Designing for Model Progression to Facilitate Students' Science Learning

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Abstract: WiMVT (**W**eb-based **i**nquirer with **M**odeling and **V**isualization **T**echnology) is designed as a learning system combining guided inquiry, modeling and visualization with the social interaction. In the paper, we first present the design rationale of the system, briefly describe the main functions, then discuss the features supporting model progression in science learning. Following it, we describe a pilot study of WiMVT implementation in the secondary science class. The data analysis demonstrates the pedagogical value of WiMVT on students' conceptual understanding, and indicates that appropriate peer feedback can promote students' model elaboration in the modeling activities.

Keywords: WiMVT, model progression, collaboration, peer feedback

Introduction

Due to the learning effectiveness of the models and modeling tools for science education, in particular, the computer-supported Model-based Science Learning Environment (MbSLE), a number of researchers have invested great effort in building and implementing MbSLEs in science learning (e.g. Model-it, ModelingSpace, NetLogo, WISE). Besides modeling tools, these applications may have design elements such as curriculum materials, proposed pedagogy (e.g. inquiry, CSCL, model progression) and communicative tools. However, few of them have been designed with the integration of all these design elements. For example, most of them are unable to support online collaborative modeling; some of them do not allow for importing of multiple visual representations; and some of them do not facilitate model progression in pupils. With the intention of creating an innovative application for secondary school students to acquire sophisticated understanding of scientific conceptions, develop critical learning skills, we have developed a web-based science learning environment named WiMVT (**W**eb-based **i**nquirer with **M**odeling and **V**isualization **T**echnology, http://www.sstlsl-wimvt.sg/wimvt). It is designed as a system in which guided inquiry, modeling and visualization, and social interaction, are integrated - which is unique among existing science learning environments (Sun & Looi, 2012).

The work reported in this paper focuses on one of core features of the system: model progression. In this paper, we first introduce the design rationale and the basic functions of the system. Then we emphasize the feature of model progression in the system. Finally, we present some results from a pilot study to illustrate the educational value of the model progression with WiMVT system. The study is used to answer the research questions below:
1) How to integrate a science learning environment featuring model progression into a real learning context?
2) What is the learning efficacy of the model progression for students' conceptual understanding in science?
3) Does the peer feedback promote students' modeling progression in the WiMVT lessons?

1. The Design Rationale of WiMVT System

The learning efficacy of the model-based inquiry in science education has been demonstrated in many studies (Schwarz & Gwekwerere, 2007). Its generic learning pattern can be summarized as question, hypothesis, plan, investigation, model, and conclusion (Bell, et al., 2009). The pattern serves as the guide for the form of WiMVT inquiry cycle. Additionally, informed by the principle of POE (Predict-Observe-Explain) adopted in science class in some Singapore schools (White & Gunstone, 1992), we propose a phase called Pre-model (to explicate students' initial ideas) with the corresponding phase: Model (to explicate students' post ideas) in the inquiry. The design guides students to present their predictions of the science phenomena before investigation, and then to verify their predictions through investigation, thus ultimately improving their understanding of the science phenomena. Hence, the main purpose of embedding model progression by including Pre-model and Model into guided inquiry is to help students elicit and expose their prior knowledge through pre-models and to elaborate their models in Model phase after a series of activities. Afterward students refine their understanding and seek validation them in the Reflect and Apply phrases. Finally, a revised model-based inquiry cycle incorporating eight phases is created: Contextualize, Question & Hypothesize (Q&H), Pre-model, Plan, Investigate, Model, Reflect, and Apply (WiMVT inquiry cycle).

WiMVT is a complicated system, so we employ a standard approach: the Rapid Application Development (RAD) for the system development in consideration of the research condition. The development process consists of five short development cycles which mostly involve: design → discussion → adopted features development→ discussion & usability test → redesign. At each stage, consultants and collaborators from different research including science education, computer technology, and educational technology areas are invited to give feedback and comments on the design of the system. Subsequent revisions are made based on the feedback. During the whole process, to verify the validity of the system at each stage, usability testing is conducted to collect data for revising and improving the design and development. Up to date, we have finished several usability tests and two pilot studies. The existing WiMVT system has been revised and improved based on the usability report and feedback from trial implementation in the pilot school.

