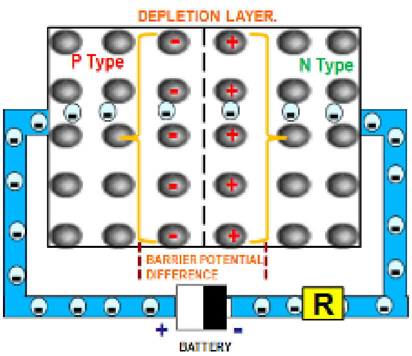
THINK
&
CONNECT

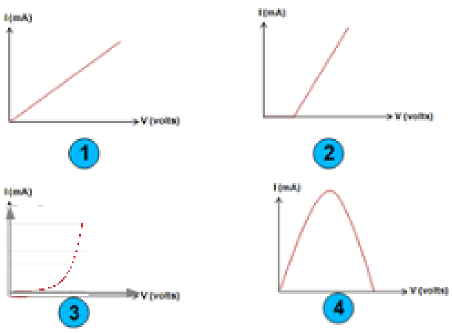
Trace Path

Take Notes

Would you like to trace your path? Or take down your own notes?

Micro World: IF THIS…	Macro World: THEN THAT…
PN Junction	Current V/S Voltage Graph





Help to Predict Graph

Submit

25

Step 5:

Refer to slide 25

Description of the action/ interactivity	Text to be displayed
•If the user clicks on 'Trace Path' then show them all the steps taken by them till they clicked on this radio button and allow them to go to any stage by clicking on it. •If the user clicks on 'Take Notes' then let a box open which allows text entry. •Retain which ever stage user has reached on the left hand side.	

26

Your reason for selecting option ___ was ________________________.

Let us analyze why your prediction and reasoning was incorrect. Observe the micro world again.

Which of the following most closely matches what you observed in the microscopic model of the PN junction:

1. As the voltage is increased, the electron flow increases gradually and varies linearly with the voltage and that it has no dependence on the depletion lay ◯
2. Initially there is no electron flow across the junction due to the presence of the depletion layer and that once this barrier is overcome, there is a larger flow of electrons for a small increase in the applied voltage. ◯
3. Initially the electron flow goes on increasing then reaches a maximum and later goes on reducing and that this is on account of the depletion layer. ◯
4. Initially the electron flow goes on increasing then saturates after reaching a maximum ◯
5. None of the above. ◯

Go back and observe Model

See Summary of PN Junction

27

Description of the action/ interactivity

- Let there be radio buttons for selection along with each option as indicated.
- If the user selects option 1 go to slide 29.
- If the user clicks selects option 2 go to slide 31.
- If the user clicks selects option 3 then display this in the rectangle on top in slide 22 " That's right! This is reason why you get an exponential IV characteristics curve for a PN junction. You have correctly applied the microscopic model in order to arrive at this conclusion."
- If the user selects option 4 go to slide 33.
- If the user selects option 5 then display this in the rectangle on top in slide 22"You need to carefully observe the microscopic model of the PN junction. Go back and observe carefully what happens when you increase the externally applied voltage."
- If the user clicks on 'Go back and observe Model' then go to step 1.
- If the user clicks on 'See Summary of PN junction' then go to slide 34.
-

28

You say that 'As the voltage is increased, the electron flow increases gradually and varies linearly with the voltage and that it has no dependence on the depletion layer.'

Let us check if this is what you observed in the microscopic model of the PN junction: (If you want, then you can go back and vary the voltage, observe what happens and then answer these questions.)

1. There a low electron flow initially. **True** **False**
2. There is a varying rise in the number of electrons when you vary the externally applied voltage. **True** **False**
3. There is a connection between the current flow and the depletion layer.
4. **True** **False**
5. The current increased only when you applied a certain amount of external voltage. **True** **False**
6. The externally applied voltage had to exceed the barrier potential in order to have a rise in the current. **True** **False**

Go Back and Observe Model

29 **Proceed**

Description of the action/ interactivity

•Allow user to answer one question at a time. When first question is answered, display feedback for that, then display the next question and while displaying second question remove the feedback for the earlier question.
•If the user clicks on 'Yes' for option 1 then display, "Yes! That's right. Go ahead and answer the next question."
•If the user clicks on 'No' for option 1 then display, " This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'Yes' for option 2 then display, "Yes! That's right. Go ahead and answer the next question."
•If the user clicks on 'No' for option 2 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'Yes' for option 3 then display " That's right! Go ahead and try to think how the two are related."
•If the user clicks on 'No' for option 3 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'Yes' for option 4 then display " That's right! Now think about the pattern in which the current increases."
•If the user clicks on 'No' for option 4 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'Yes' for option 5 then display " That's right! Now think about the pattern in which the current increases when you exceed the barrier potential."
•If the user clicks on 'No' for option 4 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•Allow the user to answer one question at a time and then proceed to the next question. Then show the first question faded and allow them to answer next question.
•Display this feedback in the rectangle on top in slide 22.
•If the user clicks on 'Go back and observe Model' then go to step 1.
•If the user clicks on 'Proceed' then go to slide 34.
•

30

You say that 'Initially the electron flow goes on increasing then reaches a maximum and later goes on reducing and that this is on account of the depletion layer'

Let us check if this is what you observed in the microscopic model of the PN junction:

(If you want, then you can go back and vary the voltage, observe what happens and then answer these questions.)

1. Was there a low electron flow initially? **Yes** **No**
2. Did the current rise with the externally applied voltage and then decrease as you further increased the voltage? **Yes** **No**
3. Do you think there is any connection between the current flow and the depletion layer? **Yes** **No**
4. Did you not notice that the current increased only when you applied a certain amount of external voltage? **Yes** **No**
5. Don't you think that the externally applied voltage had to exceed the barrier potential in order to have a rise in the current? **Yes** **No**

Go Back and Observe Model

31

Proceed

Description of the action/ interactivity

•Allow user to answer one question at a time. When first question is answered, display feedback for that, then display the next question and while displaying second question remove the feedback for the earlier question.
•If the user clicks on 'Yes' for option 1 then display, "Yes! That's right. Go ahead and answer the next question."
•If the user clicks on 'No' for option 1 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'Yes' for option 2 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'No' for option 2 then display, "Yes! That's right. Go ahead and answer the next question."
•If the user clicks on 'Yes' for option 3 then display " That's right! Go ahead and try to think how the two are related."
•If the user clicks on 'No' for option 3 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'Yes' for option 4 then display " That's right! Now think about the pattern in which the current increases."
•If the user clicks on 'No' for option 4 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•If the user clicks on 'Yes' for option 5 then display " That's right! Now think about the pattern in which the current increases when you exceed the barrier potential."
•If the user clicks on 'No' for option 4 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the PN junction"
•Allow the user to answer one question at a time and then proceed to the next question. Then show the first question faded and allow them to answer next question.
•Display this feedback in the rectangle on top in slide 22.
•If the user clicks on 'Go back and observe Model' then go to step 1.
•If the user clicks on 'Proceed' then go to slide 34.

32

•

You say that 'Initially the electron flow goes on increasing then saturates after reaching a maximum.'

Let us check if this is what you observed in the microscopic model of the PN junction:

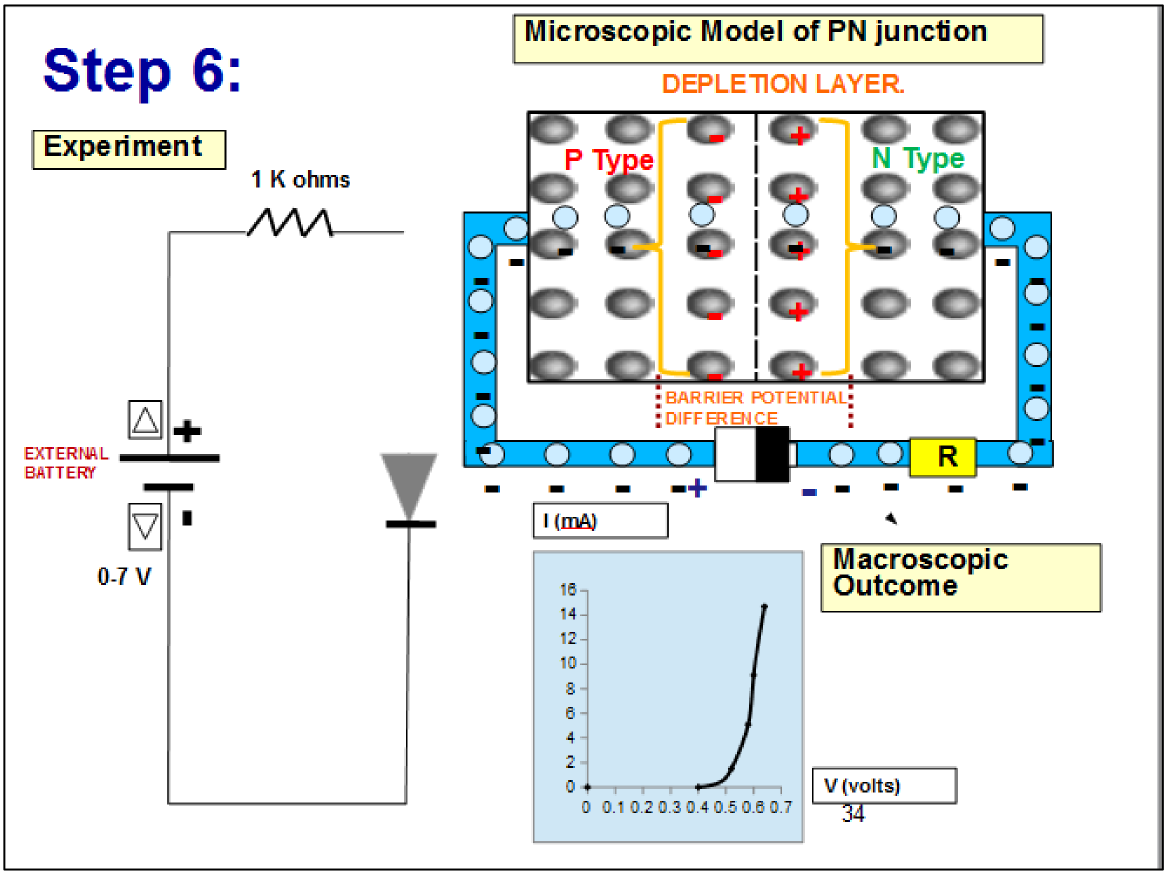
(If you want, then you can go back and vary the voltage, observe what happens and then answer these questions.)

