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

Thesis Defence Seminar

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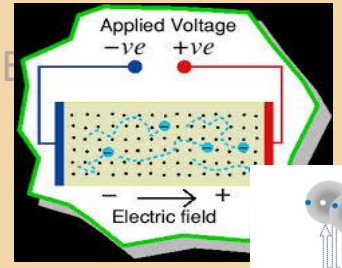
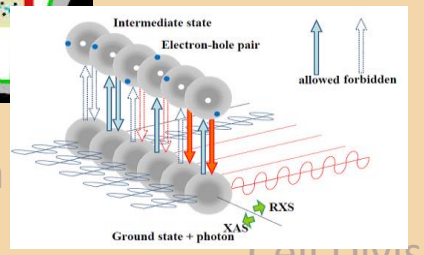
Microscopic
(invisible elements, molecular level)





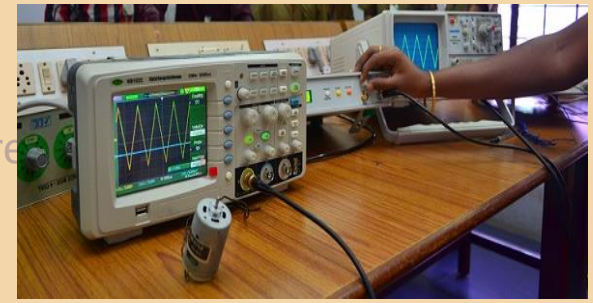
Protons

Atom Vibration

Cell Division

Chemical Reaction

Macroscopic
(directly observable)



Colour Change

Temperature

Doping

Understanding and Co-relation needed across Levels [Wilensky & Resnick,1999]

Not Always [Gabel, 1998]

?

Why????

Are students able to link the two?

Difficulty In Linking A Micro Level To Macro Level

- Difficulty transferring from a macroscopic level of representation to the microscopic level [Gabel, 1998]
- Can correctly solve numerical problems but unable to identify a pictorial solution on a molecular level. [Hinton & Nakhleh,1999]
- Stud… level of repr…
- If c… eptions [Gilbert,2004].

Problem: Micro-Macro Thinking needs to be explicitly developed.

What is Micro-Macro Thinking?

- **Students should be able to-**
  - Describe what is being observed in the micro world. **Observe**
  - Devise an explanation for observed pattern by co relating outcomes in macro world and dynamics in micro world. **Explain**
  - Make a reasonable prediction in the macro world based on explanation **Predict**
  - Decide whether prediction and outcome agree/disagree in the macro world. **Test**
  - Alter explanation co relating micro & macro worlds based on which prediction was made and justify changes. **Revise**

Overall, student should be able to establish a link between invisible/theoretical variables in a micro world and its corresponding manipulable variables in a macro world in order to predict the functionality for any given system. We refer to this as Micro-Macro Thinking.

Also reported as a key aspect of: Systems Thinking [Wilensky & Resnick, 1999]; Scientific Modeling [Etkina et.al., 2006]; Scientific Thinking [Wilkening & Sodian 2005].

Micro Macro Thinking in Professional Scenario

Pharmacy (lab technician)

Designing, developing and manufacturing electrical components

Pathologists

Instrument design (E.g.: medical)

Initial Research Goal

Create & Evaluate a TEL Environment to develop Micro-Marco thinking skills.

Existing Interventions

F2F Classroom Solutions

Model-based Analysis and Reasoning in Science (MARS) [Raghavan & Glaser, 1995]

Investigative Science Learning Environment (ISLE) [Etkina & Van Heuvelen, 2007]

Technology Enhanced Learning Solutions

WISE (Web-based Science Environment) [Slotta, 2004]

Web-based inquirer with modeling and visualization technology (WiMVT) [Sun & Looi, 2013]

Model-It [Fretz et.al., 2002]

nQuire [Mulholland et.al., 2012]

Inquiry Island [White, et.al., 2002]

CO LAB (Virtual Lab) [van Joolingen et.al., 2005]

GO LAB (Virtual Lab) [Govaerts et.al., 2013]

Sim Quest [Van Joolingen, & Jong, 2003]

Modeling Space [Avouris et.al., 2003]

Why can't these be modified for our research goal? The teacher plays a crucial role by facilitating/giving prompts, methods include other components such as lab work, field trips, discussions and assignments, these are part of a peer learning process. Mostly for middle and high school science curriculum.

Our Target Audience: College Students who need to apply their knowledge in professional scenarios ahead in the absence of a mentor.

The Research Objective of This Thesis

Create & Evaluate a TEL Environment to develop Micro-Marco thinking skills for tertiary education in the context of self learning.

MICroscopic Observations MAcroscopic Predictions (MIC-O-MAP)

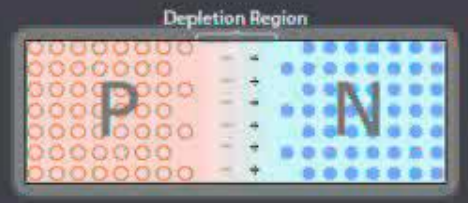
What Is The Scope Of The Research?

- Setting = Self Learning i.e. There is no special guidance expected from a teacher.
- Domain = Basic Analog Electronics
- Target Audience = Under Graduate Students, Fluent In English, Familiar With Technology

Intervention Tour (MIC-O-MAP)

DIODE CHARACTERISTCS

Home



GET STARTED

PN Junctions

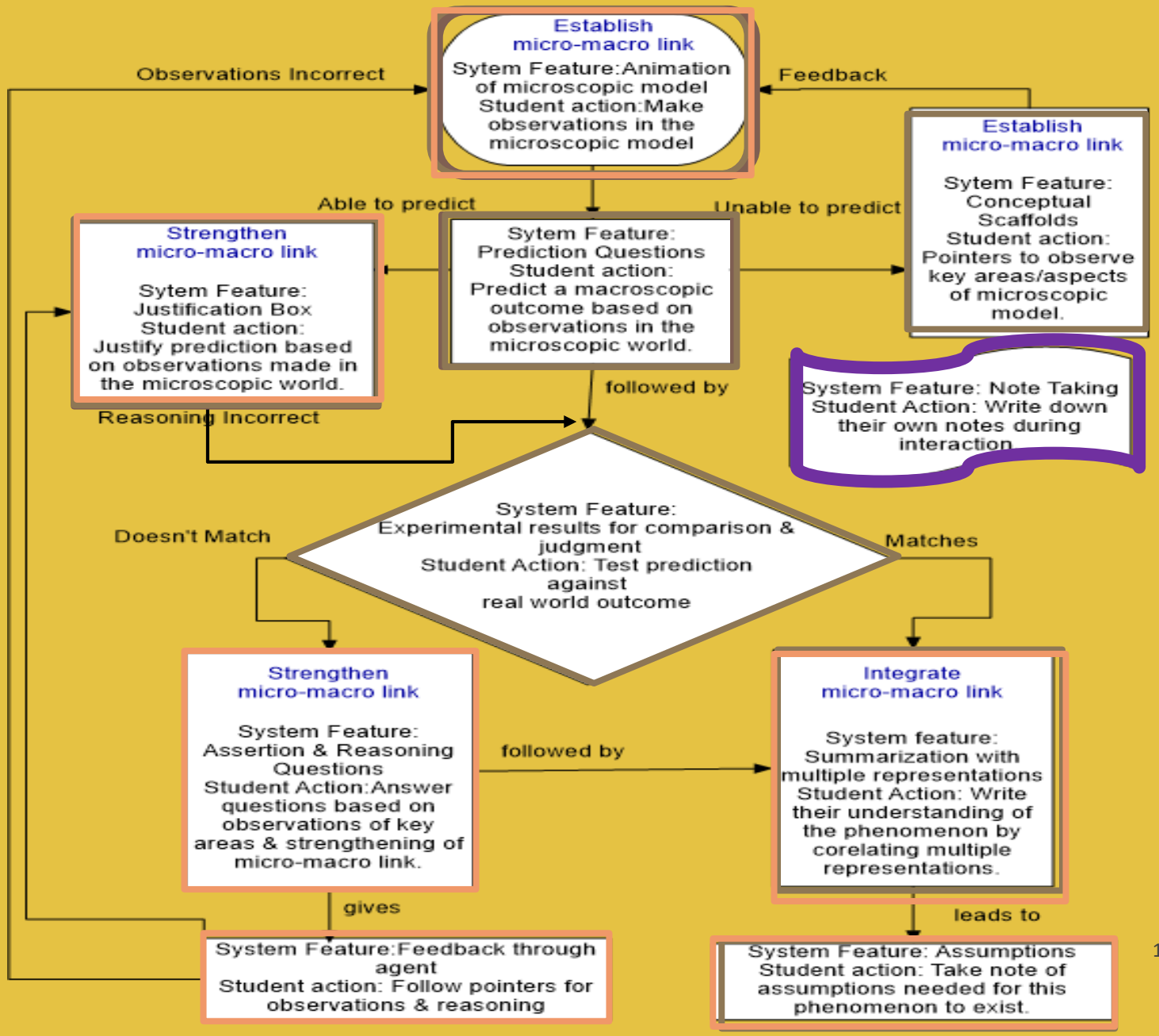
A device with a junction between a p-type and an n-type semiconducting material

Learning Objectives

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

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

OUR SOLUTION



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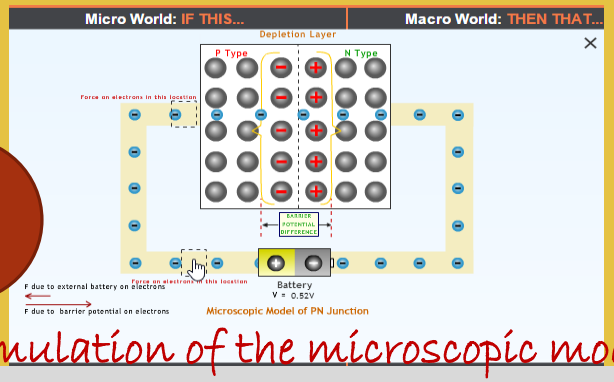
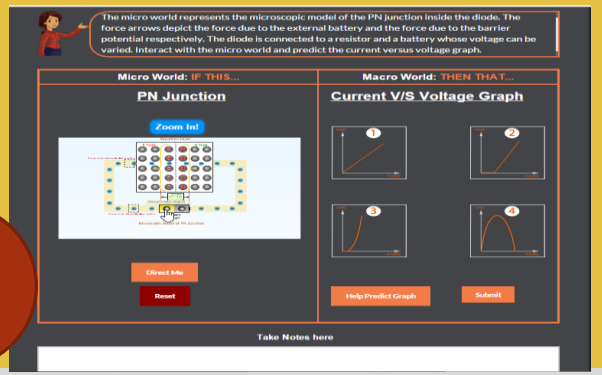
1



Simulation of the microscopic model

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].

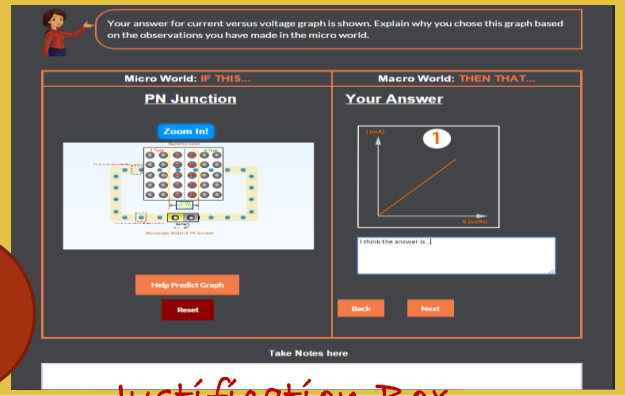
2



Adaption of a known model to the specifications of the given problem [Wilkening & Sodian, 2005].

