A Self Study Learning Environment for Modeling Abilities: Do all learners take the same Learning Path?

Anura. B. Kenkre
Inter-Disciplinary Program in Educational Technology
Indian Institute of Technology
Bombay, India
anura.kenkre@iitb.ac.in

Sahana Murthy
Inter-Disciplinary Program in Educational Technology
Indian Institute of Technology
Bombay, India
sahanamurthy@iitb.ac.in

Abstract*— LEMA (Learning Environment for Modeling Abilities) is an ICT based tool developed in order to promote students‘ modeling abilities such as developing explanations of phenomena based on microscopic models, predicting the outcome of new phenomena and revising explanations in the light of experimental evidence. It is developed for the context of self study. In a prior study, we have reported that students learning with LEMA showed statistically significant difference in their learning outcomes on a modeling ability based test than the control group. While we know that LEMA helped develop students modeling skills, the prior study did not address how it helped or why. In order to gain insight into this, in this study we investigate the different paths that different learners take as they interact with LEMA. Using screen capture logs of students' interaction with LEMA, we characterize the difference in behavior between students who score low and students who score high in a modeling based post test. We find that in spite of the fact that the total time spent by all students while interacting with LEMA is the same, the duration of time spent on each feature of LEMA and the action taken within, varies for high and low scorers

Keywords-Interaction Behaviour, modeling skills, LEMA, self regulated learning.

I. INTRODUCTION

Computer-based learning environments allow learners to be active agents in the process of acquiring knowledge and support scientific practices. These environments can be used as tools not only for learning content, but also for students' development of science process skills and abilities. One such scientific ability is that of modeling, which includes the ability to create and use simplified representations to describe and explain phenomena, and the use of these simplified models to predict outcomes of new phenomena. In order for students to successfully learn from such environments, sufficient supports in the form of scaffolding need to be provided in the environment [21]. These scaffolds can be provided through features such as an animation of a microscopic phenomenon which they cannot view otherwise, giving control over the activity through variable manipulation, and providing customized feedback about their actions.

In this study we focus on the 'Learning Environment for Modeling Abilities', which aims at developing students' abilities such as developing explanations of phenomena based on microscopic models, predicting the outcome of new phenomena and revising explanations in the light of experimental evidence. LEMA is a technology-enhanced learning environment in which learners can interact with simulations of microscopic phenomena (such as the motion of electrons through a semiconductor) and relate it to macroscopic phenomena (such as voltage and current). In LEMA, learners work with a variety of features such as manipulating variables in the simulation, making predictions, receiving feedback on their answers, being asked to explain their reasoning. LEMA also provides learners scaffolds in the form of guided-inquiry conceptual questions and feedback.

In a prior study [39], we have reported that students who received LEMA as the learning material had statistically significant difference in their post-test scores of predict-test-revise modeling abilities as compared to students in the control group. Through that study we could establish that LEMA is a powerful tool in developing students modeling abilities, but the study did not target the mechanism of how or why students who learnt using LEMA performed better. In this study, we address the question of what makes the LEMA effective, by examining students' behavior as they interact with the learning material. The research goal of this study is to identify behavioral differences between learners who scored high and those who scored low on a modeling based post-test after interacting with LEMA. By identifying productive learning behaviours as students interact with various features of LEMA, we hope to gain insight into the effectiveness of the pedagogical design of LEMA. Knowledge about the difference in behaviours of successful and unsuccessful students can help us refine the design and recommend specific learning paths.

II. THEORETICAL BASIS AND RELATED WORK

We have designed a Learning Environment for Modeling Abilities (LEMA) on the basis of recommendations to promote higher engagement. This was done by taking into account the affordances of visualizations, scaffolds such as question prompts, text inputs, variable manipulation and customized feedback. LEMA incorporates the microscopic model of a physical phenomenon by means of a simulation.

