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A web-based model to enhance competency in the interconnection of multiple levels of representation for pre-service teachers

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ABSTRACT: This study aimed to design a web-based learning model to enhance pre-service teachers' competencies in the Interconnection of Multiple Levels of Representation (IMLR). The model contains multimodal representations with assignments and probing questions; it creates social engagement through online discussion forums and online assessment as feedback on learning performance. The validity of the model was evaluated by expert judgment, while the feasibilty of the model was explored through a limited test with students using the quasi-experimental method. The results showed that the implementation of a web-based model increased the pre-service teachers' abilities in IMLR on each subtopic of chemical equilibrium in aqueous solution. The pre-service students also showed good abilities to resolve problems with interconnection patterns that progressed from macroscopic to submicroscopic and symbolic, rather than starting from submicroscopic and moving to symbolic and macroscopic. It can be concluded that the web-based learning model enhanced the pre-service teachers' understanding of the submicroscopic level, changing existing problem-solving ability patterns from macroscopic–symbolic into six interconnection patterns, and improving student learning patterns.

1 INTRODUCTION

As stated by Johnstone (in Treagust, 2008), the characteristics of chemistry involve three levels of chemical representation, that is, macroscopic, submicroscopic, and symbolic. These three levels of chemical representation contain inter-connectedness information. While macroscopic observable chemical phenomena are the basis of chemistry, explanations of these phenomena usually rely on the symbolic and submicroscopic levels of representation (Treagust, 2008). Consequently, the ability of learners to understand the role of each level of chemical representation and the ability to transfer from one level to another is an important aspect of generating understandable explanations. This ability is also referred to as Interconnection of Multiple Levels of Representation (IMLR) competence.

In general, teaching and learning have been restricted to the level of macroscopic and symbolic representations. Many high school teachers tend only to use these two levels. They often do not integrate the three representation levels in their teaching but move among them without highlighting their inter-connectedness. Teachers often assume that students are able to connect symbolic to submicroscopic representations on their own (Tasker & Dalton, 2006). Students' ability to solve mathematical problems became the criterion by which they were deemed to have understood chemical concepts. However, such a view could hinder students in achieving representational competence (Chittleborough & Treagust, 2007).

Reviews of various empirical studies supported these statements. One previous study found that first-year students had difficulty in describing the scheme and transfer of symbolic representation to submicroscopic representation in acid–base equilibrium (Devetak et al., 2006). Another study showed that high school students had difficulty in representing submicroscopic levels of ionic equilibrium in weak acids, weak bases, salt hydrolysis, and buffer solutions (Murniati & Sopandi, 2007). Such problems are caused by the lack of ability of teachers to use a variety of modes of submicroscopic representation and connect them to other levels of representation (Savec et al., 2006; Weerawardhana & Ferry, 2006; Akselaa & Lundell, 2008).

Students' representational competence is tied to the learning process in classrooms, the practical laboratory and textbooks. Chemistry teachers and pre-service chemistry teachers must achieve their own internal connection of the three levels of representation, as well as re-representing the three levels in their teaching

(Farida et al., 2010). Based on the consideration that the effectiveness of teaching and learning in school depends on teachers' competence, we should endeavor to increase the professional competence of chemistry teachers through the provisioning of IMLR competence. This paper discusses the results of research on the characteristics of a web-based learning model designed to increase the IMLR competence of student chemistry teachers, and the results of its testing.

2 RESEARCH METHODS

This research aims to engender IMLR competence using a web-based model of learning, and to analyze its impact on increasing the ability of pre-service chemistry teachers. The model was developed through three phases: a preliminary study phase, model design, and model validation. The design model was validated by expert judgment, and limited tryout on 31 students, and a model revision was then performed. The revised model was implemented to 37 students using the quasi-experimental method: a one-group pre-test/post-test design. IMLR competence was measured using an online test (two-tier multiple-choice test). An online questionnaire was used to determine student opinion of the model.

3 RESULTS AND DISCUSSION

Theoretical studies were reviewed to analyze the characteristics of chemical concepts, the mapping relationship among those concepts and the levels of chemical representation. For this purpose, we chose the concept of chemical equilibrium in aqueous solution for study. Contextually, this concept plays a crucial role in many biological and environmental processes (McMurry & Fay, 2006).