Prediction Questions

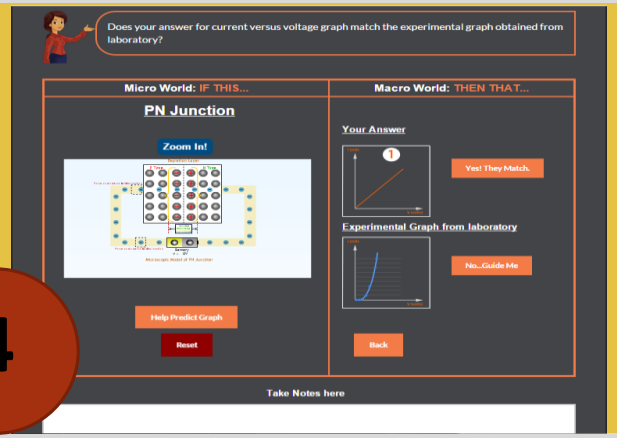
3



Justification Box

Students should be able to justify their conclusions for a given experiment [Wells et.al., 1995].

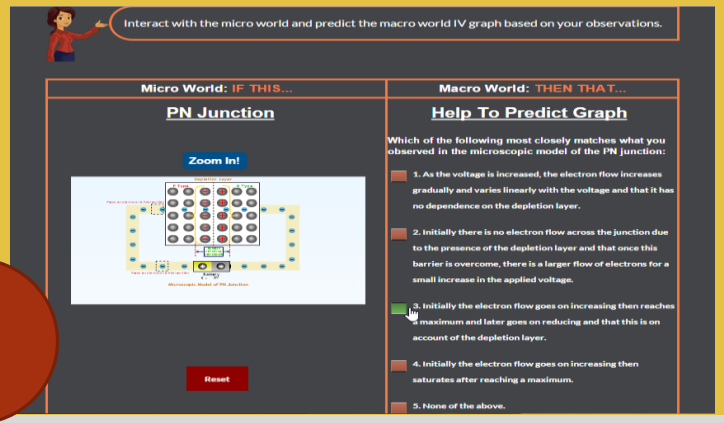
4



Students should be able to analyze the outcomes of an experiment.

Real World Answer for Testing

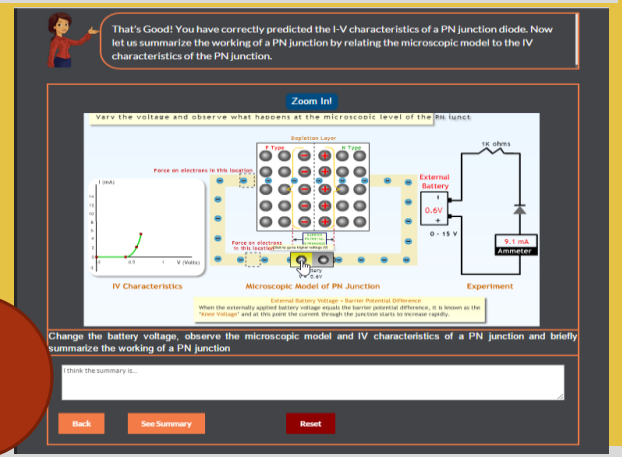
5



Question prompts can facilitate explanation construction and making justifications [Wielinga et.al., 1992; Davis, 2000]

Assertion & Reasoning Questions

6



employing a variety of representations is helpful in understanding the underlying relations and processes. [Kozma et.al., 1997]

Multiple Representations

Theoretical Basis Of MIC-O-MAP

Theoretical Base	Recommendation from theory	Application to MIC-O-MAP
Inquiry Learning	Involve students in cycles of orientation, hypothesis generation, experimentation & reaching conclusions, evaluation, planning & monitoring [Quintana et.al., 2004].	Sub skills involves an inquiry cycle wherein students make observations in the micro world, predict an outcome in a macro world and justify this based on the micro-macro link, also test this prediction against a laboratory outcome. **Features of MIC-O-MAP:** Simulation of Micro World, Prediction Questions & Justification Box, Real World Answer, Assertion and Reasoning Questions, Multiple Representations

Theoretical Basis Of MIC-O-MAP

Theoretical Base	Recommendation from theory	Application to MIC-O-MAP
Self Learning	An active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition in the service of those goals [Winne, 2001; Zimmerman & Schunk, 2001; Winne & Hadwin, 1998]	We want students to reflect and decide their actions without a teacher **Features of MIC-O-MAP:** Assertion and Reasoning Question, Dialogue with an agent Note taking, Path Tracing

Theoretical Basis Of MIC-O-MAP

Theoretical Base	Recommendation from theory	Application to MIC-O-MAP
Question Prompts	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].	Instances when students are unable to predict an outcome or justify their prediction based on a micro-macro link, a series of questions will be asked based upon their choices. **Features of MIC-O-MAP:** Assertion and Reasoning Questions, Dialogue with an agent

Theoretical Basis Of MIC-O-MAP

Theoretical Base	Recommendation from theory	Application to MIC-O-MAP
Feedback & Assessment	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].	Students will receive feedback based on their choice of answers directing them towards an area of the simulation or aiding them in establishing a link between the microscopic and macroscopic worlds **Features of MIC-O-MAP:** Assertion and Reasoning Questions, Dialogue with an agent

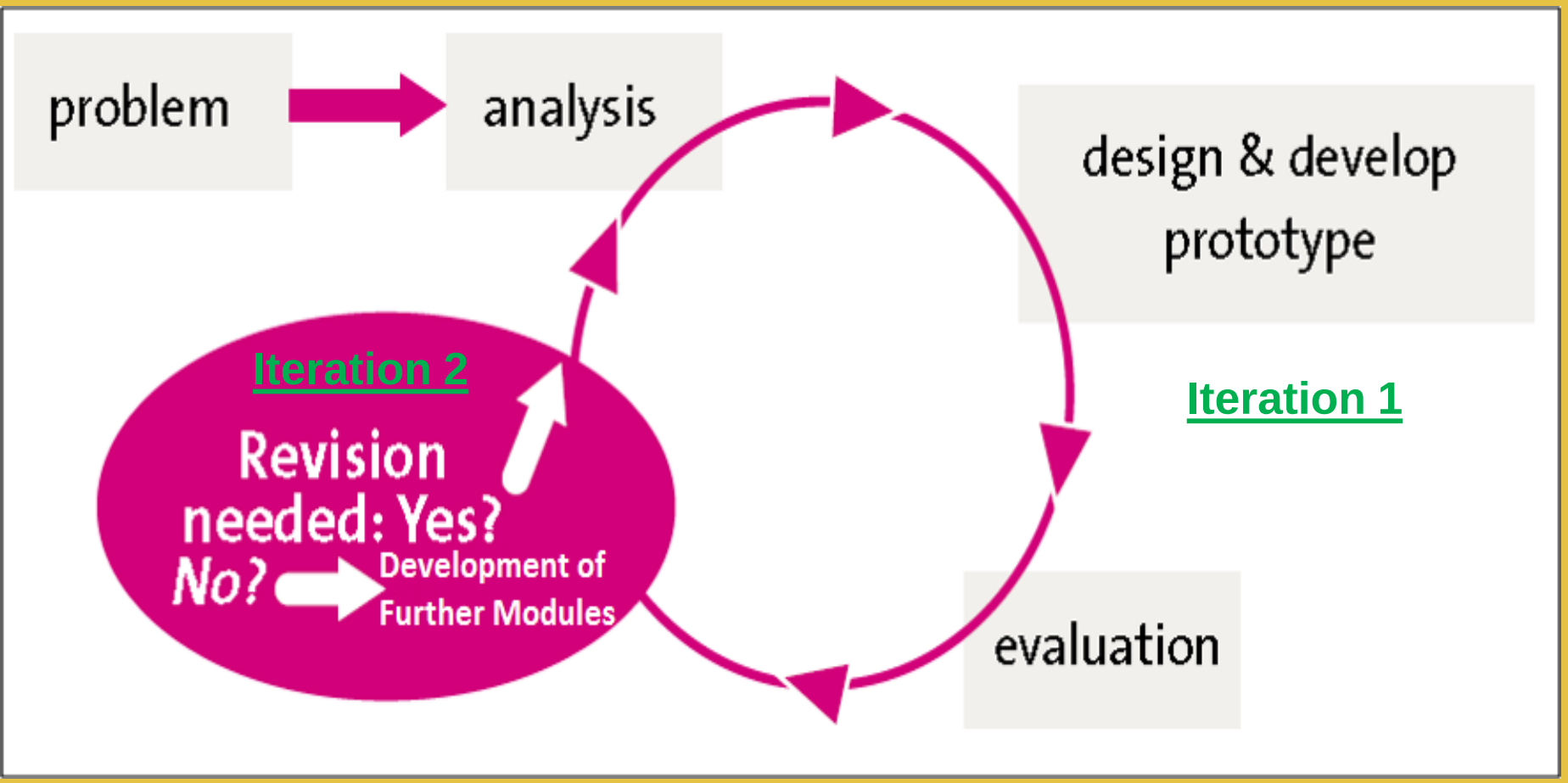
Theoretical Basis Of MIC-O-MAP

Theoretical Base	Recommendation from theory	Application to MIC-O-MAP
Types of Scaffolds	Conceptual scaffolds i.e. hints and prompts [Vye et.al., 1998], metacognitive scaffolds i.e. human or nonhuman learning agents, procedural scaffolds which assist with learning to use resources [Azevedo et.al., 2004] and strategic scaffolds which expose students to the solution paths [Azevedo & Lajoie, 1998]	The feedback provided to students is mediated through a pedagogical agent and they are allowed to trace their navigation path in order to help them reach any specific choice of task. **Features of MIC-O-MAP:** Dialogue with an agent, Note taking, Path Tracing

HOW WAS MIC-O-MAP CREATED?

Design Based Research (DBR) Process

Why?



[Wang & Hannafin, 2005]

- ✓ **Iterative cycles of development, implementation [DBR, 2003]**
- ✓ **Both quantitative and qualitative methods- document why and how adjustments are made [Collins et al., 2004]**
- ✓ **Outcomes from previously conducted designs provide explanatory frameworks for next cycle [Cobb et al., 2003]**

Solution Approach To Build MIC-O-MAP

Literature Review of Exiting Solutions → Identification of features

✓ COMPLETE

Development of MIC-O-MAP Version 1

✓ COMPLETE

Iteration 1

Evaluation

Quantitative study – micro macro skill development.
Qualitative study – Identification of learning related problems

Revision Needed? Yes?

No? → Development Of Further Modules

Themes for the Research Work

- Theme 1 (T 1): Learning of micro-macro thinking using MIC-O-MAP
- Theme 2 (T 2): Interaction of learners with MIC-O-MAP
- Theme 3 (T 3): Process of acquiring micro-macro thinking

- T1 will be based on statistical evaluation where as T2 and T3 will based on a qualitative evaluation of a student wise interaction with the TEL environment.

Over All Research Goal: To design a TEL environment that will enable students to develop micro-macro thinking skills.

Research Questions

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

RQ2: a) What interaction paths do students follow as they learn with MIC-O-MAP?

RQ2: b) What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

RQ2: c) What was the effect of the improvised design on students' interaction with the various features of the learning environment?

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

Solution

Theme 1 | Theme 2 | Theme 2 | Theme 2 | Theme 3

Creation of a TEL Environment (MIC-O-MAP) for developing Micro-Macro Thinking Skills.

