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Development of Predict-Test-Revise Modeling Abilities via a self-study Learning Environment

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Abstract: In addition to developing students' content knowledge, an important goal of science instruction is to improve students' ability of modeling, such as, the ability to create and use simplified representations to describe and explain phenomena, and predict outcomes of new phenomena. It has been shown that students face difficulty in developing these abilities unless they are explicitly addressed in the curriculum. ICT-based solutions to this problem have been developed, such as the WISE and MARS, have mostly been implemented at the middle and high school levels and the teacher facilitates the process. In this paper we describe the design of LEMA, which addresses modeling abilities in college level science topics. LEMA is a self-regulated learning environment in which students are given various activities and customized formative assessment to achieve the above goals. We tested the effectiveness of LEMA through a two-group post-test controlled experiment. Students who learnt with LEMA performed significantly better on abilities of prediction, testing and revision of models. We also identified student perceptions of which features of LEMA helped them develop these abilities.

Keywords: predict-test-revise abilities, modeling, learning environment, self study

1. Introduction & Related Work

The goal of traditional classroom instruction in science and engineering has typically been that students develop certain other science *process-related* abilities in addition to their content knowledge. One such ability is that of modeling which refers to the use of models or simplifications to create faithful representations of the processes of science by providing satisfactory explanations of the phenomena in the world as experienced and predict outcomes of new phenomena (Gilbert, 2004). Studies have shown that under traditional instruction, students have difficulty in understanding and using models (Gilbert, 2004), especially in the understanding the predictive nature of models (Grosslight, et.al., 1991). There have been instructional interventions such as WISE (Linn & Slotta, 2000; Linn & Hsi, 2000), MARS (Raghavan, et.al., 1993; Raghavan & Glaser, 1995) and ISLE curriculum (Etkina &Van Heuvelen, 2007) which are two week to a semester long interventions which integrate a computer supported environment with classroom activities and have succeeded in developing students understanding about the interpretive and predictive nature of models. But in all these methods, the teacher plays an important role by facilitating the process, giving prompts or grading the student's efforts at a later stage (Raghavan & Glaser, 1995; Treagust, et.al, 2002; Verschaffel & De Corte, 1997) and these curricula have been implemented mostly at the middle school and high school levels, and to some extent in introductory college courses. In this paper, we introduce the rationale for the design of a Learning Environment for Modeling Education (LEMA) which is an ICT-based solution made specifically for the context of self study wherein each topic has a learn time of 45-60 minutes. We have performed a two-group quasi-experimental study to determine whether LEMA helps students in developing abilities of using models, prediction, testing and revision. Students' perceptions using reflection questions were used to ensure that LEMA features are consistent with our design rationale for including these features.

Students make sense of the world around them, and what they are taught, by means of conceptual models that they form in their minds. If these models are incorrect, it leads to flawed reasoning and misconceptions (Gilbert, 2004). An important aspect of modeling is to explain the macroscopic outcome of a given situation by applying a model at a microscopic level. Research shows that students have difficulty transferring from a macroscopic level of representation to the microscopic level (Gabel, 1998). Multimedia tools such as animations and simulations, which help students connect between these levels, have been shown to promote conceptual understanding (Kozma et. al., 1997). However, in order for students to be able to learn in the absence of a teacher or facilitator, the process of self-regulated learning has been recommended. Formative assessment in the form of rich and timely feedback, along with the opportunity to revise responses, has been shown to support the development of learner self regulation (Nicol & Macfarlane-Dick, 2006) and research has shown that question prompts can facilitate explanation construction (Bereiter & Bird, 1985), monitoring and evaluation (Davis, 2000), and making justifications (Lin & Lehman, 1999).

2. Design of the Learning Environment for Modeling Education (LEMA)

The process of designing LEMA included identifying specific modeling abilities to target, identifying learning objectives, determining the features to be included and creating the instructional design. The modeling abilities were adapted from the scientific abilities rubrics (Etkina, et.al., 2006).

We define 'Modeling ability' as a measureable set of abilities in which students learn to make predictions, test predictions with respect to experimental results, and revise predictions if necessary. In the prediction phase, students should be able to devise an explanation for an observed pattern, make a reasonable prediction based on explanation. In the testing phase, students should be able to decide whether the prediction and the outcome agree/disagree. And in the revision phase, students should be able to revise the explanation when necessary.

LEMA was designed using features suggested for the development of students scientific abilities such as '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' (Etkina, et.al., 2006). On the basis of all these features an Instructional Design Document was created and was given to two subject matter experts for content validity. Fig 1 given below shows a screen shot of the important features of LEMA. Left to Right- Simulation of the Microscopic Model, Prediction Questions, Justification Box, Experimental Results for comparison and judgement and Assertion and Reasoning based questions with customized feedback.