2. The Introduction of the WiMVT System

The WiMVT system operates via the Internet and is accessible through a general web browser. Figure 1shows the work flow of the system as a pedagogical scenario. The number tags (A-D) corresponds to the four operational procedures of the system, see discussion below.

A. Establishing the project: the authoring tool in the teacher module supporting the design of the project[1]: 1) Present brief project description, learning objectives, and tasks for Home; 2) Edit content accompanying various types of information (e.g. videos, images, simulations) for Contextualize; 3) Design questions for Q&H, and assign tasks for Plan, Pre-model and Model, Reflect, and Apply. 4) Insert simulations together with guided questions into the Investigate tab where students are required to do certain virtual experiments. Finally, the teacher configures the students' groups in the Group Management section and assigns the projects to the students.

[1] The teacher module consists of six sections: My Profile, My Subjects, Project Management, Solutions Review, Simulation Library, My Mailbox. The section of Project Management provides an authoring tool for teachers to design and edit the instructional content.

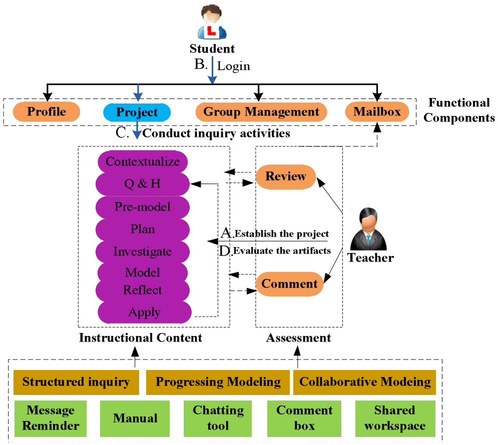

Figure 1. The work flow of WiMVT system

B. Logging onto account: the student module comprises four functional components: My profile, My project, Group Management and Mailbox. The general information of the assigned project can be retrieved in My Project section after the students log into the system with their accounts and passwords.

C. Conducting inquiry activities: The typical work surface in student module is illustrated in Figure 2. It is split into four panes: shared workspace which holds the textual information or tools associated with each phase, status of group members (online students' username is visible at all times), name list of group members, and a chat box.

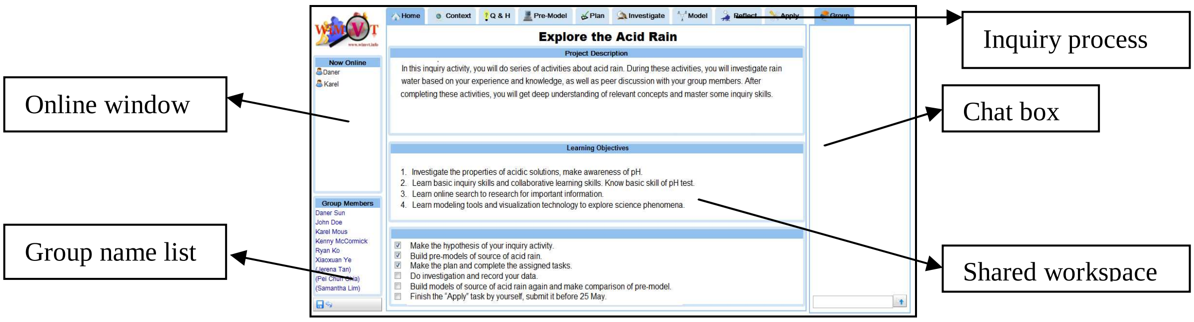

Figure 2. The interface of students' work session

The process of WiMVT inquiry can be briefly described as below: After accessing the "Home" tab, the students are guided to engage in a series of learning activities: students formalize their hypothesis of the questions in Q&H; create pre-models of scientific concepts they will learn based on their prior knowledge when in Pre-Model; design the plan in the Plan and then collect and discuss the data in Investigate. Additionally, they can also engage in the manipulation of several simulations to do virtual experiments, as well as answer the guided questions. They are then asked to revise their pre-models through peer review and discussion in Model, and to reflect upon artefacts being built when getting into the Reflect phase.