Method

Prototype 1

Prototype 2

Overall Research Design is Design Based Research (DBR)

Research Studies

Study 1: Two Group Quasi Experimental Research Design (N= 73)

Study 4, 6: Single Group Pre Post test Research Study (N=46) (N=30) (N=29) (N=30)

Study 7: Exp Repeated Measures Study (N=29)

Study 2: Qualitative Study with the screen capture of experimental group from Study 1

Study 3: Qualitative Study with the screen capture of students from Study 1

Study 5: Qualitative study – Semi structured Interviews (N=12)

Study 8: Qualitative study – 3 Case Studies

Cycle 1: Testing & Refinement

Over All Research Goal: To design a TEL environment that will enable students to develop micro-macro thinking skills.

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

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Theme 1

Theme 2

Theme 2

Theme 2

Theme 3

Solution

Creation of a TEL Environment (MIC-O-MAP) for developing Micro-Macro Thinking Skills.

Method

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Prototype 2

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(Study 1)

Study 2: Qualitative Study with the screen capture of experimental group from Study 1

Study 3: Qualitative Study with the screen capture of students from Study 1

Study 5: Qualitative study – Screen Capture Analysis

Study 8: Qualitative study – 3 Semi structured interviews and Case Studies

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

Methodology: QUANT	Two Group Controlled Experiments
Sample Characteristics	Exp. Gr (N=37) & Control Gr (N= 36) Control Group given 2 page write up to establish equivalence.Topic: P-N Junctions-forward biased, from the subject of physics. Prior knowledge→ XII standard science. Time period: 1 hour.
Data Analysis Technique	Post Test mapping to O-P-T-R skills Grading using the scientific abilities rubrics inter rater reliability : Cohen's Kappa : 0.839 with $p<0.001$.

Results & Implications

The experimental group performed significantly better than the control group for all the abilities except observation.

Mann-Whitney U Test Scores

SIGNIFICANT DIFFERENCE

Micro-Macro Thinking Skills	Experimental Group (Mean rubric score)	Control Group (Mean rubric score)	p-value
Describe observations without explanations	1.97	1.77	0.195
Devise an explanation for an observed pattern	1.62	0.83	0.000
Make prediction based on explanation	1.62	1.19	0.003
Decide whether the prediction and the experimental outcome agree	2.27	1.83	0.014
Revise the explanation when necessary	0.64	0.22	0.008

Over All Research Goal: To design a TEL environment that will enable students to develop micro-macro thinking skills.

Research Questions

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RQ2: a) What interaction paths do students follow as they learn with MIC-O-MAP?

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Solution

Theme 1 | Theme 2 | Theme 2 | Theme 2 | Theme 3

Creation of a TE . Environment (MIC-O-MAP) for developing Micro-Macro Thinking Skills.

Method

Prototype 1 | Prototype 2

Overall Resear Design Based Research (DBR)

(Study 2, 3)

Research Studies

Study 1: Two Group Quasi Experimental Research Design (N= 73)

Study 4, 6: Single Group Pre Post test Research Study (N=46) (N=30) (N=29) (N=30)

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Study 8: Qualitative study – 3 Semi structured interviews and Case Studies

RQ2: a) What interaction paths do students follow as they learn with MIC-O-MAP?
RQ2: b) What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

Methodology: QUAL	Screen Capture Log Analysis
Sample Characteristics	Experimental Group (N=37)
Data Analysis Technique	Screen Capture was transcribed
	Codes were allotted to Transcripts
	Codes were converted into categories depicting student behaviours.

Students' Interaction with MIC-O-MAP

Learning Time: On an average, all the students spent around 30 minutes interacting with all the features of MIC-O-MAP.

Time Spent

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

SIGNIFICANT DIFFERENCE IN TIME SPENT BY HIGH & LOW SCORERS ON DIFFERENT FEATURES.

- **Low scorers spent double the time in answering prediction questions compared to high scorers.**
- **High scorers spent thrice the amount of time in answering conceptual scaffolds and following the feedback.**

Students' Interaction with MIC-O-MAP

Frequencies

Code	Low Scorer	High Scorer
Reasoning using assertion and reasoning questions	8	16
Basis for justification-reason micro to macro link	4	26
Make informed choice in multiple choice question in prediction activity	2	11

- **High scorers made more than 5 times the number of attempts to make an informed choice of the prediction and establishing a micro-macro link while writing their justification as compared to low scorers.**
- **High scorers made twice the number of attempts in following question prompts compared to low scorers.**

This establishes a difference in the reasoning method of students who score high and those who score low.

Clickstream Analysis [Taniguchi, 2009]

Interaction Pattern

High Scorer:

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

Low Scorer:

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

High Scorers follow the interaction path as advised in our design!

Solution Approach To Build MIC-O-MAP

Literature Review of Exiting Solutions → Identification of features

✓ COMPLETE

Development of MIC-O-MAP Version 1

✓ COMPLETE

Iteration 1

Evaluation

Quantitative study – micro macro skill development.
Qualitative study – Identification of learning related problems

✓ COMPLETE

Revision Needed? Yes?

No? → Development Of Further Modules

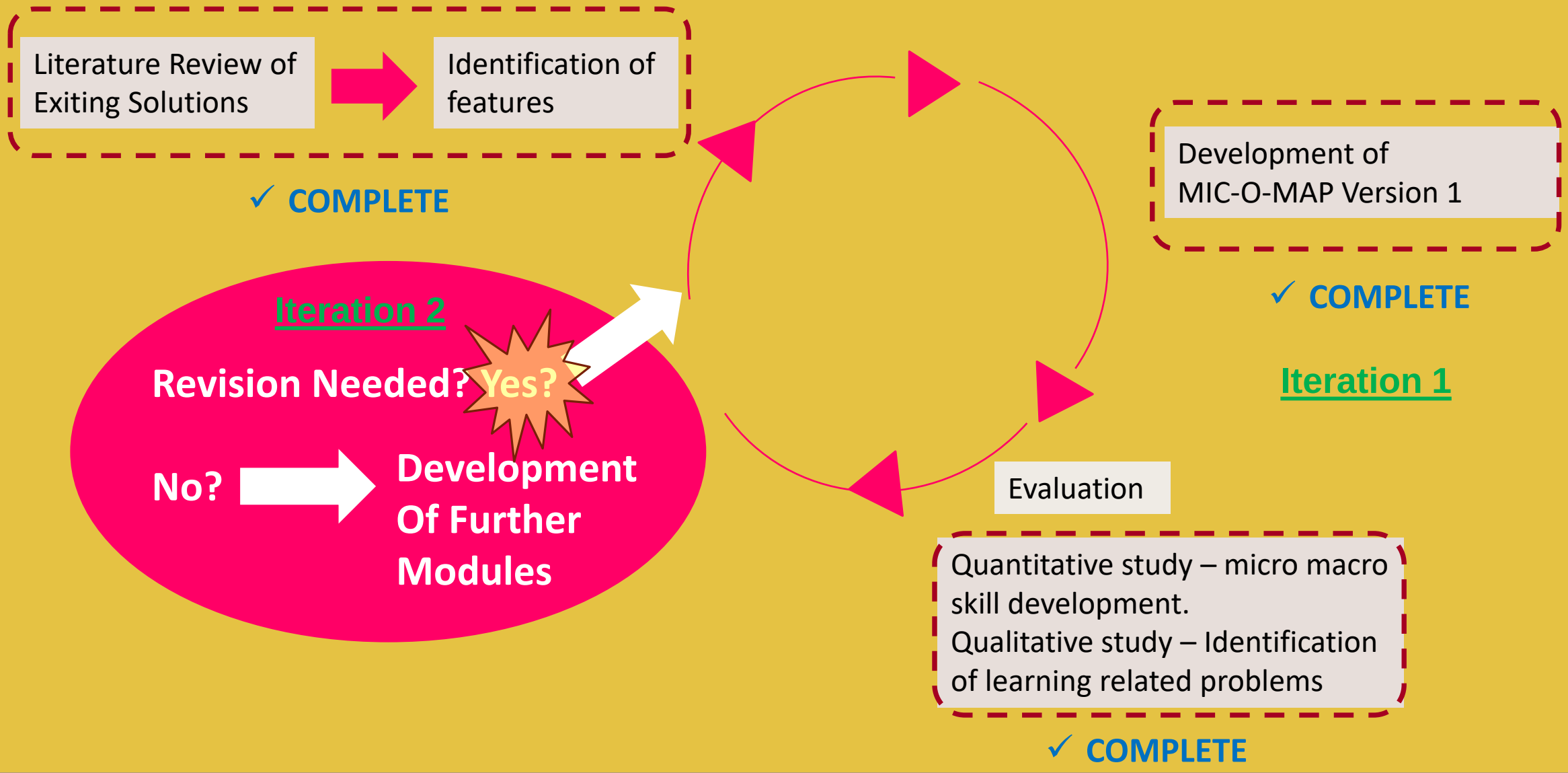
Redesign Elements from problems identified

Observations from qualitative analysis of Experiment 1(N=10)	Learning related problems located	Possible reason for problem	Requirement	Redesign step to address problem
No of visits to Prediction Questions : 132 Making an informed choice of prediction: 11 No. of visits to Justification feature = 62 Attempts to establish a micro to macro link : 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.	Shift student attitude to view conceptual scaffolds as helpful prompts and not evaluation. & Provide pointers to key areas	Incorporating the **question prompts at two stages**: when a choice of graph is made and justification is written & when testing indicates incorrect prediction. Option to take notes.
No. of visits to Question prompts = 34 Attempts to follow pointers and indulge in sense making: 20	Leaving task half way after getting multiple answers incorrect.	Perceiving question prompts as assessment.		Including a **pedagogical agent** and providing feedback as a **dialogue**.

Redesign Elements from problems identified

Observations from qualitative analysis of Experiment 1(N=10)	Learning related problems located	Possible reason for problem	Requirement	Redesign step to address problem
No. of visits to Animation of micro world: 88. Attempts to follow pointers and indulge in sense making: 20 No. of visits to Question prompts = 34 Attempts to follow pointers and indulge in sense making: 20	While number of observations in the animation was high, the number of times feedback from the question prompts was followed was much lower.	Overload on memory to recollect pointers from feedback while interacting with animation of microscopic model.	Enable learners to figure out which area they have less interacted with and ensure that they co relate the graphical outcomes and the animation viewed.	**Simultaneous display of animation of micro world and rest of the features** including question prompts. Including a pedagogical agent and providing feedback as a dialogue.
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.	Allow learner to a previously attempted task quickly and modify not rewrite their answers.	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.

Solution Approach To Build MIC-O-MAP



Cycle 2: Testing & Refinement

Over All Research Goal: To design a TEL environment that will enable students to develop micro-macro thinking skills.

Research Questions

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

RQ2: a) What interaction paths do students follow as they learn with MIC-O-MAP?

RQ2: b) What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

RQ2: c) What was the effect of the improvised design on students' interaction with the various features of the learning environment?

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

Solution

Theme 1 | Theme 2 | Theme 2 | Theme 2 | Theme 3

Creation of a TEL Environment (MIC-O-MAP) for developing Micro-Macro Thinking Skills.

Method

Prototype 1 | Prototype 2

Overall Research Design is Design Based Rese (Study 5)

Research Studies

(Study 4)

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Study 7: Exp Repeated Measures Study (N=29)

Study 5: Qualitative study – Screen Capture Analysis

Study 8: Qualitative study – 3 Semi structured interviews and Case Studies

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

Methodology: QUANT	Single group pre post research design
Sample Characteristics	One group (N=46) Prior knowledge→ XII standard science. Answer Pre test questions Interact with MICOMAP for 1 hour. Answer Post test questions.
Data Analysis Technique	Grading using the scientific abilities rubrics

Results & Implications

SIGNIFICANT DIFFERENCE

Matched Pair t test results Ability to	Pre Test (Mean rubric score) N=46	Post Test Mean rubric score) N=46	p-value
Describe observations without planations	1.27	1.84	0.000
Devise an explanation for an served pattern	1.48	2.13	0.002
Make prediction based on planation	1.75	2.53	0.000
Decide whether the prediction and experimental outcome agree	2.42	3.0	0.002

There exists statistically significant difference in the pre-post test results.