The results of the conceptual analysis showed that there are three main types of concept of chemical equilibriums in aqueous solution: 1) abstract concepts with concrete examples; 2) concepts in the form of processes; 3) concepts in the form of principles. The representation levels included macroscopic, submicroscopic and symbolic.

The prerequisite concepts involved the three levels of representation too, and were: 1) proton transfer reaction (Brønsted–Lowry acid–base concepts); 2) weak acids, weak bases and water dissociation; 3) the strength of acids and bases, and pH; 4) solubility. These prerequisite concepts must be understandable to appreciate three main concepts: 1) salt hydrolysis; 2) buffer solutions; 3) solubility equilibrium.

An analysis of levels of representation is required to determine the modes of representation that are appropriate for these concepts. The modes of representation available were pictorial mode, graphics, animation, simulation and ChemSense Animators (http://chemsense.sourceforge.net/). The ChemSense Animator tool provides shape templates for modeling techniques and processes from the simple to the complex to help visualize and explain chemical phenomena (Toplis, 2008). An animation of a chemical process can be constructed frame by frame using a simple toolbox, so as to support reasoning and discussion about the submicroscopic changes occurring during the reaction. The use of modes of representation is integrated in the learning, as suggested by Tasker and Dalton (2006), and by Mayer (in Kozma & Russell, 2005).

The characteristics of web-based learning model found in this study were:

1. Content- and activity-based learning (problem-based and question-driven).
2. Problem-solving is done through periodic tasks for each topic in order to develop competence in IMLR. Based on these tasks, students' IMLR competence can be explored and elaborated.
3. Learning materials for each topic are multimodal representations in the form of text, images, graphics, animation, simulation and tools aimed at facilitating the development of IMLR ability in any topic. Their use is integrated into learning activities via the web.
4. A social atmosphere is created through an online discussion forum to allow students to construct meaning and reflect their abilities.
5. Online assessment was conducted independently as progress feedback on individual learning performance.

These characteristics included three main elements associated with web-based learning (Garrison & Vaughan, 2008): 1) cognitive presence; 2) social presence; 3) the role of instructors in creating and facilitating the cognitive and social climate (teacher presence).

Learning phases were developed according to these characteristics as follows: orientation, exploration, elaboration, reflection, confirmation, and evaluation. The orientation phase is performed offline or through a face-to-face meeting, while the subsequent phases are implemented in a web-based learning environment. The courseware for the web-based learning is installed into a learning management system (Moodle 2.0). It is in accordance with every teaching phase. Dynamic features of Moodle 2.0 apply the principles and learning strategies based on social pedagogy constructivism (Stocker, 2010), thus enabling: interactive learning materials management; periodic content upload; multimedia integration, which facilitates multiple levels of representation; communication forums; and online assessment (Gudimetla & Mahalinga, 2006).

Thus, the Moodle features that are activated are:

1. Lesson activity: an interactive web page with questions in card format, which present the topic of

acid–base equilibrium. This feature is integrated with animation, slideshows and images related to the topic. Lesson activity can enable students to get feedback so that they can assess and reflect on their own knowledge and then play it back to really understand the learning content. Lesson activity features act as a triggering event and can be adapted.

2. Assignment involving advanced uploading of files that is used to load worksheet and send tasks. Assisted tasks are accomplished using ChemSense Animator tools, animation and simulation. For completion of acid–base, salt hydrolysis, and buffer solution tasks the Animator tool can be used, and can be supplemented with animations and PhET science simulations (http://phet.colorado.edu).
3. Discussion forum: for reflection and sharing of knowledge between students and discussion of the problems they face in relation to the study topics. From this discussion forum, how students make use of IMLR to solve problems can be traced.
4. Online assessment tools are used to test the ability of students' IMLR competence before and after the implementation of learning activities. Online assessment is carried out to obtain feedback on the progress of students' learning performance.
5. Chat room: used to communicate synchronously, so that students can directly exchange ideas, ask questions about various aspects of the material or technical terms. This feature was not enabled at the time of the online test/quiz.
6. Feedback feature: includes an online questionnaire to obtain feedback from students regarding the learning model. This feature can be accessed after the student has completed the entire learning package.

Each feature has a sequenced arrangement of access and time limit, so that student access to learning content is more structured. The continuity of learning of each student can be traced by using block completion tracking settings, as advised by Stocker (2010) and Gillani (2003).