D. Reviewing and commenting on artefacts: The teacher thereby can access the artefacts and interactions generated by students while navigating in Solutions Review, and comment on each student or each group's hypotheses, plan, investigation report, pre-models and models, reflective content, as well as their responses in Apply if any. Thus, the system supports both formative and summative assessments.

3. Model Progression in the WiMVT System

The model progression is a way to present models in increasing complexity gradually through expanding the number of components or the levels of relations among variables of models (Swaak, et al., 1998; Mulder,et al., 2011). As indicated earlier, the design elements of the system support model progression. Specifically, a sketch tool serves as a drawing-based modeling tool is designed to assist low-ability students' creation of the models both Pre-model and Model (Lerner, 2007). Compared to the drawing-based tool, the qualitative modeling tool and quantitative modeling tools in Model provide more opportunities for students to construct high level scientific models. In the system, when students define objects and establish relations between variables of a qualitative model, the modeling functions were mainly executed as an invisible simulation engine for processing relationships which are specified in the form: 'If A increases, B increases' (Avouris, et al., 2005). In the quantitative modeling scenario, the relations are established via precise mathematical forms involving variables. In this way, modeling thereby can be progressive because the students can start from simple (novice) models to complex (expert) models using the sketch tool. Otherwise, they can work from more qualitative modeling without defining formulas and then get into the stage of more quantitative modeling when figuring out the formulas finally. Moreover, synchronous collaboration in Pre-model and Model is facilitated via the shared workspace and a chatting tool. It means that students can co-construct a model in real-time, and then modify and elaborate it through online peer discussion.

4. Research Design and Methods

4.1 Participants

In this study, 46 students from two classes were randomly selected from a junior secondary school in Singapore. A female physics teacher with 9 - year teaching experience conducted the class. She had participated in a series of teacher-researcher working sessions of WiMVT project, and thus had some good understanding of the system. The computer facilities in the school were excellent, and each student owned and used a Macbook for daily lessons in the various subjects.

4.2 The design of WiMVT lessons

The WiMVT lessons were co-designed by WiMVT team, science teachers and collaborators. The classes studied "Current Electricity and D.C. Circuit". The topic was divided into 8 50-minute lessons, in which four lessons were incorporated by the system. Table 1 summarizes the lesson flow and relevant information.

The students drew a model of a circuit needed to run a quiz show for 3 teams of participants, and to point out the direction of the current flow as well in lesson 1. The teacher reviewed the pre-models and identified the major misconceptions amongst the students. Students' initial ideas of simple circuits then further explored and elicited in lesson 2 through doing hands-on experiments of connecting possible circuits. During lesson 3 and 4, the students interacted with three levels of PhET simulations, as well as answered guided questions individually. After obtaining new understanding through investigation, they were guided to Model phase to elaborate initial models drawn in lesson 1, and to reflect on their conceptual changes in Reflect. In this pilot study, the qualitative and quantitative modeling tools are not incorporated into the system. The students mainly worked with the sketch tool to create models. They were encouraged to provide online peer feedback for models creation and elaboration within the group members. Before class time, the students were asked to log onto WiMVT at home to sufficiently familiarize themselves with the system. The teachers integrated the instructional content in the system and managed the grouping of the students. As 23 students in each class were divided into 8 groups with heterogeneous, they mainly worked in triads (one group worked in dyads each class).

4.3 Data source and data analysis

The study aimed to examine the pedagogical value of model progression of the system in students' science learning, as well as the impact of peer feedback on students' modeling performance. We used software to capture the screen activities with the intention of validating data analysis. Videotaped recordings of the teacher and students' interactions were used to identify patterns of change for triangulation purposes. One audio recorder was directed at each of 8 groups in both of classes. After all sessions, we interviewed the teacher and 16 students using a semi-structured interview protocol for approximate 20 minutes. In data analysis, all videotapes and audios were transcribed to examine students' performance in WiMVT activities. The students' peer feedback generated in chatting log during the modeling process was also saved, identified and transcribed. It was used to investigate the relation between students' model quality and their peer feedback. The results were subsequently verified by cross-referencing collected data.