1. Was there low electron flow initially? **Yes** **No**
2. Did the current start increasing along with externally applied voltage and then remained constant? **Yes** **No**
3. Do you think there is any connection between the current flow and the depletion layer? **Yes** **No**
4. Did you not notice that the current increased only when you applied a certain amount of external voltage? **Yes** **No**
5. Do you think that the externally applied voltage had to exceed the barrier potential in order to have a rise in the current? **Yes** **No**

Go Back and Observe Model

33

Proceed



Step 6 contd:

Change the battery voltage, observe the microscopic model and IV characteristics of a PN junction and briefly summarize the working of a PN junction:

See Summary

Description of the action/ interactivity

- Show the three images from slide 34. Use the table from slide 35 to plot graph and for allowing the user to change voltage values in the external battery in the experiment and along with those values display the corresponding microscopic picture using values from slide 36 .
- Allow students to enter text input in the above figure.
- If the user clicks on 'See Summary' , display the following:

'Summary:
A PN junction is a P type semiconductor and an N type semiconductor separated by a depletion layer. When there is no externally applied battery voltage, there is zero electron flow in the circuit. When the P type semiconductor is connected to the positive terminal and the N type is connected to the negative terminal of an external battery, initially very few electrons are able to cross the depletion layer to the barrier potential difference across the depletion layer. As we increase the externally applied battery voltage more number of electrons are able to cross the depletion layer and when the external battery voltage is equal to the barrier voltage there is a large electron flow in the circuit. When the external battery voltage exceeds the barrier potential difference, the electron flow in the circuit shoots up and starts increasing exponentially.
Check your answer and take note of which points you need to revise.'
Write 'Self Assessment below this. And let a button for 'Proceed' come up.

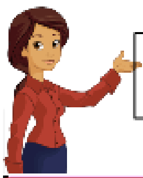
- If the user clicks on 'Proceed' then go to slide 37.

35

Table for plotting the graph:

V(volts)	I(mA)
0	0
0.4	0
0.52	1.5
0.58	5.1
0.6	9.1
0.64	14.7

36

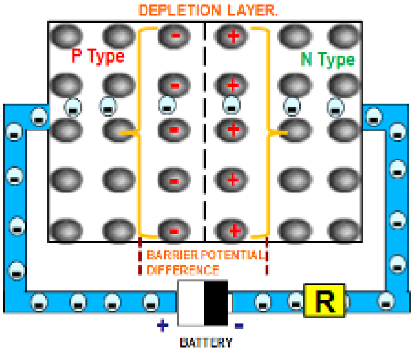


Let us see what assumptions are to be kept in mind so that we get the real world IV graph.

THINK & CONNECT

Micro World: IF THIS...

PN Junction



Direct Me

Assumptions

For the Questions to be displayed here go to slide 38.

Predict Graph Again

37

What assumptions did you take into account while making this prediction?

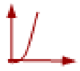
1. The doping on the P and N side of the junction is equal. Yes No
2. The size of the P and N part of the junction is equal. Yes No
3. The presence of current limiting resistor. Yes No

submit

38

Description of the action/ interactivity

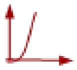
- Display the above question to the user.
- Allow the user to click on yes and no for all the three options.
- If the user selects yes for all the three options, display " You are completely correct! All the three assumptions are needed in order to get the output characteristics as



Assumption 1 is needed because if the doping on the n side was higher then the knee voltage would be very small and a very large current flow would be there for small increases in voltage which would in turn burn out the diode. If the doping on the p side was higher then the knee voltage would be very large due to which it would take a very long time for the diode to conduct or depending upon the amount of doping, it might not conduct at all.
Assumption 2 is needed because if either side was larger, it would take a very long time for the diode to conduct or depending upon the size, it might not conduct at all. Where as if either size was small, then it could lead to burning out of the diode.
Assumption 3 is needed because post the knee voltage there is a large amount of current for small increases in voltage and hence the resistor ensures that the diode does not burn out,

39

Description of the action/ interactivity

•If the user selects yes for all the three options, display " If you did not make these assumptions then you would not get the output characteristics as 

•

•

Assumption 1 is needed because if the doping on the n side was higher then the knee voltage would be very small and a very large current flow would be there for small increases in voltage which would in turn burn out the diode. If the doping on the p side was higher then the knee voltage would be very large due to which it would take a very long time for the diode to conduct or depending upon the amount of doping, it might not conduct at all.
Assumption 2 is needed because if either side was larger, it would take a very long time for the diode to conduct or depending upon the size, it might not conduct at all. Where as if either size was small, then it could lead to burning out of the diode.
Assumption 3 is needed because post the knee voltage there is a large amount of current for small increases in voltage and hence the resistor ensures that the diode does not burn out,

•If the user selects any other combination of the options, display " You are partially correct. All the three assumptions are needed in order to get the output characteristics as 

•

•

Assumption 1 is needed because if the doping on the n side was higher then the knee voltage would be very small and a very large current flow would be there for small increases in voltage which would in turn burn out the diode. If the doping on the p side was higher then the knee voltage would be very large due to which it would take a very long time for the diode to conduct or depending upon the amount of doping, it might not conduct at all.
Assumption 2 is needed because if either side was larger, it would take a very long time for the diode to conduct or depending upon the size, it might not conduct at all. Where as if either size was small, then it could lead to burning out of the diode.
Assumption 3 is needed because post the knee voltage there is a large amount of current for small increases in voltage and hence the resistor ensures that the diode does not burn out,

40

Links for further reading

Books:

1) Principles of Electronics – V.K.Mehta

2) Basic Electronics- Uday A. Bakashi.

43

Summary

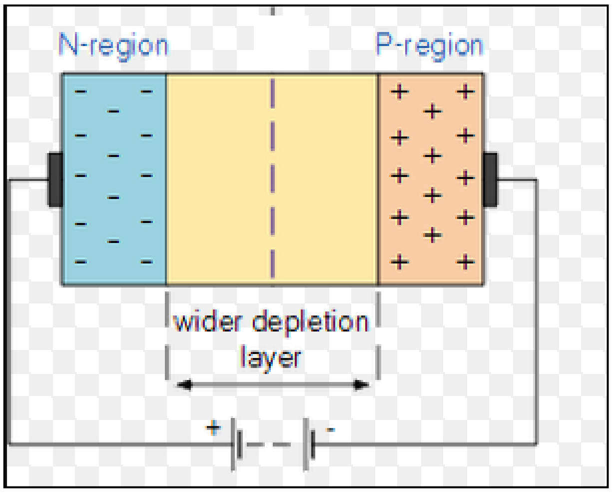
- A diode is the intersection of a p type and an n type semi conductor.
- A diode will conduct only when the knee voltage is crossed.
- The I-V characteristics of the diode are non linear, i.e the current is not proportional to the applied voltage. It is an exponential curve.
- The knee voltage is 0.7 V for Si and 0.3 V for Ge.
- The P and N sides of a diode always have equal doping and are of equal sizes. If this is not maintained then there are chances of the diode burning out or of it not conducting at all.
- A current limiting resistor is always kept is series with the diode so as to avoid chances of excess current passing through the diode.

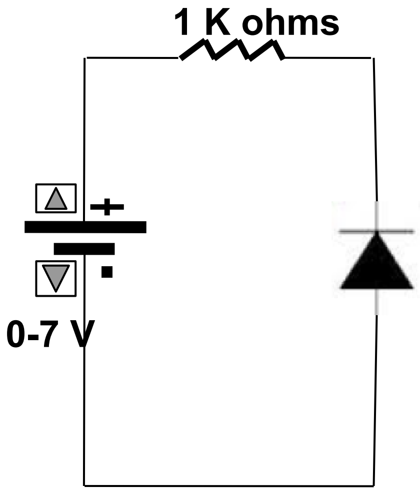
45

Appendix B Micro-Macro Thinking Post Tests
Appendix B.1 – P N Junction Reverse Biased

Name: **College:**

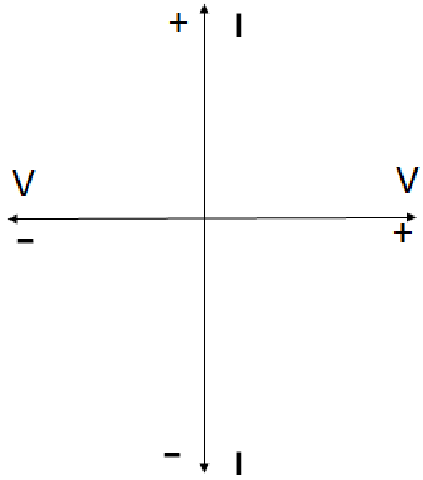
You are given a microscopic model of a material as shown below where P type is connected to negative terminal and N type is connected to the positive terminal:





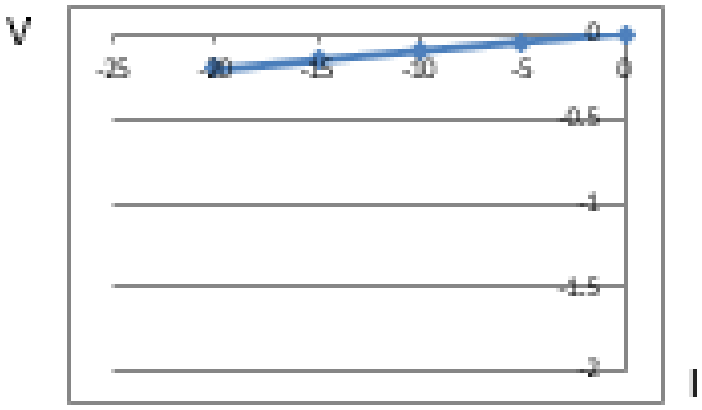
Given beside it is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its IV characteristics as the voltage is increased.

1. Describe what should happen to the current in the circuit when battery voltage is gradually increased. Explain the reason for your answer, relating the voltage and current to the direction of battery connection, electron motion and depletion layer. Write your detailed answer and use as much space as needed.
2. Draw the IV characteristic graph for this material:



3. State the assumptions, if any, that you are making while drawing this graph:

When this experiment is performed in a lab, the IV characteristics obtained are as follows:



4. Is the graph drawn by you same as this? It is ok if your original graph is not same as this. **DO NOT CHANGE** THE PREVIOUS GRAPH.

5. List all the differences between the IV characteristics drawn by you in Q 2 and the ones obtained in the experiment shown in Q 4. If no difference, say that they were the same.

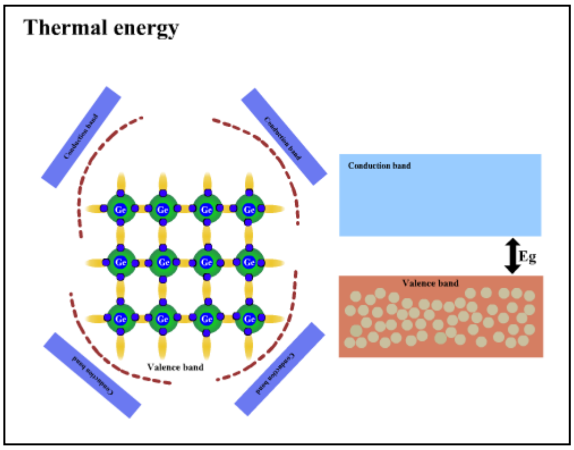
6. Answer this part only If your predicted graph did not match the experimental graph:
   a.) Explain the reason for your answer, relating the voltage and current to the direction of battery connection, electron motion and depletion layer.