RQ2: c) What was the effect of the improvised design on students' interaction with the various features of the learning environment?

Methodology: QUAL	Screen Capture Log Analysis
Sample Characteristics	One group (N=46)
Data Analysis Technique	Screen Capture was transcribed
	Codes were allotted to Transcripts
	Codes were converted into categories depicting student behaviours.

Did Redesign Work?

Observations from qualitative analysis of Experiment 1(N=10)	Learning related problems located	Redesign step to address problem	How do we know that the problem went away in cycle 2 for High scorers? (N= 10)
No of visits to Prediction Questions : 132 Making an informed choice of prediction: 11 No. of visits to Justification feature = 62 Attempts to establish a micro to macro link : 26	Struggle in establishing a micro-macro link in first/second attempt, making an informed prediction and phrasing a justification.	Incorporating the **question prompts at two stages**: when a choice of graph is made and justification is written & when testing indicates incorrect prediction. Option to take notes.	No of visits to Prediction Questions : 89 Making an informed choice of prediction: 37 No. of visits to Justification feature = 50 Attempts to establish a micro to macro link : 40
No. of visits to Question prompts = 34 Attempts to follow pointers and indulge in sense making: 20	Leaving task half way after getting multiple answers incorrect.	Including a **pedagogical agent** and providing feedback as a **dialogue**.	No. of visits to Question prompts = 32 Attempts to follow pointers and indulge in sense making: 35

Did Redesign Work?

Observations from qualitative analysis of Experiment 1(N=10)	Learning related problems located	Redesign step to address problem	How do we know that the problem went away in cycle 2 for High scorers? (N= 10)
No. of visits to Animation of micro world: 88. Attempts to follow pointers and indulge in sense making: 20 No. of visits to Question prompts = 34 Attempts to follow pointers and indulge in sense making: 20	While number of observations in the animation was high, the number of times feedback from the question prompts was followed was much lower.	**Simultaneous display of animation of micro world and rest of the features** including question prompts. Including a pedagogical agent and providing feedback as a dialogue.	No. of visits to Animation of micro world: 64. Attempts to follow pointers and indulge in sense making: 35 No. of visits to Question prompts = 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.	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.

Student Interaction Pattern (All students of Cycle 2)

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
0.59	2.5	0.1	1.27	1.62	1.05	0.15	0.03	1.16	1.06	1.49	0.1	0.1	0.05	0.11

PQ	JUS	PQ	GLO	REF	GLO	LO	SIM	PQ	JUS	RWA	ARQ	JUS	SUM	GLO
0.02	0.05	0.03	0.05	1.63	0.19	0.03	0.48	0.04	2.07	0.2	0.08	2.06	4.94	0.04

SIM	ARQ	GLO	SIM	PQ	JUS	RWA	SUM	PQ	JUS	SIM	PQ	JUS	SIM	PQ	ARQ	SIM	PQ	JUS
0.02	0.03	1.68	0.01	0.02	2.13	0.09	0.08	0.62	0.06	0.05	0.02	0.13	0.03	0.04	0.01	0.02	0.1	0.52

→TIME ENDS

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

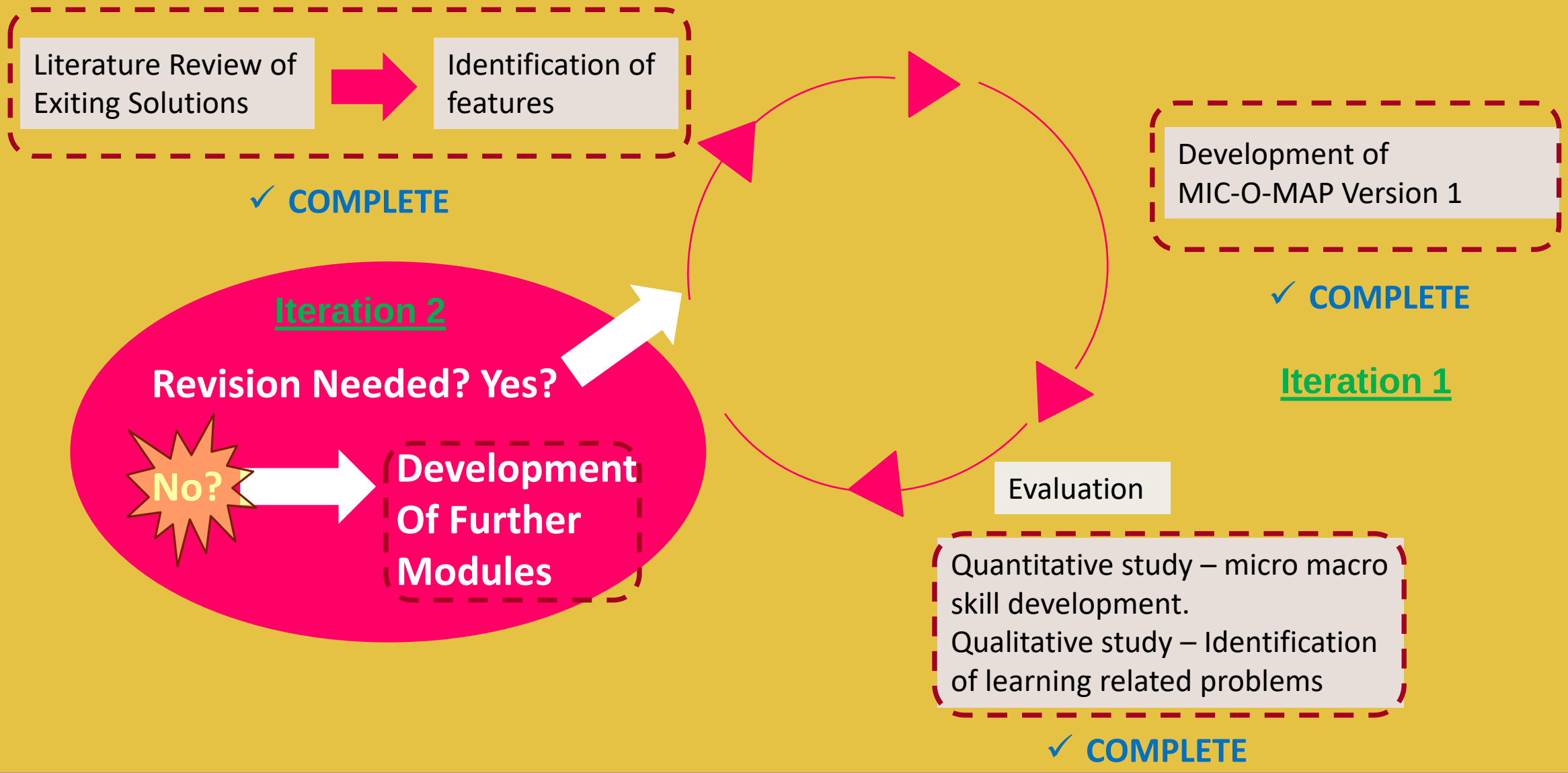
REF	GLO	HE	LO	SIM	PQ	JUS	RWA	PQ	JUS	SUM	GLO	SIM	PQ	GLO	SIM	PQ	JUS	RWA
1.63	0.19	0.13	0.03	0.48	0.04	2.07	0.2	0.08	2.06	4.94	0.04	0.02	0.03	1.68	0.01	0.02	2.13	0.09

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

SAME AS CYCLE 1 HIGH SCORERS!!

Solution Approach To Build MIC-O-MAP



Evaluation & Testing – All MIC-O-MAP Modules

Topic covered as a lab experiment as well as in theory course in same year.

Topics chosen consisted of multiple levels, with connections between levels

MODULES -

1.PN Junctions

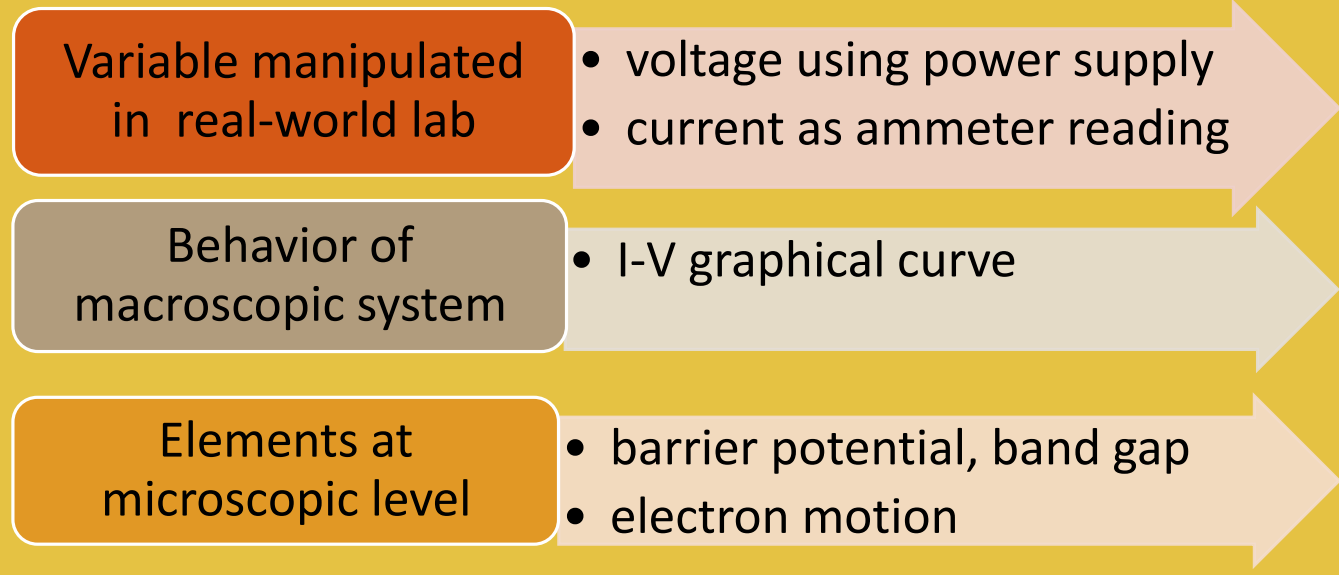
2. Formation of extrinsic semiconductors

3. Conductivity in intrinsic semiconductors

4. Conductivity in extrinsic semiconductors.

5. Thermistors

6. Light Dependant Resistors (LDR).



Over All Research Goal: To design a TEL environment that will enable students to develop micro-macro thinking skills.

Research Questions

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

RQ2: a) What interaction paths do students follow as they learn with MIC-O-MAP?

RQ2: b) What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

RQ2: c) What was the effect of the improvised design on students' interaction with the various features of the learning environment?

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

Solution

Theme 1

Theme 2

Theme 2

Theme 2

Theme 3

Creation of a TEL Environment (MIC-O-MAP) for developing Micro-Macro Thinking Skills.