Thus, instructional design has to accommodate the characteristics of effective online learning according to Horton (2006) and Dawley (2007). Learning tools were developed by incorporating the principles of dynamic linking, as suggested by Kaput (in Snelson, 2005), and according to Mayer's multimedia learning principles (in Kozma & Russell, 2004). For each topic, eight indicators were developed that interconnect each level of representation to a relational understanding, as described by Treagust et al. (2003).

Overall, the assessment involves expert judgment of the design of the courseware material, and testing of the validity of its content. A limited test was conducted with 31 students and was intended to establish the design feasibility of the learning steps through the use of the web and supporting devices. On the basis of the limited testing, there were several components that needed repair, including the presentation of text and images, instructions for using the application, and the strategy for using discussion forums and features, as well as consideration of the allocation of timings to access assignments. Through trial, it is found through the reliability test using Cronbach's Alpha is at 0.86 with index of discrimination, difficulty level, and internal validity.

According to Table 1, the highest increase observed in student IMLR competence was on the topic of acid–base equilibrium, while the lowest increase was in relation to buffer solutions. The overall improvement in capability was moderate (N-gain = 0.5). A non-parametric Wilcoxon test was conducted on the pre-test/post-test data to determine significance, for all topics: the value of asymptote using 2-tailed significance level = 0.00 < 0.05. This indicates that the IMLR abilities of the students increased significantly after the learning intervention for all topics.

Data on the activity and quality of student writing was obtained from the discussion forum and traced from the data recordings of when students logged in to each forum. There was a tendency for discussion activity on a topic to decrease from topic I to IV. Students who did not actively follow these discussions averaged 37%. These students were recorded only as observers on the discussion forum: they were seen reading posts on the forum, but did not leave comments or ask questions.

Compared with the results of the preliminary phase of the study, these findings showed that the overall pattern of interaction occurring between students was strengthened and the ability of students to solve problems through IMLR was improved. These findings indicate the importance of the role of online discussion forums as a process of interaction (Snelson, 2005), which encourages the formation of knowledge (Stocker, 2010) and a deeper learning experience (Kozma & Russell, 2005).

The obligation for every student to post and answer at least one question on the discussion forum was intended as an encouragement to take an active

Table 1. Data of pre-test/post-test analysis of student IMLR competence on all topics.

Topic	Mean score (%)		Mean gain	N-gain
	Pre-test	Post-test		
I. Acid–base equilibrium	10	68	58	0.7
II. Hydrolysis of salts	21	58	37	0.5
III. Buffer solutions	17	52	35	0.4
IV. Solubility equilibrium	16	58	42	0.5
Mean	20	58	38	0.5

role in discussions. For every post or answer, students get an assessment based on set criteria. Based on the recordings of the discussions, the higher-performing students developed more ideas and answered more questions. They were more active and motivated to answer questions posed by other students. When they had a doubt about something, they tended to ask the lecturer for confirmation. In any discussion forum, the lecturer only responded if there was an indication of conceptual error. However, most of the medium- and low-performing students remained at zero levels of participation (not following the discussion, posting an idea or answering a question). Most of them only entered the discussion forums at the end of the time limit, when they simply read a post in the forums without making any comment. Such decreases in general discussion activity are a problem that often occurs in online learning. Garrison and Vaughan (2008) have explained that the motivation of students decreases in online discussions, because their expectation is that they will always get a response to the problems they face. However, differences in online schedules cause such responses to be delayed, so that the feedback becomes less focused. This is one of the weaknesses of an asynchronous communication system. Justifications given manually can effect decreases in motivation too. Therefore, consideration should be given to an automatic assessment system for forum discussions.

Overall, most of the students responded positively to the web-based model. They felt that the learning was more interactive, motivating and structured, even though previously they had never learned through the web. They expected web-based learning to be extended to other chemical topics.

4 CONCLUSIONS

The web-based model enhanced the pre-service teachers' competencies through its comprehensive features, which enabled them to experience many multimodal representations. Through periodic problem tasks given on each topic, students' IMLR competence could be explored and elaborated. Multimodal representation, in the form of text, images, graphics, animation, simulation and tools, facilitated the development of students' IMLR abilities. The online discussion forum feature in the web-based model allowed students to construct meaning and reflect their abilities. Thanks to these characteristics, the web-based model designed here can be used as an alternative for improving pre-service teachers' competencies in IMLR.

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