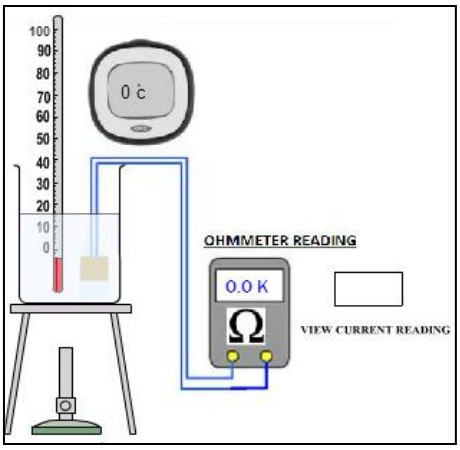
   b.) Your earlier reason in Q1 may have been wrong since your prediction did not match the experimental outcome. So you may have had to make changes in part (a). Now, compared to your original answer write what was wrong in your reasoning.

Appendix B.2 – Thermistors

<u>Name:</u> **<u>College:</u>**

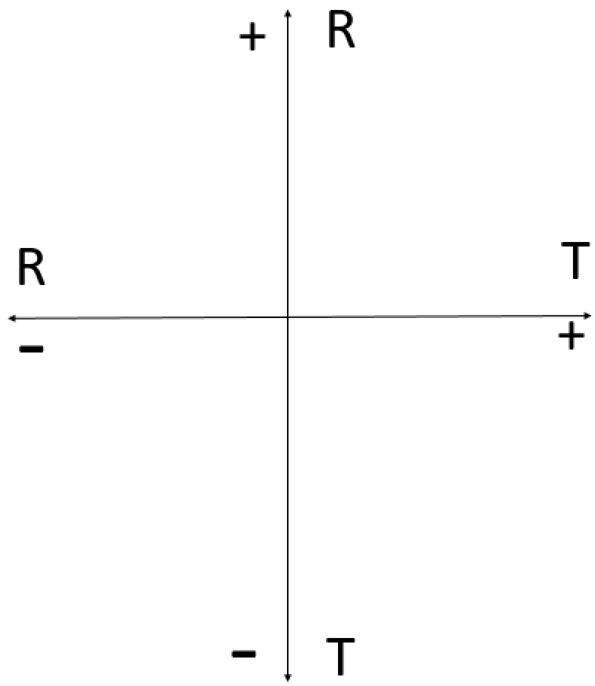
You are given a microscopic model of a thermistor:





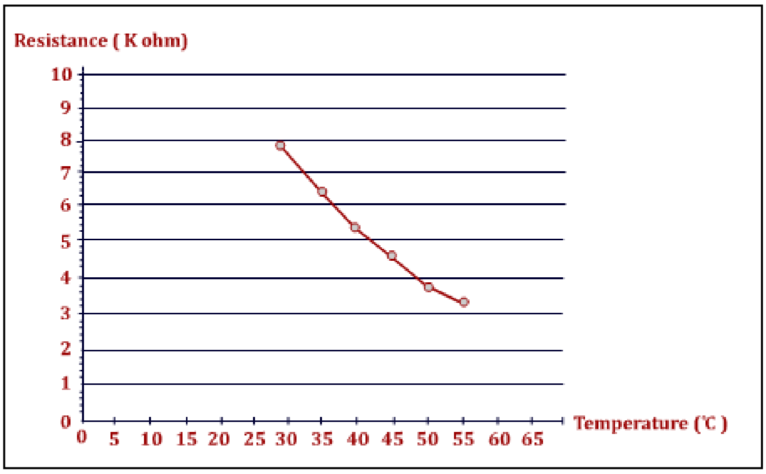
Given beside it is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its resistance versus temperature graph.

1. Describe what should happen to the resistance of the material as the temperature is varied. Explain the reason for your answer, relating the temperature to the energy band diagram. Write your detailed answer and use as much space as needed.
2. Draw the resistance versus temperature graph for this material:



3. State the assumptions, if any, that you are making while drawing this graph:

When this experiment is performed in a lab, the resistance versus temperature graph obtained is as follows:



4. Is the graph drawn by you same as this? It is ok if your original graph is not same as this. **DO NOT CHANGE** THE PREVIOUS GRAPH.

5. List all the differences between the resistance versus temperature graph drawn by you in Q 2 and the ones obtained in the experiment shown in Q 4. If no difference, say that they were the same.

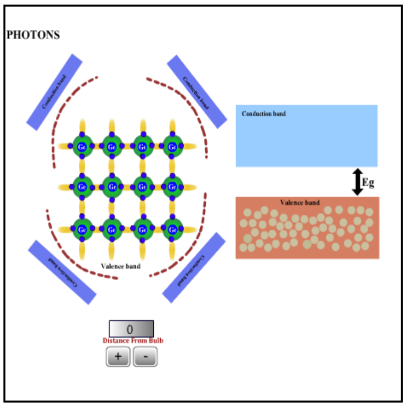
6. Answer this part only If your predicted graph did not match the experimental graph:
   a.) Explain the reason for your answer, relating the temperature to the energy band diagram.

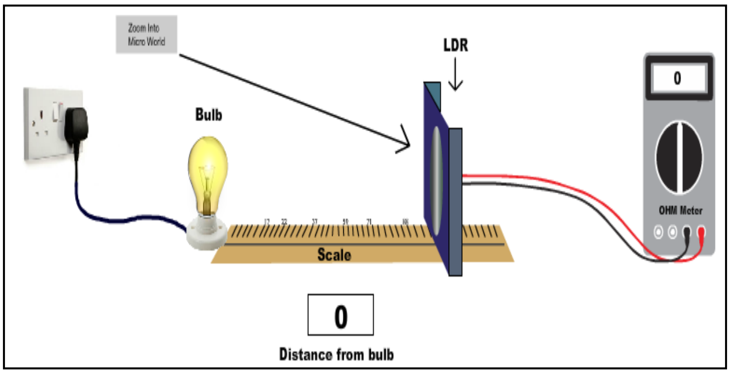
   b.) Your earlier reason in Q1 may have been wrong since your prediction did not match the experimental outcome. So you may have had to make changes in part (a). Now, compared to your original answer write what was wrong in your reasoning.

Appendix B.3 – Light Dependent Resistors

Name: **College:**

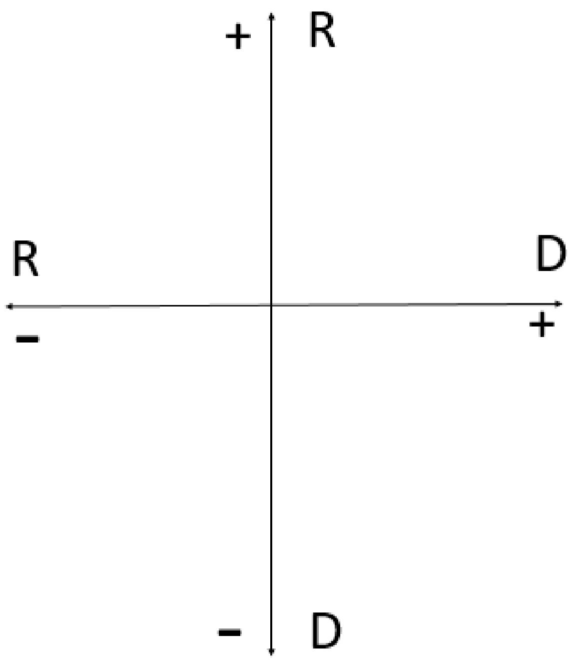
You are given a microscopic model of a light dependant resistor:





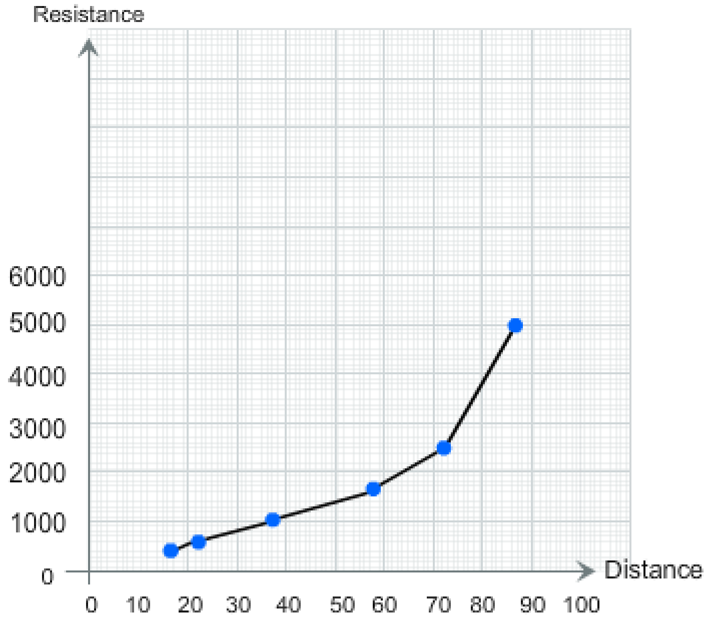
Given beside it is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its resistance versus distance graph.

1. Describe what should happen to the resistance of the material as the distance from the bulb is varied. Explain the reason for your answer, relating the distance from the light source (bulb) to the energy band diagram. Write your detailed answer and use as much space as needed.
2. Draw the resistance versus distance from light source (LDR) graph for this material:



3. State the assumptions, if any, that you are making while drawing this graph:

When this experiment is performed in a lab, the resistance versus distance graph obtained is as follows:



4. Is the graph drawn by you same as this? It is ok if your original graph is not same as this. **DO NOT CHANGE** THE PREVIOUS GRAPH.

5. List all the differences between the resistance versus distance graph drawn by you in Q 2 and the ones obtained in the experiment shown in Q 4. If no difference, say that they were the same.