Method

Prototype 1

Prototype 2

Overall Research Design is Design Based Research (DBR)

Research Studies

(Study 6, 7)

Study 2: Qualitative Study with the screen capture of experimental group from Study 1

Study 3: Qualitative Study with the screen capture of students from Study 1

Study 5: Qualitative study – Screen Capture Analysis

Study 8: Qualitative study – 3 Semi structured interviews and Case Studies

73)

Study 4, 6: Single Group Pre Post test Research Study (N=46) (N=30) (N=29) (N=30)

Study 7: Exp Repeated Measures Study (N=29)

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

Methodology: QUANT	Single group pre-post design
Sample Characteristics	30 students for each topic (total 148) Prior knowledge - 12th standard physics Pre-test, questions on micro-macro thinking Interact with MICOMAP learning module, ~1 hour. Post-test, questions on micro-macro thinking. (topics for learning modules different than topics in test)
Data Analysis Technique	Post Test mapping to O-P-T-R skills Grading using the scientific abilities rubrics inter rater reliability : Cohen's Kappa : 0.839 with $p<0.001$.

Results & Implications

	Mean rubric scores (out of 3)								
	Thermistor			Light dependent resistor			Conductivity in S.C		
Ability to	Pre-test	Post-test	p	Pre-test	Post-test	p	Pre-test	Post-test	p
Describe observations of pattern	1.53	2.80	0.000	1.7	2.4	0.000	1.58	2.60	0.001
Devise an explanation for an observed pattern	1.73	3.00	0.001	1.8	2.63	0.000	1.8	2.70	0.000
Make prediction based on explanation	1.10	2.50	0.000	1.93	2.53	0.000	1.55	2.55	0.003
Decide whether prediction and experimental outcome agree	0.93	2.50	0.002	2.26	2.63	0.001	1.68	2.65	0.002

Statistically significant improvement in pre-post test scores for all topics, all sub-skills of micro-macro thinking

Repeated Measures Study

Methodology: QUANT	Repeated Measures Study
Sample Characteristics	Single Group (N = 29), 1.5 day workshop (2 modules per day) Time: 1 hour per module, Pre-Test, Interaction with module, Post Test, Post Test of first session serves as pre test of next session (Total – 3 modules) Session 1: PN Junctions forward biased. Pre test & Post Test: PN Junction reverse biased. Session 2: Conductivity in Intrinsic SC: Post Test: Thermistors. Session 3: Formation of Extrinsic SC : Post Test: LDR. Session 4: Thermistors: Post Test: Formation of Extrinsic SC. Session 5: LDR: Post Test: Conductivity in Intrinsic SC Session 6: Conductivity in Extrinsic SC : Post Test: Conductivity in Extrinsic SC
Data Analysis Technique	Tests were scored and compared to interpret variation of the score for each subskill across the tests.

Results & Implications

	Mean rubric scores (out of 3)											
	Day 1						Day 2					
Ability to	Pre-test	Post-test 1	p	Post-test 1	Post-test 2	p	Post-test 2	Post-test 3	p	**Pre-test**	**Post-test 3**	p
Describe observati… pattern	1.206	2.413	0.000	2.413	2.655	0.090	2.655	2.896	0.052	1.206	2.896	0.000
Devise explanati… observed pattern												0.000
Make prediction based on explanation	1.206	1.724	0.000	1.724	2.586	0.000	2.586	2.620	0.850	1.206	2.620	0.000
Decide whether prediction and experimental outcome agree	1.827	2.172	0.165	2.172	2.793	0.009	2.793	3.000	0.014	1.827	3.000	0.000

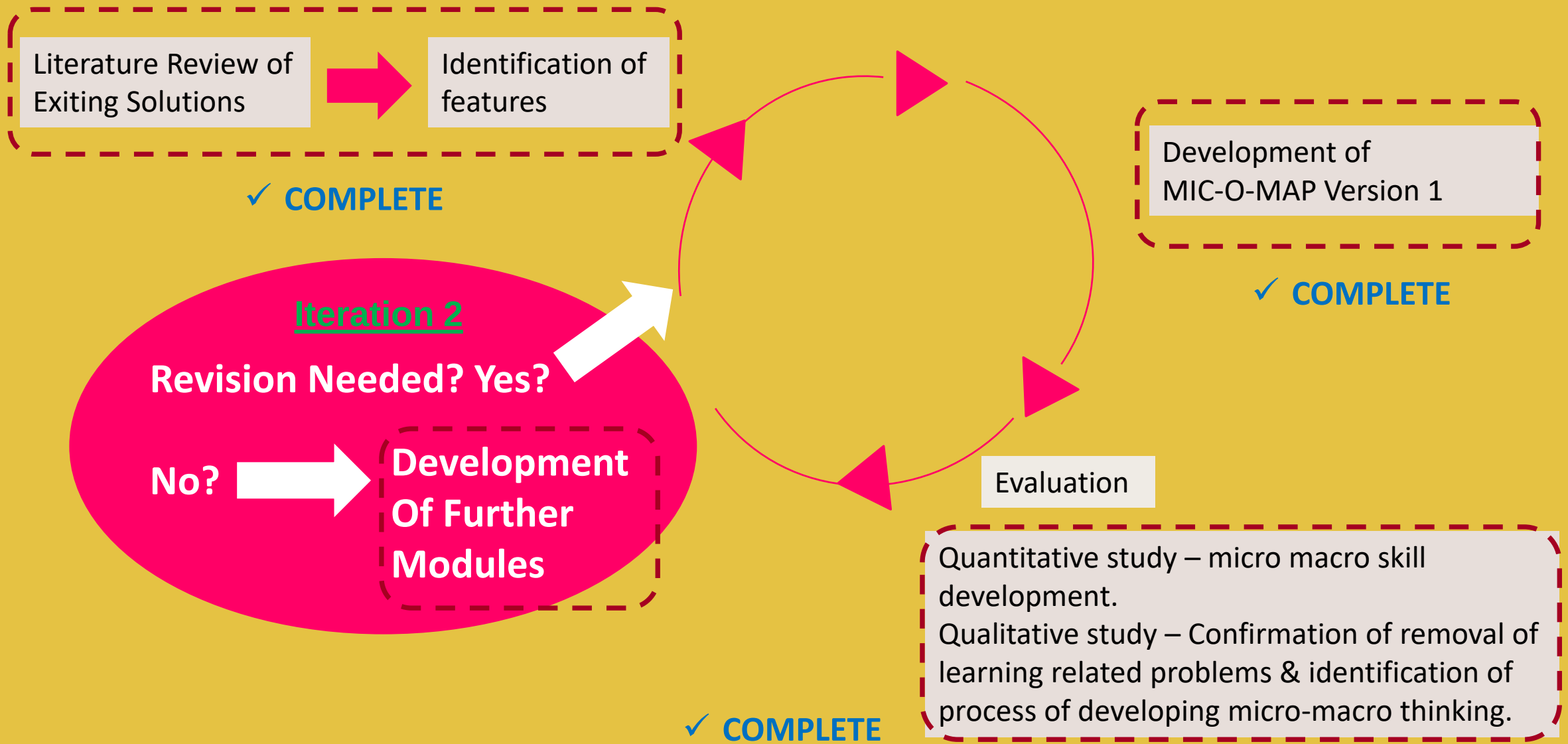
Conclusion: Overall there is a statistical significance in their test scores even though there is a variability in the significance when a pair wise comparison is calculated.

Limitations Of This Study

- ✓The difficulty level of the topics chosen for this study is the same.
- ✓The time gap between interaction with each MIC-O-MAP module is very less.
- ✓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.
- ✓Inter-participant variability is largely ignored in group based analysis and contributes to weak effects (statistical insignificance for the subskill of explanation).

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

Solution Approach To Build MIC-O-MAP



How do students develop micro-macro thinking skills while interacting with MIC-O-MAP??

Over All Research Goal: To design a TEL environment that will enable students to develop micro-macro thinking skills.

Research Questions

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

RQ2: a) What interaction paths do students follow as they learn with MIC-O-MAP?

RQ2: b) What difficulties do students face while interacting with MIC-O-MAP for developing micro-macro thinking?

RQ2: c) What was the effect of the improvised design on students' interaction with the various features of the learning environment?

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

Theme 1

Theme 2

Theme 2

Theme 2

Theme 3

Solution

Creation of a TEL Environment (MIC-O-MAP) for developing Micro-Macro Thinking Skills.

Method

Prototype 1

Prototype 2

Overall Research Design is Design Based Research (DBR)

Research Studies

Study 1: Two Group Quasi Experimental Research Design (N= 73)

Study 4, 6: Single Group Pre Post test Research Study (N=46) (N=30) (N=29) (N=30)

Study 7: Exp Repeated Measures Study (N=29)

Study 2: Qualitative Study with the screen capture of experimental group from Study 1

Study 3: Qualitative Study with the screen capture of students from Study 1

Study 5: Qualitative study – Screen Capture Analysis

(Study 8)

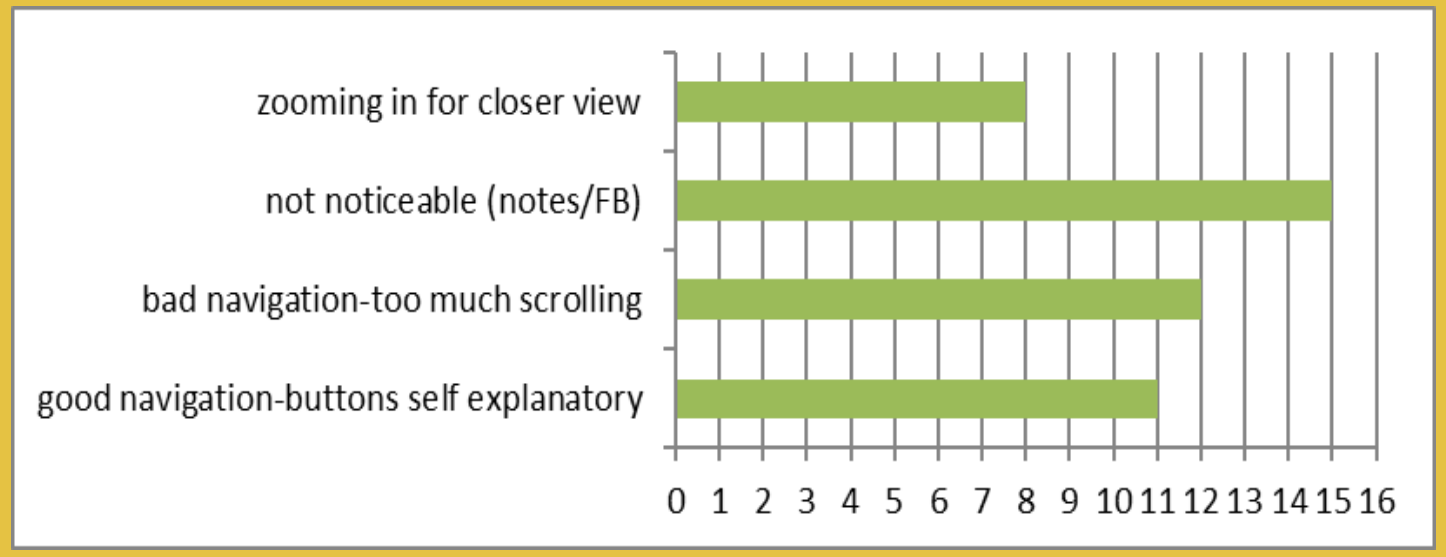
Study 8: Qualitative study – 3 Semi structured interviews and Case Studies

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

Methodology: QUAL	Semi Structured Interviews & Case Studies
Sample Characteristics	One Group (N = 12) Purposive sampling of 10 High Scoring Students. Screen Record was played.
Data Analysis Technique	Semi Structured Interviews were conducted. The unit of analysis was one question by the interviewer and a corresponding answer by the student. Interviews were transcribed and coded based on usability, purpose of visit and time spent. Inter-rater reliability was calculated using Cohen's Kappa. It was equal to 0.839 ($p<0.001$).