In general, animations can represent complex, abstract and invisible concepts [5] as well as real life examples which are otherwise difficult to mimic in classroom settings [6]. Simulations can be used to amplify cognition as they provide the opportunity for stating and testing hypotheses and multiple representations of physical phenomena such as diagrams and graphs [4,7]. This can help learners understand the mechanism underlying a phenomenon and can lead to the refinement of the conceptual understanding of the phenomenon [2, 3]. So also, student engagement is one of the three necessary attributes to judge the quality of a simulation [16] and learner self-efficacy is critical to promoting engagement in simulations. [18] The benefits of visualizations are however seen to be dependent on the engagement level that learners have with them: learning gains are seen when learners actively engage with visualizations. [20] Engaged exploration can defined as interacting with a learning material via one's own questioning. [19] Hence, in order for students to successfully learn from such environments, sufficient supports in the form of scaffolding need to be provided in the environment. Scaffolding components of different types – structural, reflective and subject-matter – are required to improve learning outcomes. [21]

LEMA has been designed for the context of self study wherein students should be able to learn in the absence of a teacher or facilitator, hence, the process of self-regulated learning has been recommended. Self-regulated learning is an active, constructive process whereby learners set goals for their learning and then attempt to monitor, regulate, and control their cognition and behavior in the service of those goals. [22] Learning environments which are to be used in this context should have a number of important features, such as the possibility of independent learning, learning goal alignment, feedback and adaptation, learner control, multiple representation, flexibility, et al, which make them a beneficial teaching and learning tool [6, 9-17] In designing learning environments, research has shown that question prompts can facilitate explanation construction [23], monitoring and evaluation [24], and making justifications [25]. 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 [26].

III. LEARNING ENVIRONMENT

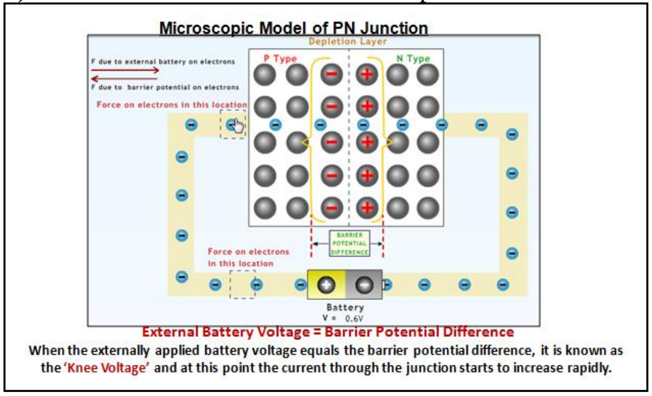
A. *Learning Objectives*

We define 'Modeling ability' in term of a measureable set of objectives, wherein students learn to make predictions, test predictions with respect to experimental results, and revise predictions if necessary. LEMA has phases of Observation, Prediction, Testing and Revision. In the Observation phase, students make observations of the microscopic phenomena and corresponding macroscopic experiment. In the Prediction phase, students should be able to make a prediction of what might happen to the state of a system if a certain parameter was varied, on the basis of the microscopic model. In the Testing phase, students should be able to analyze if the predicted answer tallies with the experimental outcome after performing the experiment. In the Revision phase, students should be able to revise the explanation on which their prediction was made and justify the changes being made. Students are guided to move from one phase to another, however, they can go back to the previous phase and interact with the features again. For example, if students learn that their prediction was incorrect in the Testing phase, they can go back to the Predict phase and c

B. *Design of the Learning environment*

LEMA was designed using features recommended for the development of students' scientific abilities. These include 'learning material should allow students to explain reasoning, justify conclusions, analyze outcomes of an experiment, get immediate feedback, after sharing their explanations students design testing experiments to determine if their explanations work' [27-29]. On the basis of all these features an Instructional Design Document was created and was given to two subject matter experts for content validity. The detailed features of LEMA which aid in developing students modeling abilities are explained in below.

1) Feature: Simulation of the Microscopic Model



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.

Figure 1. 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. Students use of this feature in order to make careful observations of a microscopic phenomenon because it encourages students to explore and interact, handle parameters and observe their results. They later use the observations made here for predicting a macroscopic graphical outcome, for justifying their prediction and revising it if necessary. It is also said that features such as isolation and manipulation of parameters helps students to develop an understanding of the relationships between physical concepts, variables and phenomena [28].

2) Feature : 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. Here students try to establish a link between the microscopic phenomenon and the macroscopic properties. For example, students predict the graph of the macroscopic properties (such as voltage and current) based on the microscopic description of motion of electrons.