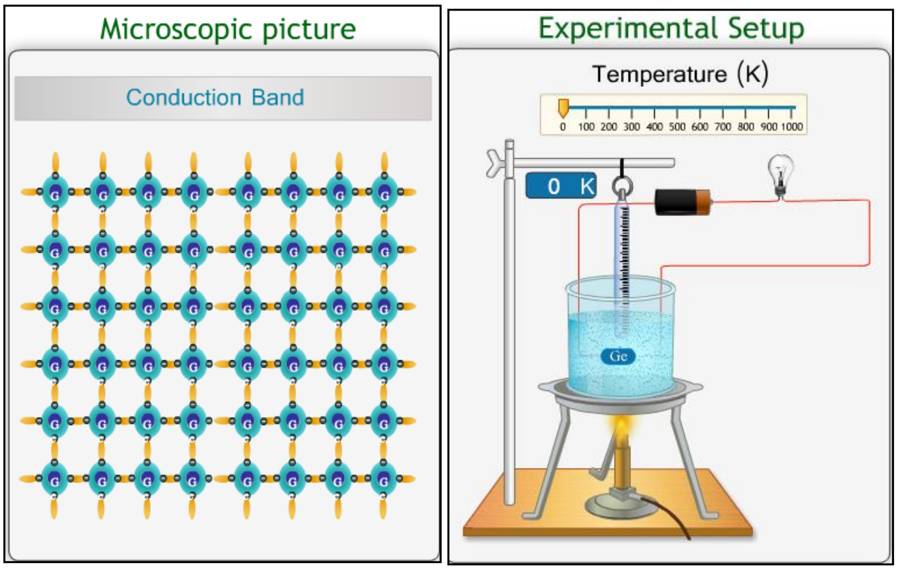
6. Answer this part only If your predicted graph did not match the experimental graph:
   a.) Explain the reason for your answer, relating the distance from light source (bulb) to the energy band diagram.

   b.) Your earlier reason in Q1 may have been wrong since your prediction did not match the experimental outcome. So you may have had to make changes in part (a). Now, compared to your original answer write what was wrong in your reasoning.

Appendix B.4 – Conductivity in Intrinsic Semiconductors

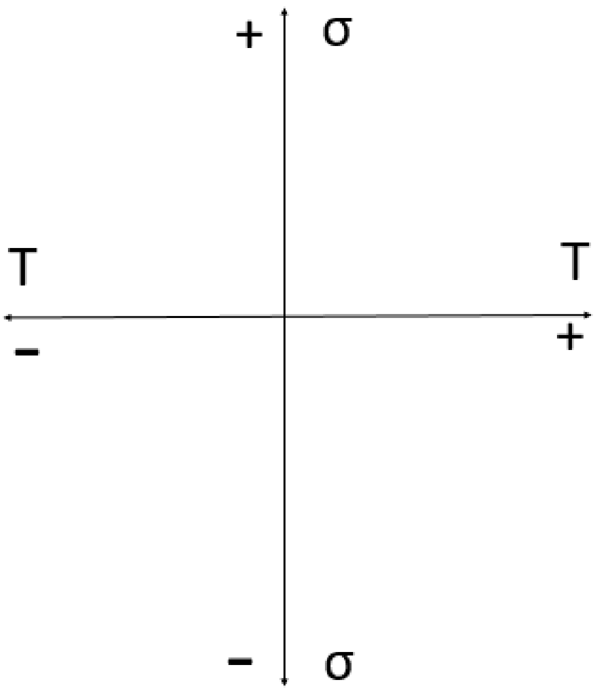
Name: **College:**

You are given a microscopic model of an intrinsic semiconductor:



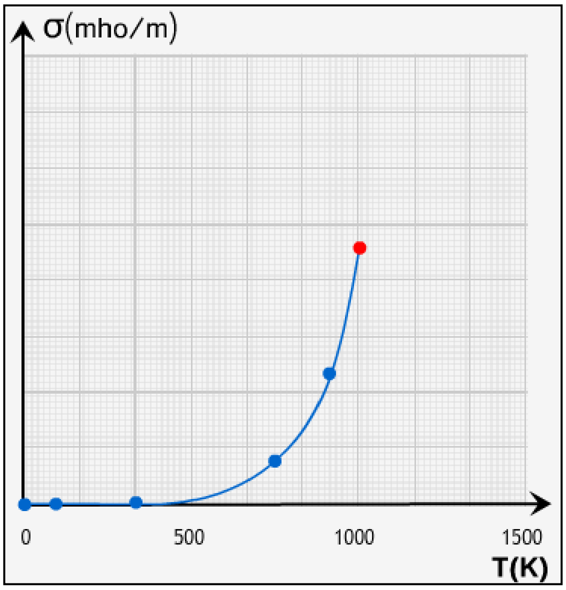
Given beside it is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its conductivity versus temperature graph.

1. Describe what should happen to the conductivity of the material as the temperature is varied. Explain the reason for your answer, relating the temperature to the energy band diagram. Write your detailed answer and use as much space as needed.
2. Draw the conductivity versus temperature graph for this material:



3. State the assumptions, if any, that you are making while drawing this graph:

When this experiment is performed in a lab, the conductivity versus temperature graph obtained is as follows:



4. Is the graph drawn by you same as this? It is ok if your original graph is not same as this. **DO NOT CHANGE** THE PREVIOUS GRAPH.

5. List all the differences between the conductivity versus temperature graph drawn by you in Q 2 and the ones obtained in the experiment shown in Q 4. If no difference, say that they were the same.

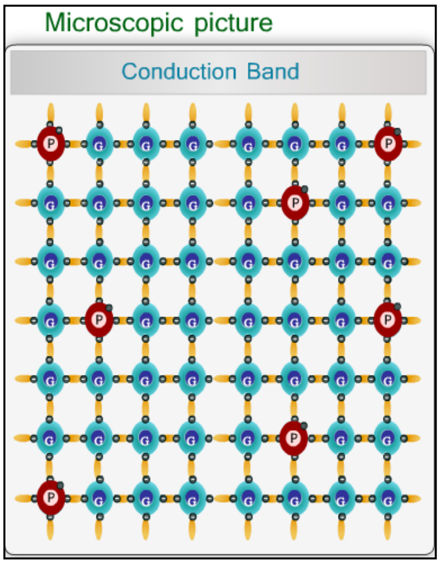
6. Answer this part only If your predicted graph did not match the experimental graph:
   a.) Explain the reason for your answer, relating the temperature to the energy band diagram.

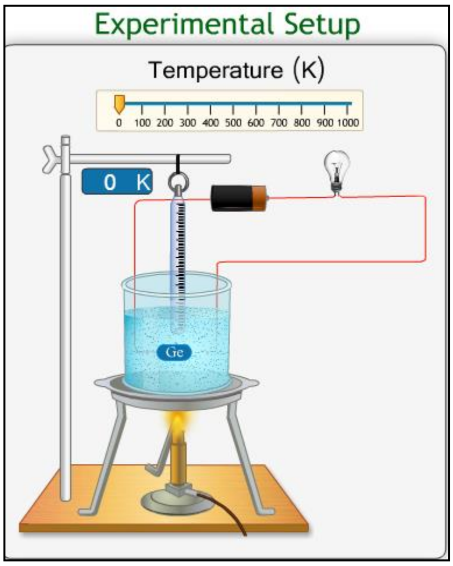
   b.) Your earlier reason in Q1 may have been wrong since your prediction did not match the experimental outcome. So you may have had to make changes in part (a). Now, compared to your original answer write what was wrong in your reasoning.

Appendix B.5 – Conductivity in Extrinsic Semiconductors

Name: **College:**

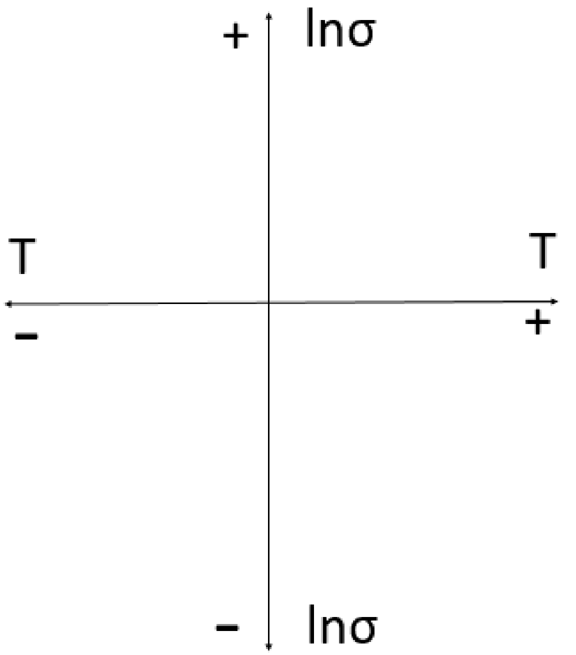
You are given a microscopic model of an extrinsic semiconductor:





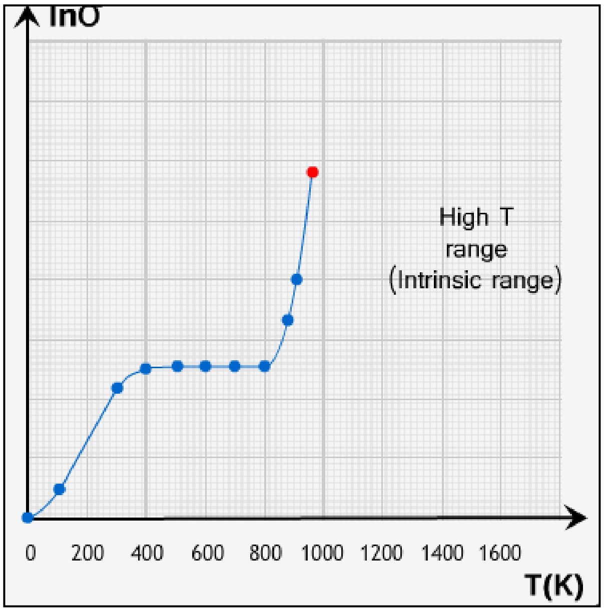
Given beside it is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its conductivity versus temperature graph.

1. Describe what should happen to the conductivity of the material as the temperature is varied. Explain the reason for your answer, relating the temperature to the energy band diagram. Write your detailed answer and use as much space as needed.
2. Draw the conductivity versus temperature graph for this material:



3. State the assumptions, if any, that you are making while drawing this graph:

When this experiment is performed in a lab, the conductivity versus temperature graph obtained is as follows:



4. Is the graph drawn by you same as this? It is ok if your original graph is not same as this. **DO NOT CHANGE** THE PREVIOUS GRAPH.

5. List all the differences between the conductivity versus temperature graph drawn by you in Q 2 and the ones obtained in the experiment shown in Q 4. If no difference, say that they were the same.

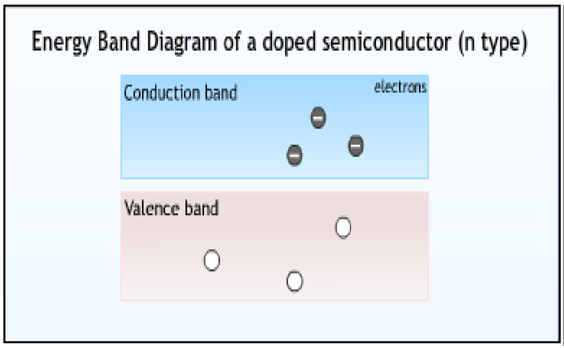
6. Answer this part only If your predicted graph did not match the experimental graph:
   a.) Explain the reason for your answer, relating the temperature to the energy band diagram.