5. Results

5.1 The progression of the models' quality

We used the quality of models as the indicator for evaluating students' modeling performance. Based on the literature review, we classified the quality of models into three levels: 1) High Quality Models (HQMs) are the model representations reflecting appropriate descriptions of science conceptions that involve components with basic properties, and depicting interactions between variables of components. 2) Medium Quality Models (MQMs) are the model representing partially accurate descriptions of scientific conceptions, in which some of appropriate components of models are included in the models. 3) Low Quality Models (LQMs) refer to the model representations which contain inaccurate descriptions of all models components, they are usually at the level of the scribble drawing (Grosslight, et al., 1991). In this study, we collected a total of 11 models in Pre-model phase and 14 models in Model phase. The outcomes of the evaluation of students' models in Pre-model and Model phases are depicted in Table 1[2].

Table 1. The number of different models in the Pre-model and Model phases

Quality of models	Pre-model stage	Model stage
LQM	1	0
MQM	5(without current direction) 3(inaccurate current direction) 1(short circuit)	6 (without current direction) 1 (inaccurate current direction) 3 (broken circuit with current directions)
HQM	1	4

Overall, the quality of students' pre-models and models were at the level of MQMs, around 82% and 71% respectively. Specifically, 45% of models in Pre-model phase presented right representations with components of bulbs, switches and batteries, but failed

[2] As the models were the products of groups' work, the number of models equals the number of groups.

to define the current flow direction, while the rate decreased to 42% in Model phase. In comparison with the 3 groups who drew the incorrect current flow direction, only one group exhibited the same mistake in Model phase. In Model phase, 3 groups defined the right components of models although they drew the current in the broken circuit, while the models of 4 groups achieved the level of HQMs. These findings indicated students' better performance as reflected by the better quality of models generated in the Model phase. The increase in HQMs further demonstrated students' progress in the understanding of core concepts and modeling skills. The students' responses on the process of understanding the circuit in the Reflect phase demonstrated their progressions as well:

- Students A: I used to think that short circuits are very complicated, but they are not. In addition, I thought that parallel circuits have different current for each bulb. But now, I think that for parallel circuits, the bulbs have the same brightness as the same amount of current is being flowed through it. Only, when the switch is closed, then the electrons can starts flowing. Bulbs in series circuits have lower brightness than bulbs in parallel connection.
- Student B: I feel that our design is correct as it is in parallel connection of the bulbs with a switch connected to it. Closing one switch will cause its corresponding light bulb to light up.

5.2 The correlation of models quality and peer feedback

Online peer feedback is particularly advantageous, due to the possibility of a less stressful and intimidating working environment from the lack of face-to-face interaction, which may promote students to be adventurous and be more involved (Guardado & Shi, 2007). In the study, students were encouraged to build, revise and elaborate their models through receiving peer feedback from their team members both in the Pre-Model and Model phases. The peer feedback coding instrument was developed based on the principles of good feedback theory and practice (Nicol & Macfarlane-Dick, 2006). It consisted of five categories: A. task-oriented (clarifies the task specificities), B. knowledge-oriented (provides necessary information on how to solve a problem), C. strategy-oriented (provides strategic plans to derive answers in the best way), D. assessment-oriented (provides constructive comments on the work produced) feedback, and E. affection-oriented (provides comments with intentions to improve motivations). Here are some examples of the peer feedback from the transcription of the discourse of a group doing the modeling, with their coding:

- *Category A +Category B: you press undo and draw the bulb.*
- *Category B: Just put more batteries to make it (electromagnet) stronger.*
- *Category C: Let us first draw and then think it.*
- *Category D: Actually it is possible. But maybe need more batteries.*
- *Category E + Category D: Nice drawing. I will draw the line.*

In the data analysis, the Pearson coefficient was computed to assess the relationship between model scores and the students' peer feedback. Thus, we scored 25 models from the range of 0 -100 according to the components of models and its relations. The LQM score was less than 60, the MQM score was between 60 and 80, and the HQM score was between 80 and 100. We calculated the quantity of peer feedback that happened at each group, as well as the number of each type of peer feedback. The results indicated that there appeared to be an upward trend, namely, as the amount of peer feedback increases, the higher the scores of the models drawn. The statistical analysis with the Pearson's r=0.972, p=0 (at the level of 0.01) reflected a strong positive correlations between students' model scores and the quantity of feedback. Table 2 presents the respective correlation for the five categories of peer feedback and the model scores.