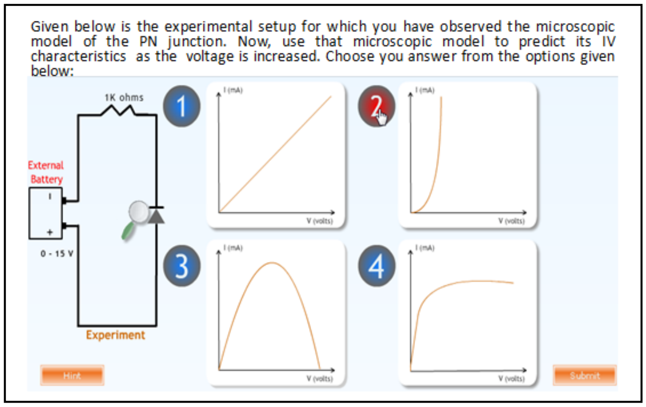
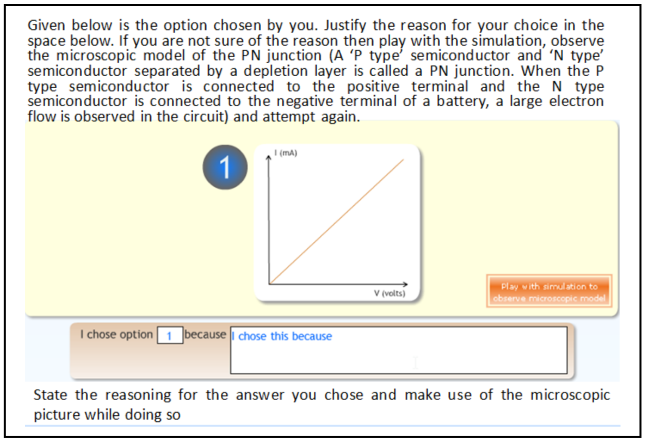

Given below is the experimental setup for which you have observed the microscopic model of the PN junction. Now, use that microscopic model to predict its IV characteristics as the voltage is increased. Choose you answer from the options given below:

Figure 2. Prediction Questions

3) Feature: Justification Box


Given below is the option chosen by you. Justify the reason for your choice in the space below. If you are not sure of the reason then play with the simulation, observe the microscopic model of the PN junction (A 'P type' semiconductor and 'N type' semiconductor separated by a depletion layer is called a PN junction. When the P type semiconductor is connected to the positive terminal and the N type semiconductor is connected to the negative terminal of a battery, a large electron flow is observed in the circuit) and attempt again.

I chose option 1 because I chose this because

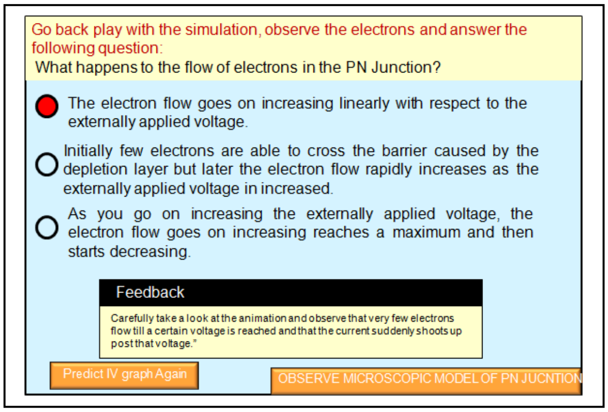
State the reasoning for the answer you chose and make use of the microscopic picture while doing so

Figure 3. Justification box

Once students have predicted the outcome of any situation, they are asked to explain their reasoning for making that prediction. They are asked to write this explanation so as to ensure that they are trying to make sense of the microscopic phenomenon while predicting this graphical outcome. This is needed because students should be able to adapt a known model to the specifications of the given problem [30].

4) Feature: Conceptual reasoning scaffolds

Students are provided with multiple choice questions that scaffold them in the conceptual reasoning process. Students are provided with these questions when they are unable to predict the macroscopic graphical outcome and need help in identifying which aspects of the microscopic model to view more carefully. These questions act as prompts and are aligned with the observations made by them in the microscopic model of the PN junction. Question prompts can facilitate explanation construction [31-33] and making justifications [25].


Go back play with the simulation, observe the electrons and answer the following question:
What happens to the flow of electrons in the PN Junction?

● The electron flow goes on increasing linearly with respect to the externally applied voltage.

○ Initially few electrons are able to cross the barrier caused by the depletion layer but later the electron flow rapidly increases as the externally applied voltage in increased.

○ As you go on increasing the externally applied voltage, the electron flow goes on increasing reaches a maximum and then starts decreasing.

Feedback

Carefully take a look at the animation and observe that very few electrons flow till a certain voltage is reached and that the current suddenly shoots up post that voltage."