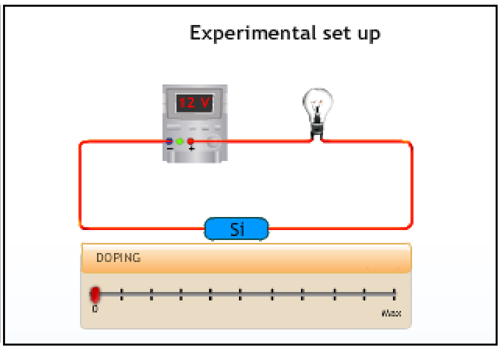
   b.) Your earlier reason in Q1 may have been wrong since your prediction did not match the experimental outcome. So you may have had to make changes in part (a). Now, compared to your original answer write what was wrong in your reasoning.

Appendix B.6 – Formation of Extrinsic Semiconductors

Name: **College:**

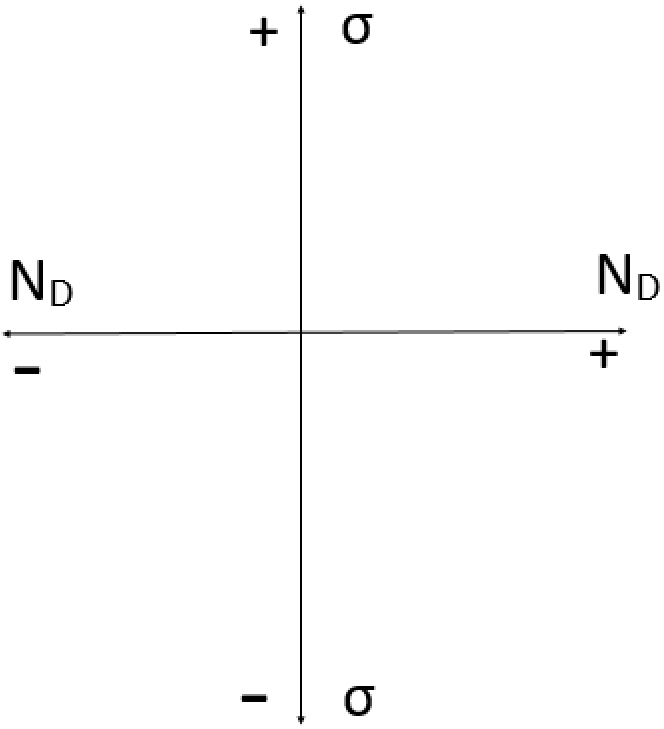
You are given a microscopic model of an extrinsic semiconductor:





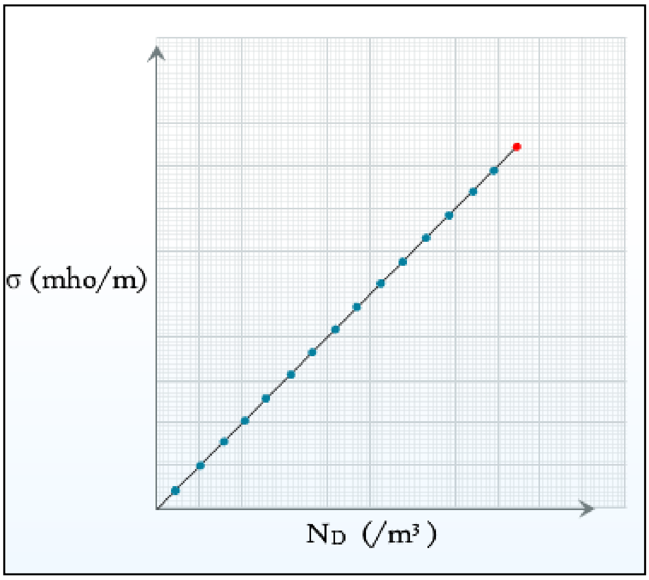
Given beside it is the experimental setup for which you have observed the microscopic model of the material. Now, use that microscopic model to predict its conductivity versus doping graph.

1. Describe what should happen to the conductivity of the material as the doping is varied. Explain the reason for your answer, relating the doping to the energy band diagram. Write your detailed answer and use as much space as needed.
2. Draw the conductivity versus doping graph for this material:



3. State the assumptions, if any, that you are making while drawing this graph:

When this experiment is performed in a lab, the conductivity versus doping graph obtained is as follows:



4. Is the graph drawn by you same as this? It is ok if your original graph is not same as this. **DO NOT CHANGE** THE PREVIOUS GRAPH.

5. List all the differences between the conductivity versus doping graph drawn by you in Q 2 and the ones obtained in the experiment shown in Q 4. If no difference, say that they were the same.

6. Answer this part only If your predicted graph did not match the experimental graph:
   a.) Explain the reason for your answer, relating the doping to the energy band diagram.

   b.) Your earlier reason in Q1 may have been wrong since your prediction did not match the experimental outcome. So you may have had to make changes in part (a). Now, compared to your original answer write what was wrong in your reasoning.

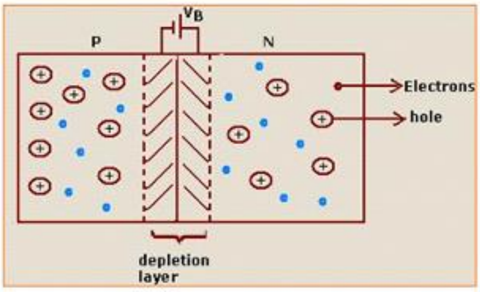
Appendix C Reading Material for the Control Group

Reading material for control group: (This was given to them while viewing the conceptual visualization not having the scaffolds present in MIC-O-MAP)

P-N Junction

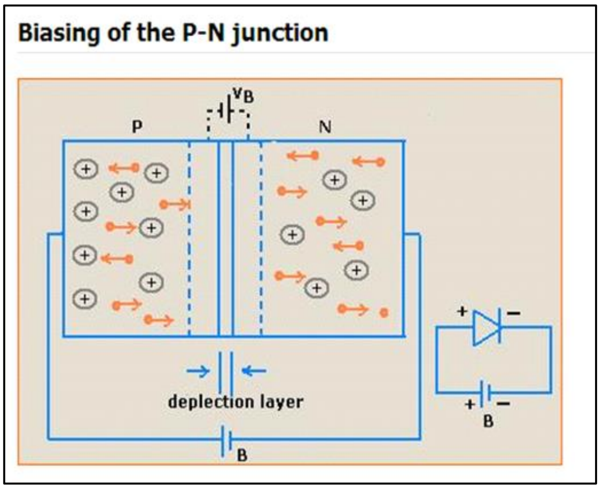
A diode is one of the simplest semiconductor devices, which has the characteristic of passing current in one direction only. However, unlike a resistor, a diode does not behave linearly with respect to the applied voltage as the diode has an exponential I-V relationship and therefore we cannot described its operation by simply using an equation such as Ohm's law.

When a p-type semiconductor is brought into a close contact with n-type semiconductor crystal, the resulting arrangement is a PN junction or junction diode. On account of difference in concentration of charge carriers in the two sections, the electrons from n-region diffuses through the junction into p region and the holes from p-region diffuse into n-region. Due to this the electron falls into the vacancy i.e., it completes the covalent bond. This process is called electron-hole recombination. As a result of the migration of charge carriers across the junction, the electrons leave ionised donor atoms which are bound and cannot move. Similarly, the p-region of the junction will have ionised acceptor atoms which are immobile. The accumulation of electric charges of opposite polarities in the two regions gives rise to an electric field. This is like a fictitious battery and prevents the further migration of charges. This battery is otherwise the potential barrier V_B. This region which is devoid of any free charges is called depletion region.

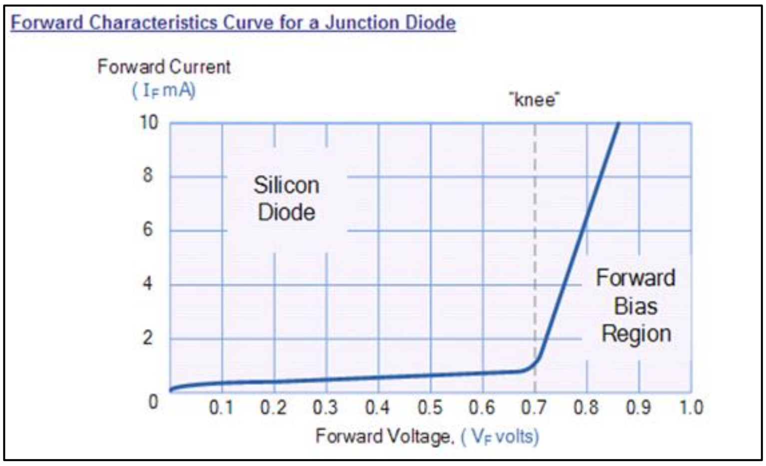


The width of the depletion region and V_B depends on the semiconductor and its doping concentration. Symbolically the p-n junction is shown as where P-side is known as anode and n-side the cathode. This junction is also called a semiconductor diode.

Forward Biasing:



If a suitable positive voltage (forward bias) is applied between the two ends of the PN junction, it can supply free electrons and holes with the extra energy they require to cross the junction as the width of the depletion layer around the PN junction is decreased. This has the effect of increasing or decreasing the effective resistance of the junction itself allowing or blocking current flow through the diode. A p-n junction is said to be forward biased, if the positive terminal of the external battery B is connected to p-side and the negative terminal to the n-side of the p-n junction. If this external voltage becomes greater than the value of the potential barrier, approx. 0.7 volts for silicon and 0.3 volts for germanium, the potential barriers opposition will be overcome and current will start to flow. This is because the negative voltage pushes or repels electrons towards the junction giving them the energy to cross over and combine with the holes being pushed in the opposite direction towards the junction by the positive voltage. This results in a characteristics curve of zero current flowing up to this voltage point, called the "knee" on the static curves and then a high current flow through the diode with little increase in the external voltage as shown below.



The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow. The point at which this sudden increase in current takes place is represented on the static I-V characteristics curve above as the "knee" point. This condition represents the low resistance path through the PN junction allowing very large currents to flow through the diode with only a small increase in bias voltage. The actual potential difference across the junction or diode is kept constant by the action of the depletion layer at approximately 0.3v for germanium and approximately 0.7v for silicon junction diodes. Since the diode can conduct "infinite" current above this knee point as it effectively becomes a short circuit, therefore resistors are used in series with the diode to limit its current flow. Exceeding its maximum forward current specification causes the device to dissipate more power in the form of heat than it was designed for resulting in a very quick failure of the device.