----------Frequencies for the Codes Generated----------

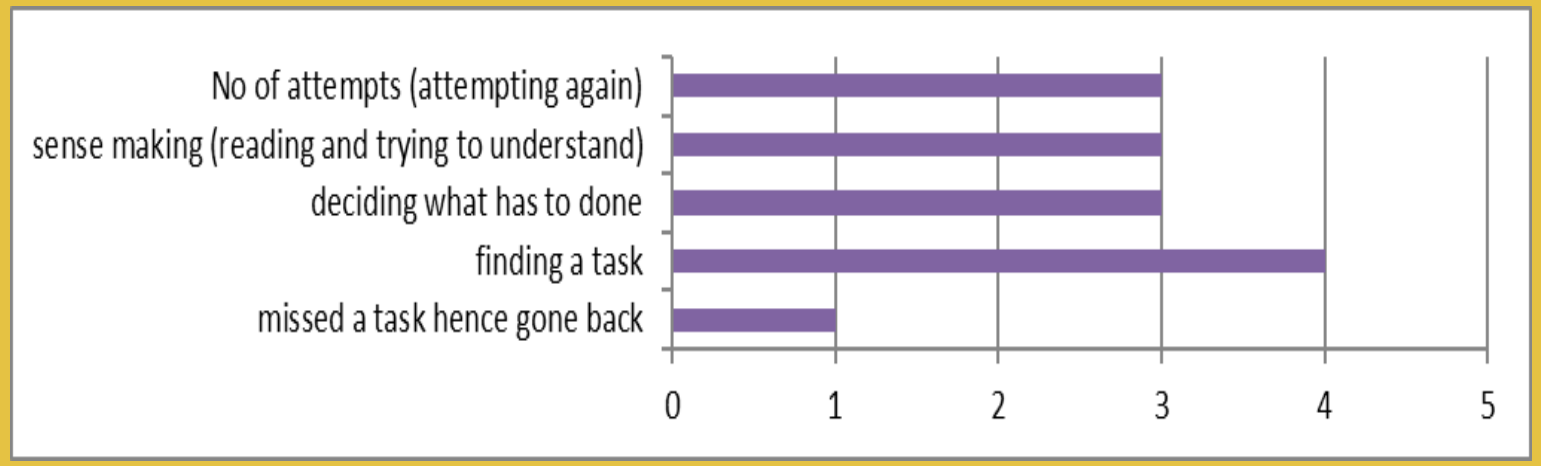
Usability Related Codes



Maximum attempts to write a note or check a feedback.

Frequencies

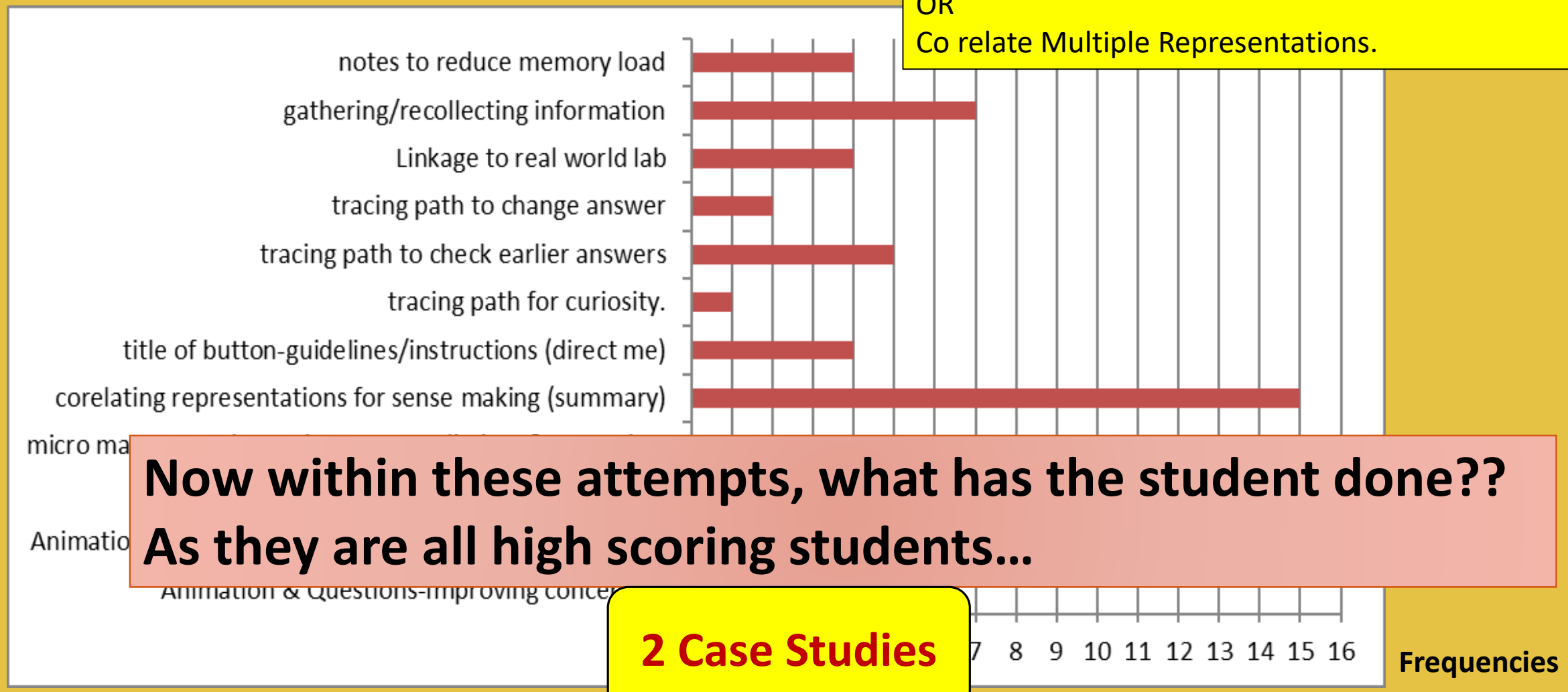
Time Spent Related Codes



Maximum attempts to find a particular task.

Frequencies

Maximum attempts to link Micro & Macro Worlds to Predict or Phrase Justification.
OR
Co relate Multiple Representations.



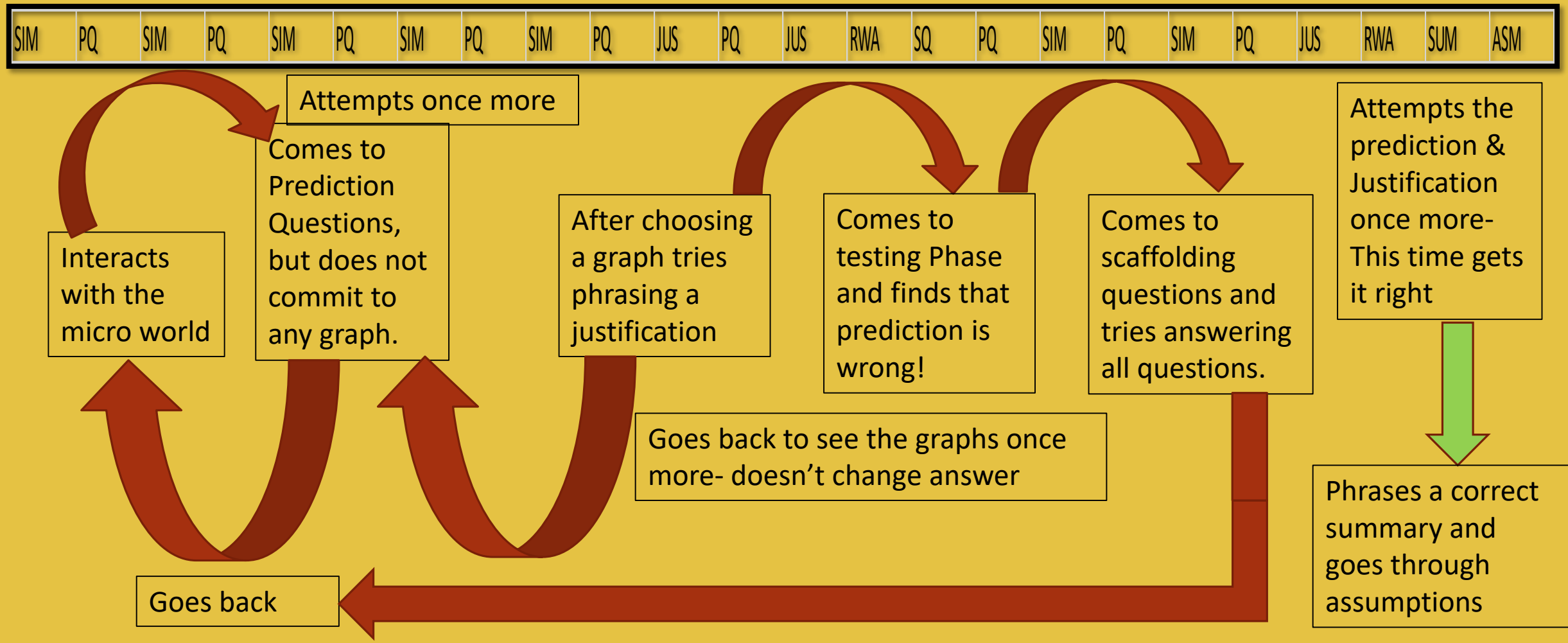
Now within these attempts, what has the student done??
As they are all high scoring students…

2 Case Studies

SIM- Simulation of the micro world,
PQ- Prediction Questions,
JUS- Justification of Prediction

Case 1- High Scorer

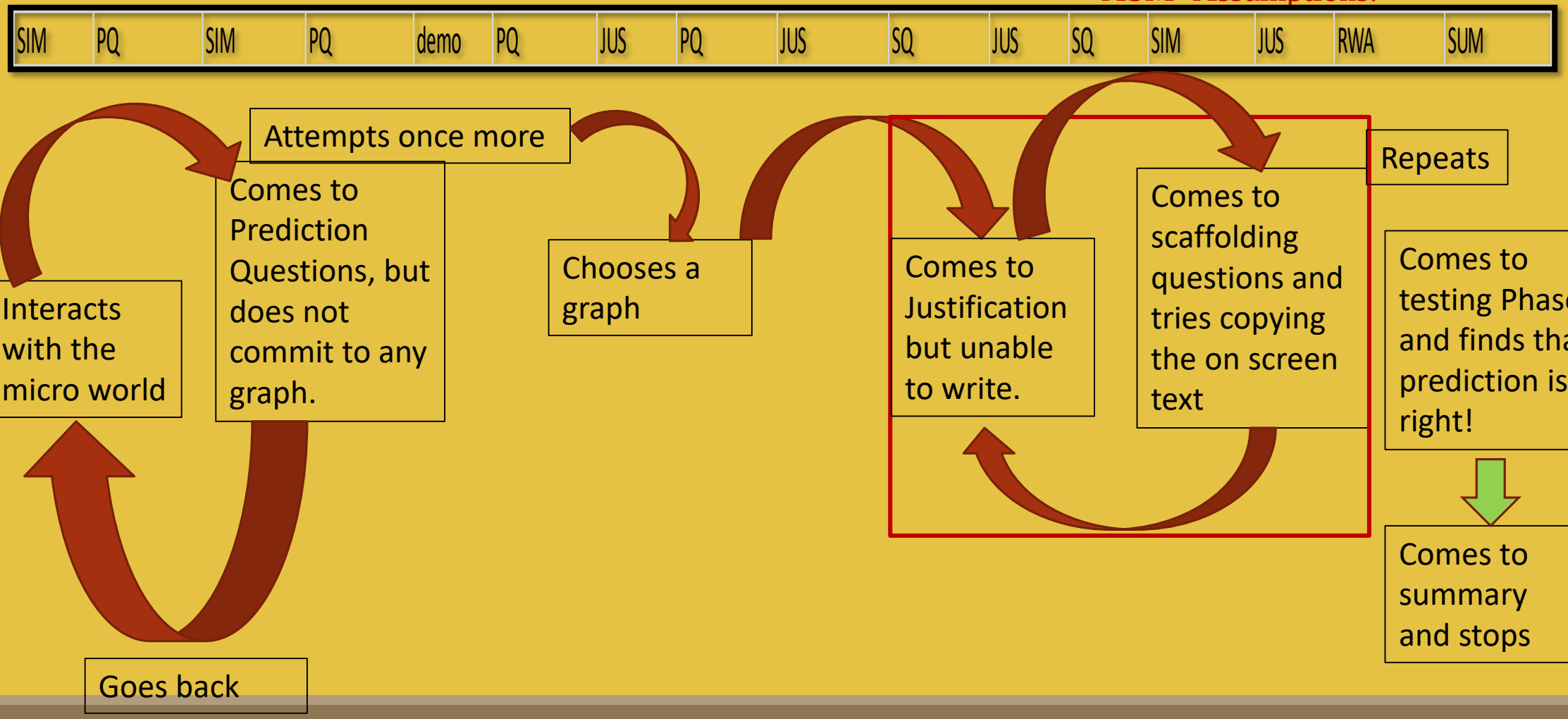
RWA- Real World Answer,
SQ- Scaffolding Questions,
SUM- Summarization,
ASM- Assumptions.