Figure 4. Conceptual reasoning scaffolds

5) Feature: Experiment Results for comparison & judgment

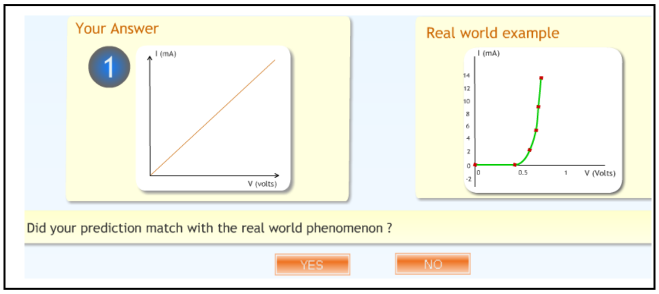

Did your prediction match with the real world phenomenon ?

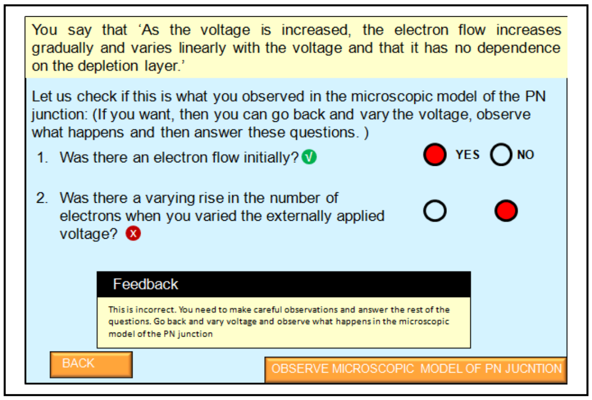
Figure 5. Experimental Results for comparion & judgement

During the Testing phase, students are provided with experimental results of IV characteristics and are asked to judge if their prediction matches the experimental results. This is important because students should be able to analyze the outcomes of an experiment and be able to justify your conclusions [30].

6) Feature: Assertion and Reasoning based questions with customized feedback.

During the Revision phase, initially students are shown the prediction made by them and the corresponding justification which did not match with the real world outcome.

Depending upon their choice of answer students are provided with a series of question prompts along with customized feedback so as to improve their reasoning. Students are asked to answer questions aligned with the prediction they made. An example is shown in Figure 6. If they are get the answers incorrect, then they are given feedback which helps them identify what was missed by them in their observations are asked to note that particular aspect by going back and interaction with the simulation. This is a very crucial feature because designing instruction using building blocks such as conceptual reasoning scaffolds, if-confused and summarization is much more powerful than designing instruction at the level of show video. [34-36]


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. Was there an electron flow initially? ✓ ● YES ○ NO
2. Was there a varying rise in the number of electrons when you varied the externally applied voltage? ✗ ○ ●

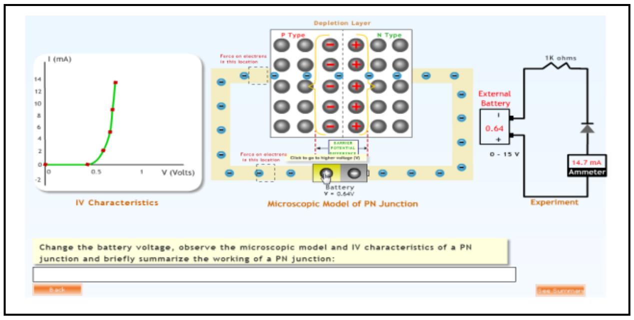
Feedback

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

Figure 6. Assertion and reasoning questions

7) Feature: Multiple representations of microscopic phenomenon, macroscopic experiment and graph.

In order to summarize LEMA, students are shown the working of the microscopic model (such as a semi-conductor PN junction), the experimental set up (such as a circuit and meters) and graphical plots (such as V-I characteristics). Students are then asked to summarize their own understanding by co-relating the microscopic phenomenon to its macroscopic graphical outcome. This is done because employing a variety of representations (pictures, animation, graphs, vectors and numerical data displays) is helpful in understanding the underlying concepts, relations and processes. [37]



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

Figure 7. Multiple representation for summarization

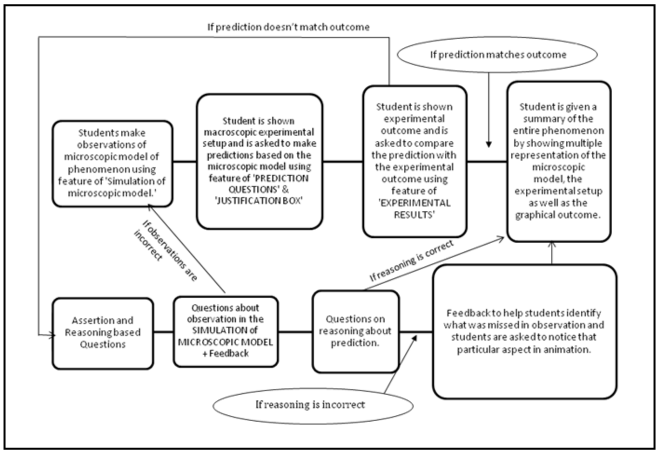


Figure 8. LEMA overview

IV. RESEARCH METHOD

The main research question of this study is: What are different students' behaviors as they interact with the various features of the learning environment?