Appendix D Rubrics used for Assessment

Revised and adapted based on https://sites.google.com/site/scientificabilities/rubrics

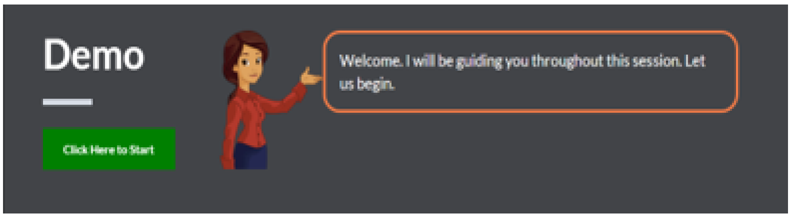
Sub Skill	Missing	Inadequate	Needs Improvement	Adequate
Observation: Is able to describe what is observed without trying to explain, both in words and by means of a picture of the experimental setup.	No description is mentioned.	A description is incomplete. No labelled sketch is present. Or, observations are adjusted to fit expectations.	A description is complete, but mixed up with explanations or pattern. The sketch is present but is difficult to understand.	Clearly describes what happens in the experiments both verbally and with a sketch. Provides other representations when necessary (tables and graphs).
Explanation: Is able to devise an explanation for an observed pattern	No attempt is made to explain the observed pattern.	An explanation is vague, not testable, or contradicts the pattern.	An explanation contradicts previous knowledge or the reasoning is flawed.	A reasonable explanation is made. It is testable and it explains the observed pattern.
Prediction: Is able to make a reasonable prediction based on a hypothesis	No prediction is made.	A prediction is made but it is identical to the hypothesis, OR Prediction is made based on a source unrelated to hypothesis being tested, or is completely inconsistent with hypothesis being tested, OR Prediction is unrelated to the context of the designed experiment.	Prediction follows from hypothesis but is flawed because *relevant experimental assumptions are not considered and/or *prediction is incomplete or somewhat inconsistent with hypothesis and/or *prediction is somewhat inconsistent with the experiment.	A prediction is made that *follows from hypothesis, * is distinct from the hypothesis, *accurately describes the expected outcome of the designed experiment, *incorporates relevant assumptions if needed.
Testing: Is able to decide whether the prediction and the outcome agree/disagree	No mention of whether the prediction and outcome agree/disagree.	A decision about the agreement/disagreement is made but is not consistent with the outcome of the experiment.	A reasonable decision about the agreement/disagreement is made but experimental uncertainty is not taken into account.	A reasonable decision about the agreement/disagreement is made and experimental uncertainty is taken into account.

Appendix E MIC-O-MAP Template for Biology Topic

Pollen Germination

The process in which a pollen grain produces a pollen tube after the even of pollination.

Course Name: Pollen Germination



1

Definitions of the components/Keywords:

- Pollen Grain: The structure that helps carry the male reproductive cells to the female reproductive parts.
- Pollination: The transfer of pollen grain from the anther of the flower to the stigma of the flower
- Stigma: The Tip of the female whorl in the flower that secretes germinating factors (that contain nutrients) that help the pollen grain to germinate.
- Germination: The process in which a pollen tube emerges out of the pollen grain upon getting the right conditions.
- Endosmosis: A process in which living cells gain water along the concentration gradient
- Intine: The inner layer (Cell membrane) of the Pollen grain
- Exine: The outer, waxy, protective covering of the pollen grains. It is not continuous, it has weak spots (Germ pores) where it is thin.
- Germ pore: A weak spot in the pollen grain's exine breaking which the pollen tube emerges.

3

IMPORTANT NOTE TO THE ANIMATOR:

•All the instructions/labels or anything WRITTEN in blue are CONTENT NOT TO BE DISPLAYED!

•All the instructions WRITTEN in black are CONTENT TO BE DISPLAYED!

•This is not applicable for images as there can be overlapping of these colours there. This should be followed for all the instructions, labels,etc...

•Kindly keep a note of this while displaying text in the animation.

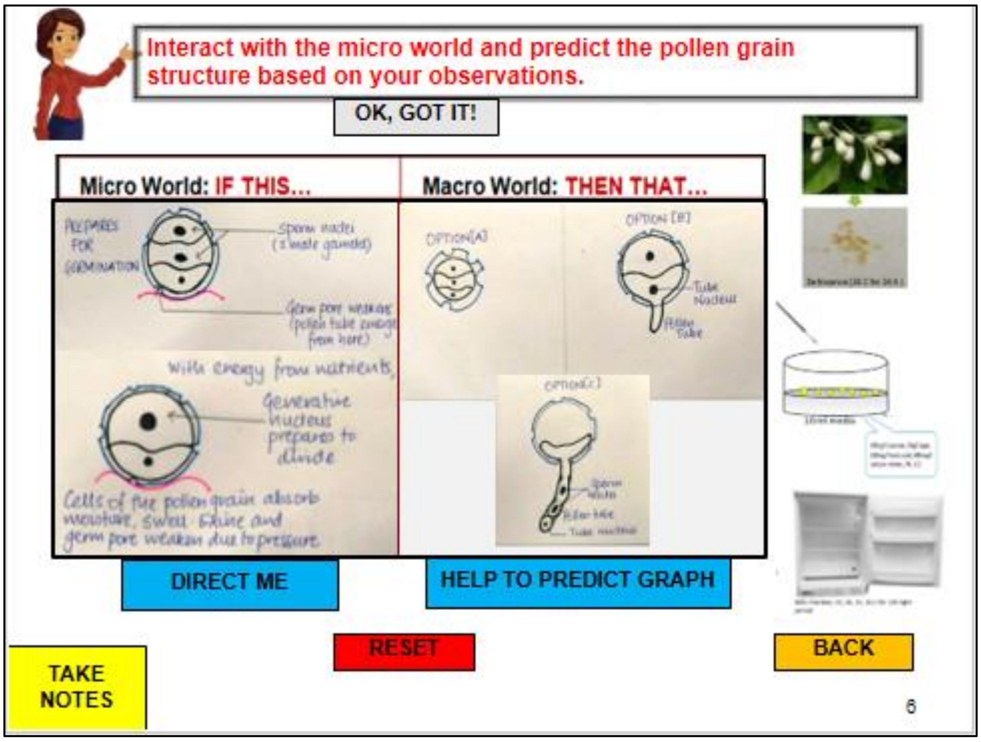
•Display the learning objectives, definitions, glossary, links to further readings and name of the author on the opening page where information from slide 2 is displayed.

4

Master Layout of the module

- Please see the design template provided in the next slide.
- This is a sample template, and you are free to change as per your design requirements.
- Try and recreate the sections/subsections as shown in the template.

5



Stepwise description of process

- The goal of the document is to provide instructions to an animator who is not a expert.
- You have to describe what steps the animator should take to make your concept come alive as a moving visualization.
- Use one slide per step. This will ensure clarity of the explanation.
- Add a image of the step in the box, and the details in the table below the box.
- You can use any images for reference, but mention about it's copyright status
- The animator will have to re-draw / re-create the drawings
- *Add more slides as per the requirement of the animation*

7

Step 0:

Refer to slide 6

Description of the action/ interactivity
•Adjust the screen space as shown in slide 6 such that the options of the simulation of the microscopic world, the graphical options in the form of a multiple choice question, the experimental setup (which should be shown on demand), radio buttons and feedback on top of the screen beside the agent all can be viewed in one screen. •There should be no scrolling. •Reset button, if clicked should bring the screen to its initial stage when the user had just opened the module with no answers retained, •If the user clicks on 'Back' then show them all the steps taken by them till they clicked on this radio button and allow them to go to any stage by clicking on it. •If the user clicks on 'Take Notes' then let a box open which allows text entry. •Retain all choices of options and text entered by the user unless the RESET button is clicked. •Allow the user to keep entering more text unless they close the module. •If the user clicks on 'OK Got It' then let the feedback/instruction disappear and enlarge the rest of the screen. Replace this with a radio button with the title of 'Show Feedback'. If the user clicks on this, re-display the prior feedback seen by the user. •Always the simulation of the microscopic world will be present on the screen. •Put a timer of 2 minutes post which if the screen is idle with no activity, then display ' You seem to be working for quite some time. Would you like to consider taking down some notes?' in the agent dialogue box – rectangle on top. 8

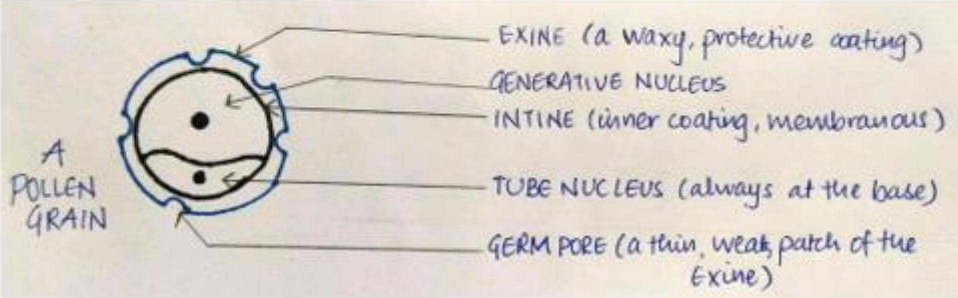
Step 1:

Refer to slide 6

Description of the action/ interactivity	Text to be displayed
•Let the opening screen look like slide 6. •The rectangle on top is the agent dialogue box. After the user clicks on any radio button in the micro world simulation display this in the agent dialogue box: 'When the pollen grain in placed in a nutrient medium, lets try to predict which option represents it structure after germination.' •If the user clicks on Direct Me or Help to Predict Graph go to slide 20. •If the user clicks on Reset go to the opening screen. •If the user clicks on 'BACK' then trace their path, follow each step taken by the user and display it. •Allow text entry in 'Take Notes' and allow enlargement of it. User should also be able to drag it around the entire screen.	The micro world represents the microscopic model of the generative nucleus inside the pollen grain. The pollen grain is placed in a nutrient medium and placed on a cavity slide under a microscope. Interact with the micro world and predict the pollen grain structure after germination. 9

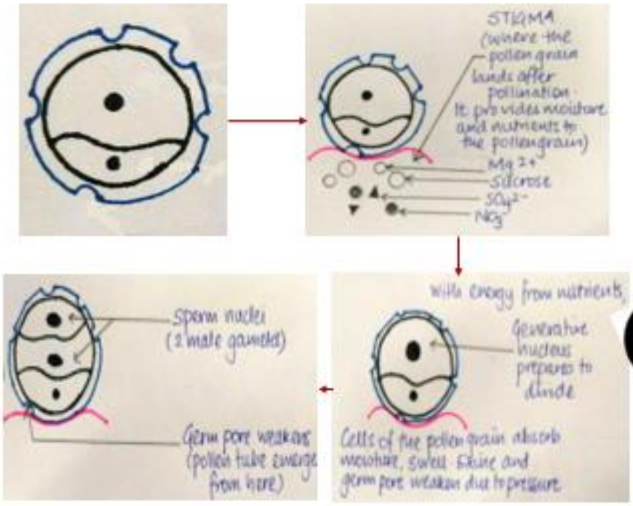
Microscopic Model of a pollen grain

Step 2:



Microscopic Model of a pollen grain

Step 2 contd:



Check the time

Description of the action/ interactivity
•Allow the students to pour the nutrient medium (sucrose and distilled water) onto the cavity slide containing the pollen grain using a glass rod. The cover slip get placed onto the cavity slide to avoid air bubbles. • A clock is to be shown beside the slide ticking till 30minutes and then a microscopic will appear and the option to view the slide under it will be visible. •Once the user clicks on view the slide under the microscope let the zoom in icon appear showing the process of germination. •Animate the four stages shown on slide 11 one after another with the text appearing next to the images as indicated. •Redraw all the images, the images on all slides are only for reference. •If the user clicks on the radio button saying 'check the time' then show '30 minutes' as the time beneath the watch icon. •Once the user clicks on the slide let the clock disappear with the button of 'Check Time' appearing on screen.