SIM- Simulation of the micro world,
PQ- Prediction Questions,
JUS- Justification of Prediction

Case 2- Low Scorer

RWA- Real World Answer,
SQ- Scaffolding Questions,
SUM- Summarization,
ASM- Assumptions.



How do students develop micro-macro thinking skills while interacting with MIC-O-MAP??

Learner Productive Actions

Guided Investigation & Way Finding

- When unable to make in informed prediction, learners undergo multiple rounds of interaction with all features of learning environment. (establishing a micro-macro link)

Accurate articulation and establishment of micro-macro link

- 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. (establishing and strengthening micro-macro link)

Dynamic linked representation for holistic sense making

- Learners simultaneously interact with the dynamically linked multiple representations to summarize understanding. (integrating micro-macro link)

Claims from the Research Work

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

Statistical difference in post test scores of the experimental and control group, statistical difference in the pre test and post test scores in the single group research design.

In the repeated measures design, variation in the scores remained in the range of 2 -3 on the scale of the rubrics

There exists a difference in the learning paths of high scoring and low scoring students – high scorers going back and forth while low scorers having a linear path.

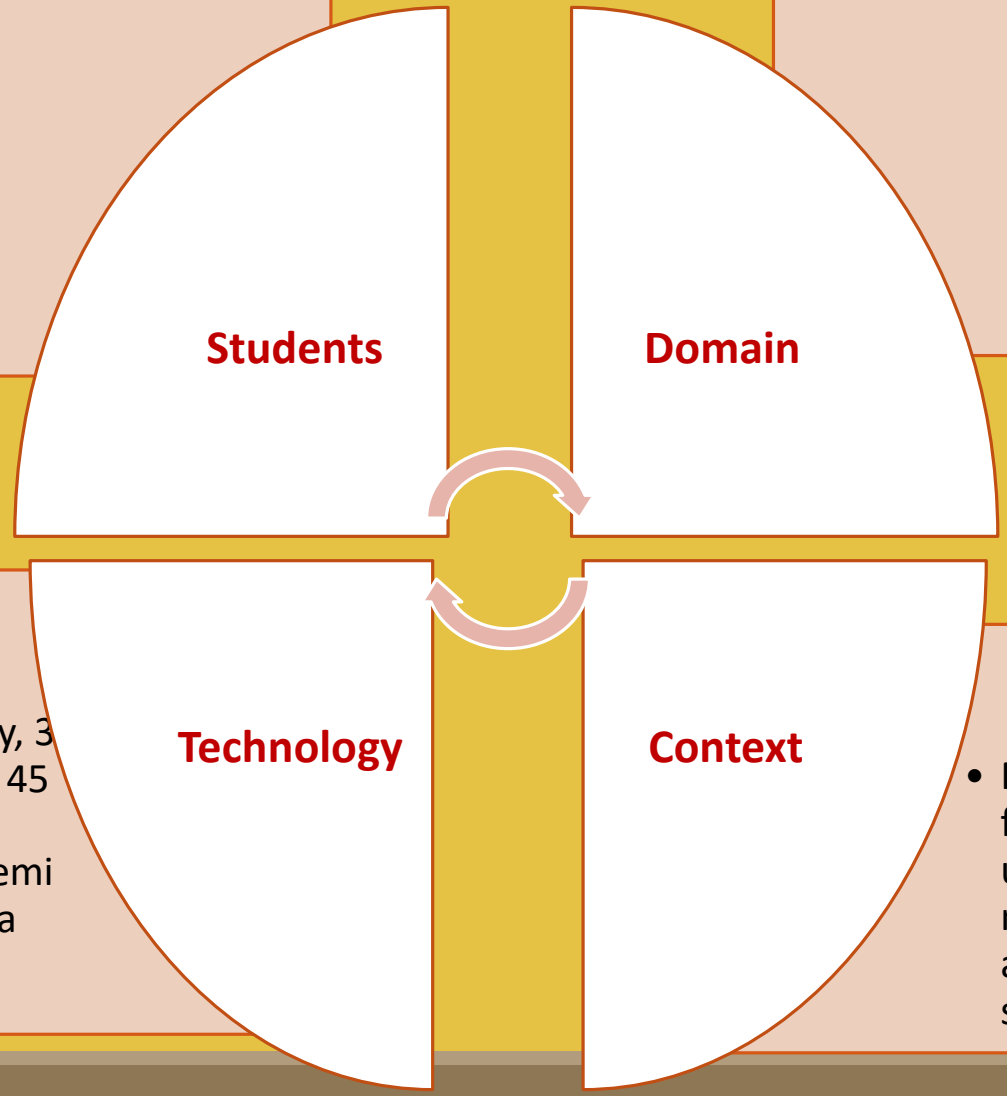
Learning paths plotted for high as well as low scoring students. It was found that the students who score high on the micro-macro thinking skill test are found to repeat interaction cycles with a combination of MIC-O-MAP features depending upon the goal.

1.Students working with MIC-O-MAP perform actions which are productive for the development of micro-macro thinking. This makes them high scoring students.

Semi structured Interviews – where high scoring students defended each choice made by them – productive actions

Generalizability of MIC-O-MAP

- Sample can be extended up to Graduation
- They have studies content but treated it as disjoint sets
- Tested by allowing students from higher grades to participate in repeated measures study



- Topics containing explanation at levels (tested 6 topics in Physics)
- Created IDD for the topic of pollen grain germination in Biology

- Augmented Reality –Pilot Study, 3 UG students, total time 1 hour 45 min, raw scores on par with studies of MIC-O-MAP, short semi structured interviews indicate a rise in interest.

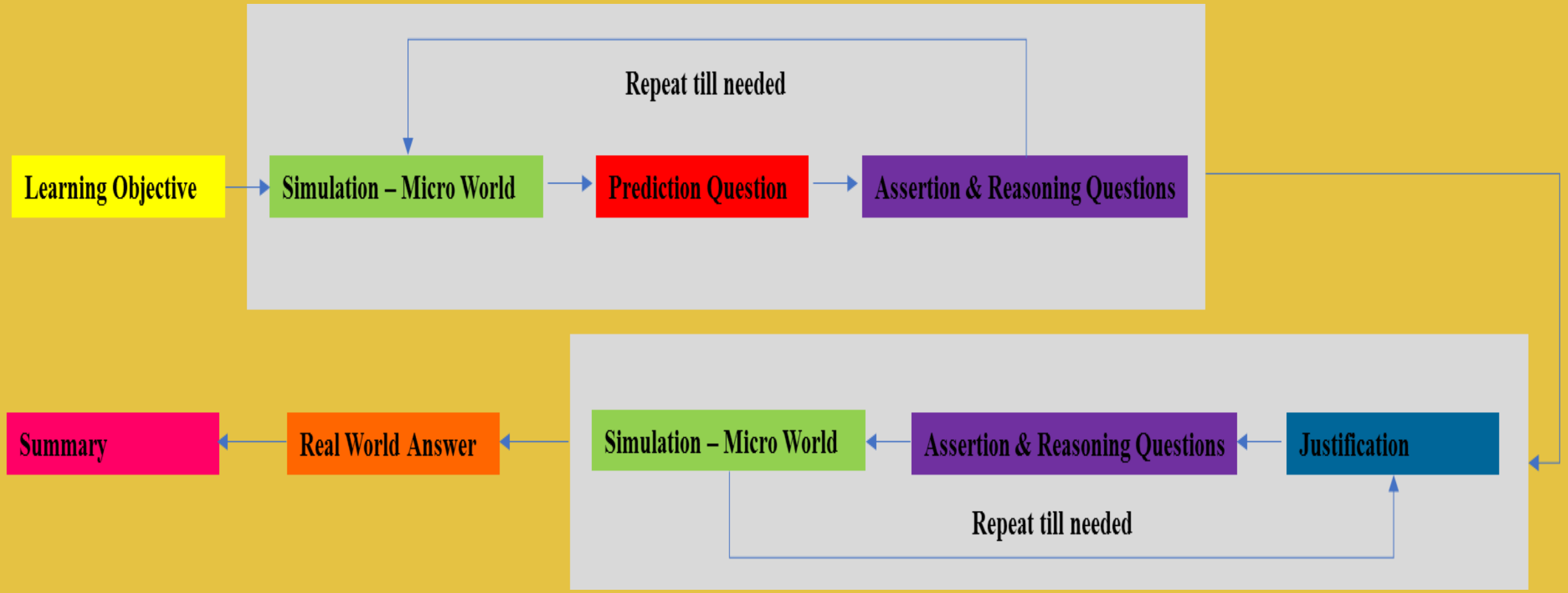
- MIC-O-MAP has been designed for self study but can also be used as supplementary teaching material, for Eg: 30 min pre lab activity or in class problem solving

Limitations

- MIC-O-MAP modules have been tested only with Urban students who are fluent with English.
- Students are assumed to be familiar with technology.
- If students are not motivated or interested in self-learning then MIC-O-MAP may not be useful to learn micro-macro thinking.
- Another methodological limitation is that MIC-O-MAP was implemented only for short durations (1 hour). Further, the testing was done immediately after students interacted with MIC-O-MAP.
- 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.

Recommendations & Design Guidelines

Interaction Path for students recommended while working with MIC-O-MAP:



Recommendations & Design Guidelines

For Researchers, guidelines given below can 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.

Recommendations & Design Guidelines

1. Provide a **simultaneous display of the scaffolding questions** and feedback along with the simulation of the microscopic processes.

2. Provide **multiple types of question prompts with customized feedback** whenever a leaner asks for guidance.
    1. A Micro-Macro Link based Question for establishing a link between the micro and macro worlds.
    2. A Microscopic Observation based Question for identifying key areas which require observations.
    3. A Macroscopic Prediction based Question for identifying parameters of the macroscopic world which can be manipulated and are linked to elements of the microscopic world.
    4. Confounding questions for indicating restarting interaction with the TELE.

Recommendations & Design Guidelines

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.

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

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.

Contributions of the Thesis

CONTRIBUTIONS OF THE THESIS ARE:

- The design of MIC-O-MAP TEL environment for developing micro-macro thinking skills.
- Six modules for MIC-O-MAP have been developed and tested in the domain of Basic Analog Electronics.
- Productive actions of students are identified which tell us the best practises while interacting with MIC-O-MAP.
- The instructional design template of MIC-O-MAP which can be used for the creation of further modules.
- Identification of learning paths of different types of students.