A. *Background: Control Experiment*

This study described here is part of a larger project to develop students' modeling abilities. In prior work [39], we have reported results of a two-group quasi-experiment (N=73) in which the experimental group learnt with LEMA for the topic of semiconductor PN junctions. The control group was given a simulation of the same microscopic phenomenon as LEMA, but did not contain the scaffolds and prompts such as justification box for prediction reasoning or assertion questions and feedback. A total time period of 1 hour was allotted to the students for learning the topic without instructor intervention. Students then attempted a modeling based post-test with questions on predict, test and revise related to a new phenomenon.

To grade the answers of the students to the post-test questions, scientific abilities rubrics [27] were used. These rubrics are designed to specifically assess prediction and testing abilities, and have been validated in several experiments. We scored the post-test on students' abilities to predict a macroscopic graphical outcome for the given microscopic phenomenon, testing their prediction and then revising it if necessary. We found that the experimental group scored significantly better on the post-test leading to the conclusion that LEMA was effective in developing students' modelling abilities.

B. *Sample*

The sample in this qualitative study is a subset of the experimental group which learnt with LEMA. 24 students who learnt with LEMA were selected in the sample for the current study. Purposive sampling was conducted to obtain 12 participants who scored high on the LEMA post-test, that is, those who developed modeling abilities; and 12 who scored low on the LEMA post-test, that is, those who did not develop modeling abilities. The rubric scores were used to identify high and low scorers: students in the top third were labeled as the 'high-scorer' group and students at the bottom third were labeled as the 'low-scorers'. All these students had learned the domain knowledge present in LEMA in their college classes. To check if students' prior achievement levels, or prior knowledge of the domain had an effect, we performed a t-test on their previous exam scores and found that the high- and low-scorers were equivalent in terms of their domain knowledge of the topic (same as that in LEMA) on a traditional exam. Thus the overall achievement level of the two groups was equivalent. It was only in the modeling abilities that the two groups were different.

C. Data Source

While students from experimental group studied the material, their screen activities were captured by My Screen Recorder software [38], screen-recording software. Post the study, all these screen capturers were analyzed and later coded in accordance with the interaction pattern observed. Students were classified as high and low scorers on the basis of their scores in the modeling 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 LEMA.

D. Data Coding & Analysis

The screen recordings of each student were first transcribed. The transcripts were segmented by activities in the learning material. The entire screen activity was analyzed 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 I and that of a transcript is shown in Table II.

TABLE I. 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 II. 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

As described in Section III, our material contains activities and features such as Simulation of the microscopic model, prediction questions, justification box, conceptual reasoning scaffolds, assertion and reasoning question and multiple representations. We took notes of the ways in which students tried to interact with these features of LEMA. 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 (High Achievers) as opposed to those students who had low scores (Low Achievers). Using this we were able to establish a behavior pattern for student who had high scores (High Achievers) as opposed to those students who had low scores (Low Achievers). Table III shows the coding scheme applied in our study.

TABLE III. 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 LEMA 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	Reasoning using conceptual reasoning scaffolds

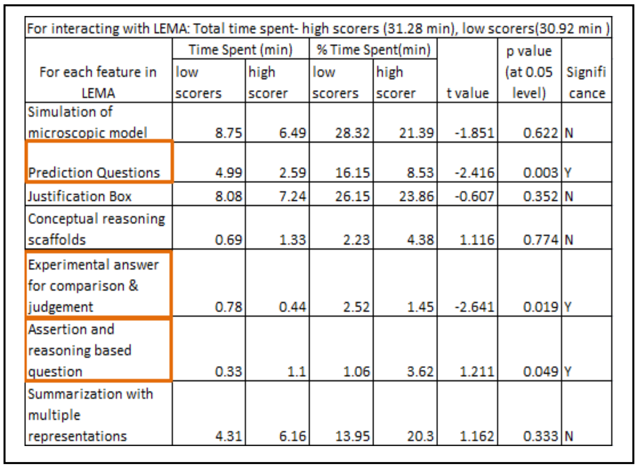
	and make careful observations accordingly	
Assertion and reasoning questions	Answer assertion and reasoning questions and try to improve our observations or reasoning by either going back and viewing animation or rephrasing justification.	Assertion and reasoning questions to improve reasoning
	Treat 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