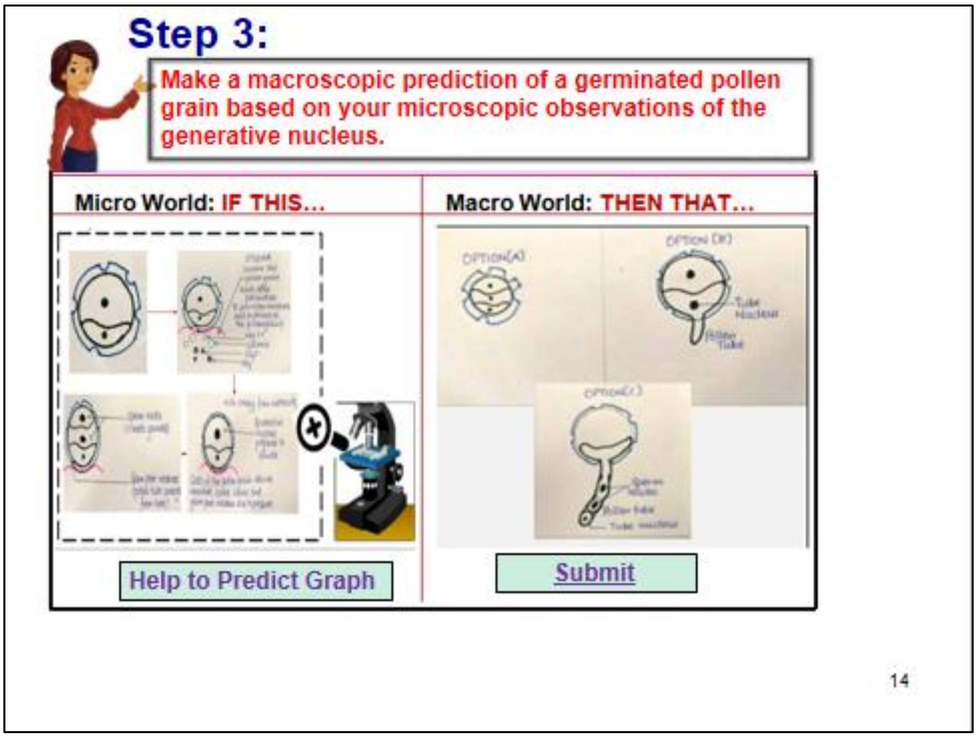
12

Step 3:

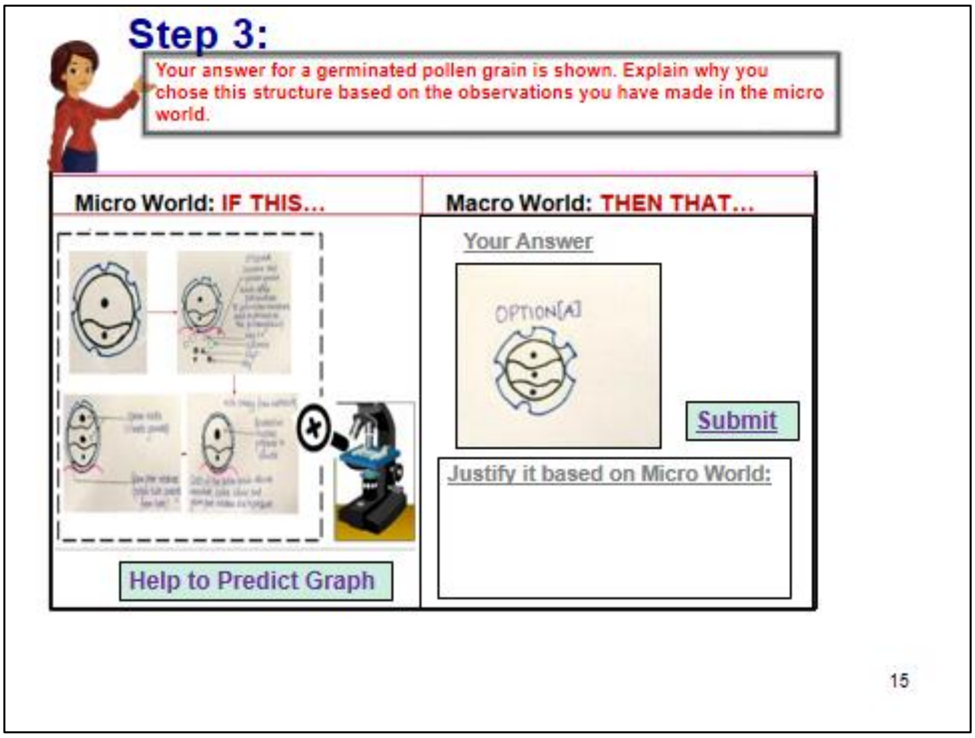
Refer to slide 14

Description of the action/ interactivity	Text to be displayed: Tell the user what macroscopic prediction they are expected to make
•Let the call out keep blinking until the user clicks on a radio button within the rectangle of micro world. •If the user clicks on Direct Me or Help to Predict Graph, Insert the series of questions as shown on slide 20 in the rectangle titled 'Did You Notice'. •If the user clicks on any one of the options under Predict Graph replace the radio button of 'Predict Graph' by 'Submit' as shown on slide 15. •When the user clicks on Submit go to slide 17	Make a macroscopic prediction of a germinated pollen grain based on your microscopic observations of the generative nucleus.

13



Step 3:
Make a macroscopic prediction of a germinated pollen grain based on your microscopic observations of the generative nucleus.
Micro World: IF THIS...
Macro World: THEN THAT...
OPTION(A)
OPTION (B)
Help to Predict Graph
Submit
14



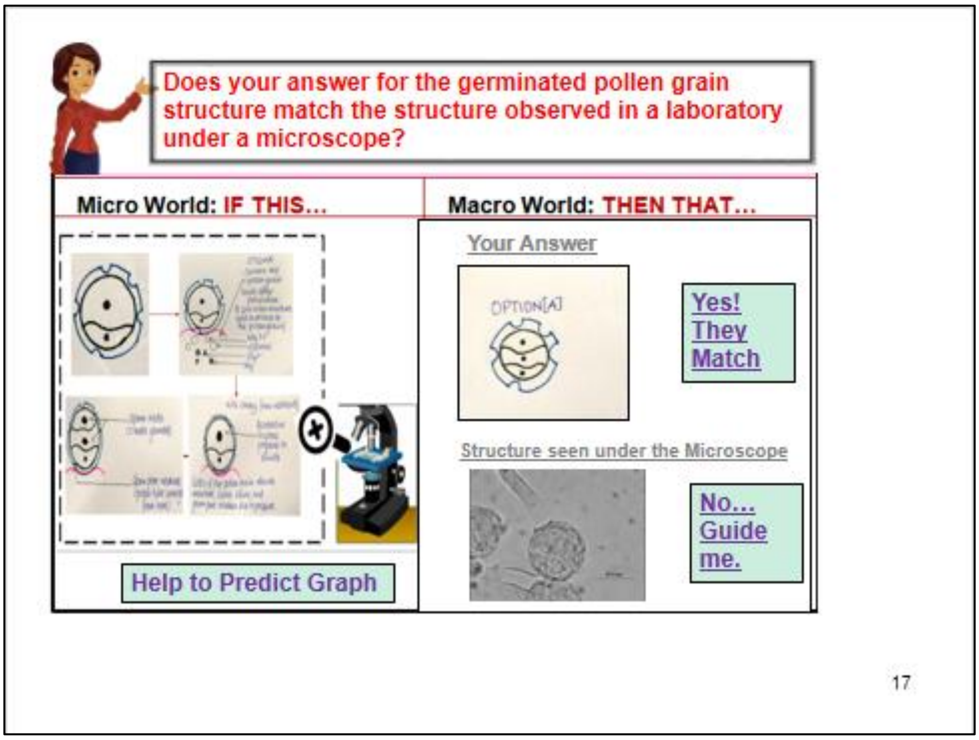
Step 3:
Your answer for a germinated pollen grain is shown. Explain why you chose this structure based on the observations you have made in the micro world.
Micro World: IF THIS...
Macro World: THEN THAT...
Your Answer
OPTION[A]
Submit
Justify it based on Micro World:
Help to Predict Graph
15

Step 3 cont:

Refer to slide 15: Tell the user which option have they chosen under the prediction question and ask them to establish a link between the observation in the microscopic world and the prediction

Description of the action/ interactivity	Text to be displayed
•Display the answer chosen by user in the right hand side space and allow text entry in the box where 'Justify it based on micro world' is written. •When the user clicks on Submit go to slide 17	Your answer for the germinated pollen grain is shown. Explain why you chose this graph based on the observations you have made in the micro world.

16



Step 4:

Refer to slide 17: Provide feedback for the choice of every option in the testing question. Sample feedback is shown below.

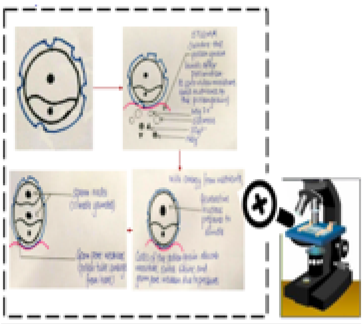
Description of the action/ interactivity

•Display the Real World answer and the graph below it under the answer chosen by user and let 2 radio buttons pop up.
If user selects 'Yes! They Match' then display this under in the rectangle where currently a question is posed : "That's Good! You have correctly predicted the structure of a germinated pollen grain. Now let us summarize the entire process of germination." Also let Proceed come up. When user clicks on this go to slide 36.

•If the user selects 'No..Guide me' then display "You need to make more careful observations and establish a link between the microscopic model of the pollen grain and its macroscopic IV characteristics. Would like to try again?" If the user clicks on Direct Me go to slide 20.

18

Let us analyze why the prediction is not matching with the real world answer.

Micro World: IF THIS...	Assertion & Reasoning Questions
	For the Questions to be displayed here go to slide 20. Here display this text as shown in the rectangle above: Let us analyze why the prediction is not matching with the real world answer.
Help to Predict Graph	Predict Graph Again

Here, if user clicks on 'Predict Graph Again' then go to slide 14. If user clicks on 'Help to Predict Graph' go to slide 20.