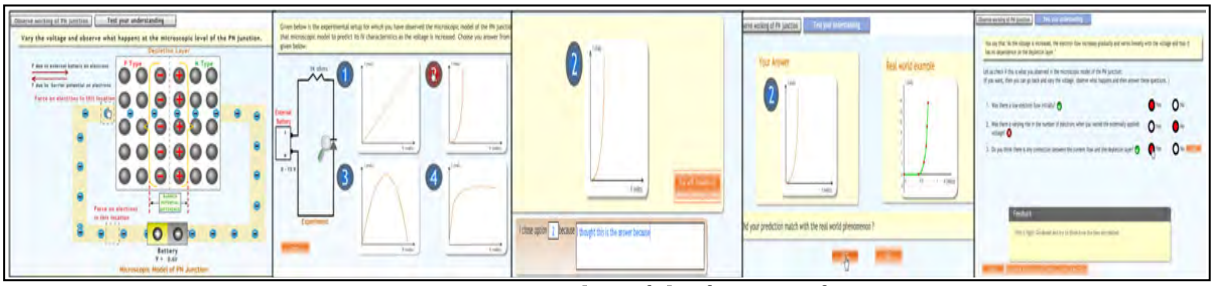

Figure.1—Screenshot of the features of LEMA

In the Simulation of the microscopic model, students are asked to interact with it with the help of variable manipulation, text entry and meter readings. This feature helps in developing all the abilities of modeling, namely the ability to make observations, predictions, testing predictions and revising them. This is done because it is 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 (Lee, et.al., 2002). In the feature of 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. This feature helps in developing the sub ability of making a reasonable prediction based on explanation in the prediction phase. This is important because any learning material should provide opportunity for predicting the outcome of a situation/experiment (Gilbert,2004). When students have predicted the outcome of any situation, they are asked to write explanation on which the prediction is based. This feature helps in developing the sub ability of devising an explanation for an observed pattern and making a reasonable prediction based on explanation. This is needed because students should be able to adapt a known model to the specifications of the given problem (Wells, et.al., 1995) During the test phase, students are provided with real world answers and hints and are asked to decide whether the prediction and the outcome agree/disagree in the testing phase. This is important because students should be able to analyze the outcomes of an experiment and be able to justify your conclusions (Wells, et.al., 1995). During the revise phase, students are shown their prediction and justification of the IV graph of the PN junction and they are asked to answer questions aligned with IV graph chosen by them. If they are getting 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 in the simulation. This is a very crucial feature because designing instruction using building blocks such as hint, if-confused and summarization is much more powerful than designing instruction at the level of show video. (Linn, et.al., 2000; Wielinga, et.al., 1992). In order to summarize LEMA, students are shown the working of the microscopic model of the PN junction, the experimental set up with meter reading and a graphical plot of the IV characteristics dynamically. 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 (Robinson, 1987)

3. Evaluation & Discussion

3.1 Research Method

The main study consisted of a two-group post-test only experimental research design, and was used to answer the following research questions:

RQ1: Did students who worked with LEMA develop modeling abilities?

RQ2: Which features in the LEMA did students perceive to helpful in answering questions related to modeling abilities?

Before the main study, a pilot study was conducted to test the validity and usability of the learning materials in LEMA and the validity of the post-test. Students from the 1st year undergraduate Bachelor of Science (B.Sc.) program from various colleges under Mumbai University, India, were chosen as the sample. A quasi experimental research design was adopted. The students (N=73) who arrived at the experiment venue were assigned to two groups by randomized assignment. Group 1 (Experimental group) contained 37 students while Group 2 (control group) contained 36 students. Students in the control group were given a visualization which contained the same animation of the microscopic phenomenon, but did not contain the scaffolds and prompts present in LEMA. A total time period of 1 hour was allotted to the students for learning the topic. At the end of the hour, a new physical phenomenon was presented to the student by means of an simulation depicting its microscopic explanation. In order to answer RQ1 related to students' development of modeling abilities, we administered a post test which contained open ended questions that mapped to each modeling sub ability. To answer RQ2 on students' perceptions of useful features of LEMA, a reflection questionnaire was used as the instrument. Students were asked to rate each feature of LEMA on a scale of 0-2 where 0-Not Helpful, 1-SomeWhat Helpful, 2-Very Helpful. To grade the answers of the students to the post-test questions, scientific abilities rubrics (Etkina, et.al., 2006) were used.

3.2 Results

The inter rater reliability for the raters was calculated and the value of Cohen's Kappa was found to be 0.839 with $p<0.001$. Post analysis of the post test results using a Mann-Whitney U-test, we found that the experimental group (LEMA) showed a statistically significant difference at $p=0.05$ level in their improvement in their abilities of making observations, predictions, testing them and then revising them as compared to the control group.

Table 1: Mann-Whitney U-test Scores.

Ability to describe observations	Ability of devising an explanation for an observed pattern	ability of making a prediction based on explanation	ability of testing a prediction	ability of revising a prediction
p=0.195	p=0.000	p=0.003	p=0.014	p=0.008

From the student perception data, we find the following percentage of students from the LEMA group who found each feature very-useful. (NA =Not Applicable)

Table 2: Student perceptions of usefulness of a feature.

Ability	Simulation of Microscopic model	Prediction Questions	Justification Box	Multiple Representations	Experimental Results for comparison and judgement	Assertion and Reasoning Questions
Predict	70.27%	64.86%	51.35%	70.27%	NA	NA
Test	72.97%	NA	NA	59.45%	72.97%	NA
Revise	64.86%	NA	NA	56.75%	NA	56.75%

We find that both groups did well in the ability of describing observations without explanations, but, the experimental group performed significantly better than the control group for all the other sub abilities, namely, the ability to devise explanation for an observed pattern, ability to make a reasonable prediction based on explanation, ability to decide whether the prediction and the outcome agree/disagree and the ability to revise the explanation when necessary. Since the only difference in treatment for the two groups was the learning material, we can argue that the features of LEMA lead to the improvement in students modeling skills. Factors such as proficiency in English, test with only one topic, data from one study as evidence could be limitations of this study. The main contribution of our work is the identification of design components of a ICT-based learning environment that explicitly targets students' modeling abilities. Future work involves creation of more number of LEMA modules in a variety of topics.

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