V. RESULTS

A. *Learning Time*

On an average, all the students spent around 30 minutes interacting with all the features of LEMA. Table IV shows the time spent by students on different LEMA 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 this 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 IV. TIME SPENT ON DIFFERENT LEMA FEATURES



For interacting with LEMA: Total time spent- high scorers (31.28 min), low scorers(30.92 min)							
	Time Spent (min)		% Time Spent(min)				
For each feature in LEMA	low scorers	high scorer	low scorers	high scorer	t value	p value (at 0.05 level)	Significance
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

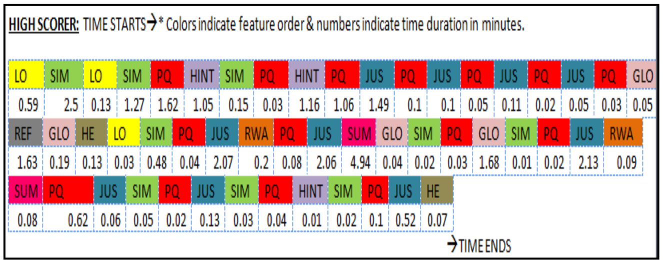
B. *Interaction Behaviour*

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

TABLE V. 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 V 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.

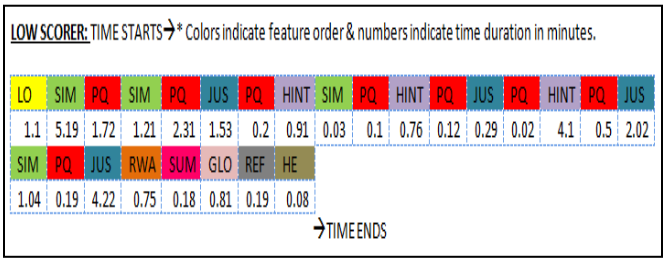


HIGH SCORER: TIME STARTS→* Colors indicate feature order & numbers indicate time duration in minutes.

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 9. Order in which features were viewed-high 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

Figure 10. Order in which features were viewed-low scorer

Figures 9 & 10 indicate a typical order in which high and low scorers interact with each feature in LEMA 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.

Figure 9 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. Post 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 10 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 predicting 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.

VI. DISCUSSION & FUTURE WORK

Our study has identified the differences in learning behavior of high and low scoring students as they interact with the Learning Environment for Modeling Abilities (LEMA).

To answer the RQ, "What are students' behaviors as they interact with the various features of the learning environment?", we have found that in spite of the fact that the total time spent by all students while interacting with LEMA is the same, the duration of time spent on each feature of LEMA and the action taken within, varies for high and low scorers. From Table V, Figure 9 & 10, we observe that there exist key differences in the behaviours of high and low scorers. High scorers on an average try to establish a strong micro to macro link and then on the basis of this make an informed decision about the macroscopic graphical outcome. Hence, while trying to phrase a justification for their choice they rephrase the reasoning until it establishes this link strongly and clearly explains why the option selected by them would be the correct outcome. In cases where they need help in making sense of the phenomenon, they are found to use the feature of conceptual reasoning scaffolds as an aid to note which area of the simulation where more observations need to be made. This is what high scorers do while making a prediction, phrasing a justification where as for these same features low scorers spend the same amount of time trying to guess one choice of answer until they get it right and on copying on screen text.

This study helped us understand which student behaviours were productive in the development of modeling abilities through LEMA. Analysis of the student interactions with LEMA gave us possible directions of refining the learning environment itself. For instructional designers of other technology enhanced learning environments, this study contains pointers to different learners' interaction behaviours, which in turn can inform the productive design of the learning environment. For example, it might help to include an active line wherein the student is aware of where he/she is in the learning environment and possibly retention of all their answers when they go back so that they can indulge in reflection of their thinking process. This learning path adopted by high scoring students can also be converted into a teaching learning strategy so that students can reap most benefits out of the learning environment.

In future work, we also plan to conduct usability studies as part of future work so as to improve students' learning process and aid in developing their modeling skills.

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