19

Your reason for selecting option ___ was ______________________________.

Let us analyze why your prediction and reasoning was incorrect. Observe the micro world again.

Which of the following most closely matches what you observed in the microscopic model of the pollen grain:

A. When inserted into the nutrient medium, the pollen grain structure is complete – exine and intine. It looks exactly like three cells one above the other. ◯

B. When inserted into the nutrient medium, the pollen tube emerges from the weak spot of the exine. The two cells can be seen because one cell splits into two. ◯

C. When inserted into the nutrient medium, the pollen tube has emerged from the weak part of the exine. Tube nucleus at the base and two sperm nuclei are present. IN total 3 cells can be seen. ◯

D. None of the above. ◯

20

Description of the action/ interactivity: Provide feedback for user's choice of every option. Sample feedback is given below.

- Let there be radio buttons for selection along with each option as indicated.
- If the user selects option A go to slide 22.
- If the user clicks selects option B go to slide 24.
- If the user clicks selects option C then display this in the rectangle on top in slide 20 " That's right! This is reason why you see the pollen grain germinating. You have correctly applied the microscopic model in order to arrive at this conclusion."
- If the user selects option D then display this in the rectangle on top in slide 20"You need to carefully observe the microscopic model of the pollen grain. Go back and observe carefully what happens when you insert the pollen grain into a nutrient medium."

21

You say that 'When inserted into the nutrient medium, the pollen grain structure is complete – exine and intine. It looks exactly like three cells one above the other.'

Let us check if this is what you observed in the microscopic model of the pollen grain: (If you want, then you can go back and insert the nutrient medium, observe what happens and then answer these questions.)

1. The exine becomes thinner. [True] [False]
2. The overall pollen grain increases in size. [True] [False]
3. There is a connection between the nutrient medium absorption and the division of the generative nucleus. [True] [False]
4. The cells of the pollen grain absorb moisture and swell, the exine and the germ pore weaken leading to the emergence of the pollen grain. [True] [False]

22

Description of the action/ interactivity: Provide feedback for user's choice of every option. Sample feedback is given below.

- Allow user to answer one question at a time. When first question is answered, display feedback for that, then display the next question and while displaying second question remove the feedback for the earlier question.
- If the user clicks on 'Yes' for option 1 then display, "This is incorrect. Go back and notice the size of the pollen grains once they have absorbed moisture"
- If the user clicks on 'No' for option 1 then display, "Yes! That's right. Go ahead and answer the next question."
- If the user clicks on 'Yes' for option 2 then display, "This is incorrect. Go back and notice the size of the pollen grains once they have absorbed moisture"
- If the user clicks on 'No' for option 2 then display, "Yes! That's right. Go ahead and answer the next question."
- If the user clicks on 'Yes' for option 3 then display " That's right! Go ahead and try to think how the two are related."
- If the user clicks on 'No' for option 3 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and observe what happens in the microscopic model of the pollen grain once it is inserted into the nutrient medium"
- If the user clicks on 'Yes' for option 4 then display " That's right! Now think about the number of cells which are formed when the generative nucleus divides."
- If the user clicks on 'No' for option 4 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the pollen grain"
- Allow the user to answer one question at a time and then proceed to the next question. Then show the first question faded and allow them to answer next question.
- Display this feedback in the rectangle on top in slide 19.

23

You say that 'When inserted into the nutrient medium, the pollen tube emerges from the weak spot of the exine. The two cells can be seen because one cell splits into two.'

Let us check if this is what you observed in the microscopic model of the pollen grain: (If you want, then you can go back and insert the nutrient medium, observe what happens and then answer these questions.)

1. The generative nucleus divides. **True** **False**
2. The tube nucleus emerges from the weak spot of the exine. **True** **False**
3. There is a connection between the nutrient medium absorption and the division of the generative nucleus. **True** **False**
4. The three cell structure formed after absorption of the nucleus medium coverts to a two celled structure after a time lapse. **True** **False**
5. The cells of the pollen grain absorb moisture and swell, the exine and the germ pore weaken leading to the emergence of the pollen grain. **True** **False**

24

Description of the action/ interactivity: Provide feedback for user's choice of every option. Sample feedback is given below.

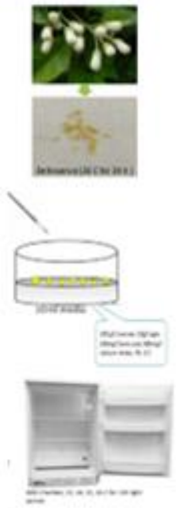
- Allow user to answer one question at a time. When first question is answered, display feedback for that, then display the next question and while displaying second question remove the feedback for the earlier question.
- If the user clicks on 'Yes' for option 1 then display, "Yes! That's right. Go ahead and answer the next question."
- If the user clicks on 'No' for option 1 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and observe what happens to the generative nucleus once it is immersed into the nutrient medium"
- If the user clicks on 'Yes' for option 2 then display, "Yes! That's right. Go ahead and answer the next question"
- If the user clicks on 'No' for option 2 then display, "This is incorrect. Go back and observe what happens to the tube structure after the division of the generative cell."
- If the user clicks on 'Yes' for option 3 then display " That's right! Go ahead and try to think how the two are related."
- If the user clicks on 'No' for option 3 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the pollen grain"
- If the user clicks on 'Yes' for option 4 then display "This is incorrect. Recollect that growth is an irreversible process and a three celled structure cannot go back to a two celled structure. Consider this and try again."
- If the user clicks on 'No' for option 4 then display, "That's right! Now think about the number of cells which are formed when the generative nucleus divides"
- If the user clicks on 'Yes' for option 5 then display " That's right! Now think about the number of cells which are formed when the generative nucleus divides."
- If the user clicks on 'No' for option 4 then display, "This is incorrect. You need to make careful observations and answer the rest of the questions. Go back and vary voltage and observe what happens in the microscopic model of the pollen grain"
- Allow the user to answer one question at a time and then proceed to the next question. Then show the first question faded and allow them to answer next question.
- Display this feedback in the rectangle on top in slide 19.

25

Step 6:

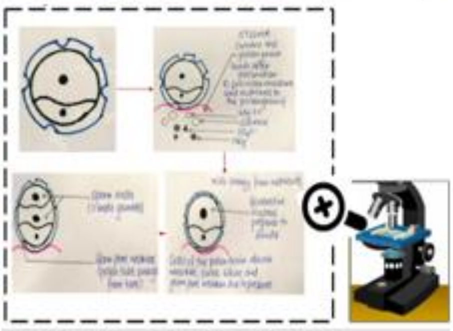
Experiment

This simulation should be exactly same as that given in slide 11.



Show the experimental setup as it is in the laboratory

Microscopic Model of Pollen Grain



Macroscopic Outcome

26

Step 6 contd:

Insert the nutrient medium on the slide, observe the microscopic model and pollen grain germination and briefly summarize the entire process of generative cell division leading to germination:

See Summary

Description of the action/ interactivity

- Show the three images from slide 26. Allow students to enter text input in the above figure.
- If the user clicks on 'See Summary' , display the following:

'Summary:

In flowering plants, however, the ovules are contained within a hollow organ called the pistil, and the pollen is deposited on the pistil's receptive surface, the stigma. On the stigma, the germination of pollen grains begins by absorption of water and nutrients and the pollen grain produces a tiny pollen tube through the style to the ovary. The tube cell enlarges and comes out of the pollen grain through one of the germ pores to form a pollen tube. The tube nucleus descends to the tip of the pollen tube.

27

Links for further reading

Books:

1) Essential Cell Biology. Ed: Bruce Alberts, Dennis Bray, Karen Hopkin and Alexander Johnson (2009) 3rd Edition Pub: Garland Science

2) Biology A Modern Introduction, B.S.Beckett (1994), GCSE Edn. Oxford Univ. Press.

28

Glossary

- Pollen Grain: The structure that helps carry the male reproductive cells to the female reproductive parts.
- Pollination: The transfer of pollen grain from the anther of the flower to the stigma of the flower
- Stigma: The Tip of the female whorl in the flower that secretes germinating factors (that contain nutrients) that help the pollen grain to germinate.
- Germination: The process in which a pollen tube emerges out of the pollen grain upon getting the right conditions.
- Endosmosis: A process in which living cells gain water along the concentration gradient
- Intine: The inner layer (Cell membrane) of the Pollen grain
- Exine: The outer, waxy, protective covering of the pollen grains. It is not continuous, it has weak spots (Germ pores) where it is thin.
- Germ pore: A weak spot in the pollen grain's exine breaking which the pollen tube emerges.

29

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Publications

Thesis Related

- Kenkre, A. B., & Murthy, S. (2014, December). A Self Study Learning Environment for Modeling Abilities: Do all learners take the same Learning Path?. In *Technology for Education (T4E), 2014 IEEE Sixth International Conference on* (pp. 10-17). IEEE.
- ICCE-2014: 'Development of Predict-Test-Revise Modeling Abilities via a self-study Learning Environment'- Anura Kenkre, Sahana Murthy & Madhuri Mavinkurve. (Accepted-poster paper)
- ICCE 2016: Students Learning Paths in Developing Micro-Macro Thinking: Productive Actions for Exploration in MIC-O-MAP Learning Environment- Anura Kenkre & Sahana Murthy (Accepted- Full paper)
- RPTEL-2016: Development of micro-macro thinking skills via a self-regulated learning environment - Anura Kenkre & Sahana Murthy. (Under Review – Round 2)
- ICALT-2017: Learning of Micro-Macro Thinking in Analog Electronics via MIC-O-MAP TEL Environment – Anura Kenkre & Sahana Murthy (Accepted – Full Paper)

Non Thesis Related:

- Kenkre, A., Banerjee, G., Mavinkurve, M., & Murthy, S. (2012, July). Identifying Learning Object pedagogical features to decide instructional setting. In *Technology for Education (T4E), 2012 IEEE Fourth International Conference on* (pp. 46-53). IEEE.
- Anand, A., Kothiyal, A., Diwakar, A., Kenkre, A., Deep, A., Reddy, D., ... & Ramesh, R. (2014, December). Designing Engineering Curricula Based on Phenomenographic Results: Relating Theory to Practice. In *Technology for Education (T4E), 2014 IEEE Sixth International Conference on* (pp. 80-87). IEEE.
- Banerjee, G., Kenkre, A., Mavinkurve, M., & Murthy, S. (2014, July). Customized Selection and Integration of Visualization (CVIS) Tool for Instructors. In *2014 IEEE 14th International Conference on Advanced Learning Technologies* (pp. 399-400). IEEE.
- Kenkre, A., & Murthy, S. (2012). Design and Evaluation of OSCAR Physics Learning Objects. *Journal of Research: THE BEDE ATHENAEUM*, *3*(1), 6-10.

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Date:

IIT Bombay, India   Anura Kenkre