Table 2. The correlations between peer feedback and models' score

Measure	A: Task	B: Knowledge	C:Strategy	D:Assessment	E:Affection
Pearson Correlations	0.839**	0.280	0.574	0.941**	-0.739
Sig.(2-tailed)	.000	.158	.253	.000	.261
N (Model)	25	25	25	25	25

** Correlation is significant at the 0.01 level (2-tailed)

The findings suggested that category A, B, C, D were positively correlated with the model scores. Significant correlation existed between category D and model scores, r=0.941, p =.000. Thus, the higher the quantity of category D, the higher the models' scores, or vice versa. There was also significant correlation between category A and the model scores (r=0.839, p=000). As for knowledge and strategy-oriented peer feedbacks, the correlations (r=0.28, p = .158; r=0.574, p=.253) for both measures with the model scores are not significant and they are weakly correlated. This could imply that knowledge and strategy-oriented feedbacks may be less related to the scoring of the model. Also, the correlation between affection-oriented peer feedback and scores is negative, r(2) = -.739, p = .261. We would like to explore these further in future empirical studies. Thus, when students are working with the modeling tool in the system, it is suggested assessment-oriented peer feedback and task-oriented feedback be provided by team members or otherwise, using words like:

- *Please don't forget that the switch is one of the objects.*
- *There appears to be a problem in that part, do you mind if you check it again?*
- *I think the two objects that you linked up may be incorrect.*

5.3 Voices of the teacher and students

The teacher and students expressed an overall positive attitude toward the WiMVT implementation in the science class. The teacher had a better understanding of the lessons which could be designed to leverage on the affordances for WiMVT inquiry. She concluded that 1) lesson plans should be adopted for best fit with WiMVT inquiry and the instruction should optimize the core features of the system; 2) The explicit inquiry mode was a good scaffold to guide students' learning activities; 3) Students were suggested to do individual modeling in the Pre-model phase, because they had different initial ideas; 4) In the Model phase, students were encouraged to converge to a solid understanding whereby they could present in one consensus model through the co-constructive way. The students agreed on that the WiMVT learning activities were more interesting and engaging compared what they had used previously. They pointed out that the small group's collaboration provided more opportunities to do tasks in the system, and the synchronized collaboration could help them finish the task faster. The modeling process directly within the system could make drawing more convenient and less time consuming. They thought that they enhanced their understanding of electrical circuits bring taught in the lesson through the comparison of pre-models and models, as well as a reflection phase to concretize the thinking process.

Conclusions

This pilot study on design and implementation of WiMVT lessons addresses the research question on how to design the WiMVT lessons, and the results demonstrated that WiMVT exhibited some value in aiding students' conceptual understanding. Specifically, the students' model progression can be achieved through the design elements of the combination of Pre-model and Model phrases in the inquiry. The preliminary finding that the quantity of peer feedback varies with the quality of the models can help inform the design of collaboration into such an environment. The students are particularly encouraged to heed assessment-oriented feedback in the collaborative activities. The teacher and students' voices suggested that more engagement needs more appropriate instructional support such as guiding students' collaboration, scaffolding students' modeling process. In summary, we provide an illustration of the WiMVT system that supports flexible collaborative students' model-based inquiry. We believed that the inquiry with WiMVT will create unique educational opportunities for students' science learning. In the future work, the investigation of students' conceptual understanding, collaborative skills, inquiry skills and reflective thinking skills will be the main avenues we will pursue with longer-term and larger scale use of the WiMVT system.

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