Contributions of the Thesis

CONTRIBUTIONS OF THE THESIS ARE:

- Recommendation of an interaction path which is productive while working with MIC-O-MAP.
- Recommendation of filters to be applied while choosing topics for development of MIC-O-MAP modules.
- Design Guidelines for creation of TELEs addressing thinking skills.

Future Work based on this Research

- Building a predictive TEL system based on learning analytics.
- Behavioural patterns can be extracted out by carrying out more detailed repeated measures research studies.
- Topic complexity and collaboration can also be explored as another dimension to this work.
- Affective states can be examined as a tangent in the dimension of learning.
- Misconception in understanding graphs in another area in which further work can be carried out.

List of publications from Thesis

Journal Paper

1. RPTEL-2016: Development of micro-macro thinking skills via a self-regulated learning environment - Anura Kenkre & Sahana Murthy. (Accepted)

Conference Papers

1. 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.
2. ICCE-2014: 'Development of Predict-Test-Revise Modeling Abilities via a self-study Learning Environment'- Anura Kenkre, Sahana Murthy & Madhuri Mavinkurve. (Accepted-poster paper)
3. 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)
4. 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.
5. 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.
6. 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.
7. Kenkre, A., & Murthy, S. (2012). Design and Evaluation of OSCAR Physics Learning Objects. Journal of Research: THE BEDE ATHENAEUM, 3(1), 6-10.

Thesis Questions & Clarifications

Examiner 1: Dr. H. C. Pradhan

Comment 1: It is precisely in the content to which the modules address. The claim is that the modules help students develop micro-macro thinking. All that the animation developed does is to show `electrons' moving faster or slower to indicate larger of smaller currents. This is just `paraphrasing' the graphs which the students have to select. As a result of the 'paraphrasing' the students may show improvement with respect to understanding of the graphs and on the post-test. But it is not a proof of their improved micro-macro thinking (as this thinking is understood in the literature surveyed, say, in Meijer's 2011 work).

Ans:

We have a progression of models ranging from simplistic to a more accurate and detailed and hence more complex model. We have made a choice of the simplistic model as we wanted students to focus on establishment of a link between the microscopic world and the macroscopic world and not the complexity of the topic. Once we are certain of students' capacity to establish these links then we would like to take them to other more complex microscopic models.

- Free Electron Model: Proposed By Paul Drude and this model assumes that around the conductor's ions (atoms) are free electrons that can move inside the conductor. He assumed that these electrons move according to Newton's laws until they scatter from 'colliding' with ions or defects, and after scattering an electron's momentum is totally random. These free electrons are treated as free particles in ideal gas. (we have used this model)
- .The nearly free electron model (based on band structures) and the quantum mechanical model (which dealt with the wave particle duality of electrons).
- Student interaction with a complex model can be evaluated as part of the future work.

Thesis Questions & Clarifications

Examiner 1: Dr. H. C. Pradhan

Comment 2: What is design-based research? What made you use it for your work?

Ans:

the requirement of the studies was an iterative method which encompassed a mixture of qualitative as well as quantitative studies. 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]. Our requirement was to choose a method that is systematic but flexible and DBR was apt for this requirement. Within DBR we have included the explanatory sequential mixed methods design within each cycle of designing the version of MIC-O-MAP.

Comment 3: You used a two group research design in Study 1. What was the pre-test here?

Ans:

The paragraph below has been added in Section 4, sub section 4.6.2, page 73, where the details of the participants for study 1 has been mentioned. This study was a two group quasi experimental research study. However, no specific pre-test was administered prior to the intervention. Instead the post-test scores were used to compare the groups.

'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).'

Thesis Questions & Clarifications

Examiner 1: Dr. H. C. Pradhan

Comment 4: In Study 4 you used a single group research design. Why did you not use a two group design here?

Ans:

In the first study i.e. Study 1, it was found that the scores of the experimental group are higher than the scores of the control group. This difference of scores is statistically significant. But it was also found that there were difficulties faced by the students while interacting with MIC-O-MAP. These were findings from qualitative studies – Study 2 and Study 3. The design of MIC-O-MAP was revised based on the difficulties faced by the students. The goal of the next study was to now evaluate whether these difficulties are addressed with the improvised design. We did not use a two-group design since it was already established that students learning with MIC-O-MAP perform better on a micro-macro thinking skill test as opposed to students learning with traditional learning material.

Comment 5: What is micro-macro thinking according to you? Do you think you can claim that the students under your project develop micro-macro thinking? What is the evidence for this?

Ans:

We define 'micro-macro thinking' as the ability to establish a link between the invisible elements in the microscopic world and their corresponding manipulable variables in the macroscopic world, in order to predict the functionality of a given system. If students are able to predict the outcome of any system (for the topic of diode characteristics, it was the prediction of an IV graph) based on the micro-macro link, i.e. they predict the correct graphical curve and justify it based on the microscopic elements such as electrons and barrier potential, then it can be said that they have developed the micro-macro thinking skill. Two evidences- drawing a correct graph and justifying it based on a micro-macro link when faced with a new situation and monitoring their learning process.

Thesis Questions & Clarifications

Examiner 1: Dr. H. C. Pradhan

Comment 6: Do you think the kind of animation exercise that you undertook can capture the complexity of the micro-macro thinking needed to be developed in the context of your content area, that is, semi-conductor physics?

Ans:

Our primary goal was to get students to establish a link between the observable variables in the macroscopic world and corresponding invisible elements in the microscopic world. An example of the observable variable is current. Initially we chose the simplest model because we want them to start making these links. We are aware that the physics of it is not entirely accurate with respect to modern understanding. Once students are able to establish this link with the simplistic model, we plan to build a model with electrons, holes and energy band structures in order to give them a more sophisticated understanding of the subject. We believe it will be possible to create simulations and animations that reflect a more sophisticated understanding of the complexity in semi-conductor physics.

Comment 7: You report that you tested the MIC-O-MAP instructional design document template in the domain of biology. Can you explain how the template would serve to develop micro-macro thinking there?

Ans:

The Instructional Design Document (IDD) template of MIC-O-MAP was filled out for a topic in biology by an SME in order to ensure that this IDD template can be used for the creation of further modules aimed to develop micro-macro thinking in different subjects. The template has been tested for the generation of a new module of MIC-O-MAP in biology. The screen shots of the filled up template has been added to the thesis as Appendix E in the thesis.

Thesis Questions & Clarifications

Examiner 2: **Dr.Wenli Chen**

Comment 1: Chapter 1: Page 23 last sentence "Teacher-led instruction and no collaboration with peers is not expected" is confusing. Rephrase it.

Ans:

The sentence in Section 1, sub section 1.5, page 23 has been rephrased to the following:

'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.'

Comment 2: Chapter 2: from the current review I am not able to tell which solution is to address the micro-Macro thinking skills.

Ans:

A paragraph has been added on Section 2, sub section 2.5, page 34, wherein a description of the instructional interventions has been provided.

Comment 3: In addition, the literature on students on interactions was reviewed at surface level. These TEL environments and were discussed at surface level.

Ans:

literature review has been added in the thesis in Section 2, sub section 2.6, page 36, wherein student interaction with TELE has been discussed

Comment 4: Chapter 4 discussed pedagogical underpinning for the design of MIC-O-MAP. A few theories were discussed such as inquiry, self-regulated learning, scaffolding, assessment or learning etc. However, these theories are discussed separately. A few recommendations from theories were proposed but the discussions on these theories were not gelled well. It would be better if the candidate can derive a set of design principle by synthesizing the theories.

Ans:

A new sub-section 4.2.6 has been added to Section 4, page 59, has been added to the thesis titled 'Implications on the MIC-O-MAP design'

Thesis Questions & Clarifications

Examiner 2: **Dr.Wenli Chen**

Comment 5: The thesis explained that an explanatory sequential design was used. However what I read is that study 1 is quantitative in nature (by comparing 2 groups' post-test scores), study 2 is qualitative in nature (screen capture analysis on interaction pattern), and study 3 is quantitative in nature comparing time spent and frequency of behaviors between high scorers and low scorers) again. Therefore, this is not a typical QUAN-qual explanatory sequential mixed method design. The candidate need to further clarify this..

Ans:

A table summarizing the two studies along with their data sources, analysis methods and metrics of evaluation in the response. Study 2 and Study 3 are qualitative in nature whose goal is to explain the different ways in which students interact with MIC-O-MAP. Study 3 was undertaken in order to understand possible reasons for the different times spent by different students, we compared the interaction behaviour of students from the high and low scoring groups.

Comment 6: Page 67, "the high- and low-scorers were equivalent in terms of their domain knowledge of the topic" is confusing. Please clarify the score is based on what? Prior achievement?

Ans:

The paragraph below has been added in Section 4, sub section 4.6.2, page 73, where the details of the participants for study 1 has been mentioned.

'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 did a t-test and found that there was no statistically significant difference between the groups at $p<0.05$ level ($t=0.412$, $p=0.685$).'

Thesis Questions & Clarifications

Examiner 2: **Dr.Wenli Chen**

Comment 7: It was stated that the research participants are from 12 colleges? What is the population size? What is the response rate (those who accepted the invitation/those who received the invitation)?

Ans:

In each graduation college, there are 35-40 students who register for a subject combination of Physics-Chemistry-Mathematics or Physics-Chemistry-Biology. The population size is 480 - 500 students. Each College gave a list of students ranging from 5 – 10 students. We did not face a drop out from the students since the college heads were asked to give the list post ensuring that only interested students are allowed to participate and the certificate of participation will be given to only those students who complete the entire workshop. Also, the workshop was scheduled in accordance with the start of their vacations due to which the students had time for participation and no attendance required in their respective colleges.

Comment 8: What is the detailed procedure of recruiting these students?

Ans:

An official letter of invitation was sent to the Head of the Department of colleges affiliated to the university of Mumbai who had an email address as the mode of communication and offered Physics as a subject of graduation in the degree of Bachelor of Science (B.Sc.). The Head of the departments were provided with a poster of the workshop to be held at IIT, Bombay and were requested to post it on the notice boards and revert back with the name, contact details and Prior XII standard scores of the students who wished to participate in the workshop. It was mentioned in the poster as well as in the email that all the students who participated would be provided with a certificate of participation.

Thesis Questions & Clarifications

Examiner 2: **Dr.Wenli Chen**

Comment 9: The participants from study 1 and 4 are the same or not? On what basis the researcher allocate them to study 1 or 4?

Ans:

The participants from Study 1, Study 4, Study 6, Study 7 and Study 8 are all different participant with not a single participant overlapping in any study.

Comment 10: How representative are the students?

Ans:

MIC-O-MAP has been designed for the context of self study wherein students can learn using the TELE in the absence of a mentor. Hence, being familiar with the usage of technology and comfortable with English as the language of instruction was conveyed prior to shortlisting the candidates. On account of this, the students who have participated in these studies are representative of an urban population who is technology savy and good in communication in English.

Comment 11: Chapter 8 summarized the findings from previous chapters and discussed the issue of generalizability and limitations of the study. It was clear that this DBR has great practical significance in that it provides both pedagogical and practical solutions for teaching practitioners. Another contribution of DBR should be on learning theories. Can the thesis be more explicit in explaining the contribution to the learning sciences theories? The language issue was discussed as one limitation of the study. I do not quite get it. Can the system have different language version to cater for the different language speakers?

Ans:

Currently, MIC-O-MAP has been coded in English and translation into another language has not been carried out, hence, a limitation for the research work and learners chosen.

Design guidelines have been added to the thesis in Chapter 8, sub section 8.6, page 161, where the Overall Discussion and Future Work is discussed.

Thank You!