Effect of Learning by Simulation-based Inquiry on Students' Mental Model Construction

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Abstract: A fundamental challenge for science learning is the need of develop meaningful understanding of the relationship between the observable phenomena and interaction at the molecular level for student. In order to understanding conceptually the complexity of scientific phenomena, essential, nonessential, and irrelevant features of the concepts must also be determined and understood for applying and evaluating to a variety of affined situations. To enhance student learning in intermolecular forces concepts, a computer-simulated experiment of water contact angle has been developed to reveal a dynamic situation of relationship between intermolecular force, hydrogen bonding, and water contact angle phenomenon under different temperature, type of solution, and type of material conditions. The simulation was designed to represent the change of phenomenon both observable and molecular level of matter to student for increasing meaningful understanding construction of the concepts. The aim of this study is explore an effect of the contact angle simulation, shortly called CA-SIM, on students' mental model. 116 college students voluntarily undertook learning with the CA-SIM. Results show a potential of the CA-SIM that it helps students to correct their mental model on intermolecular forces concepts. This finding suggests the power of the CA-SIM on enhancing students' better mental model of intermolecular forces concepts. Additionally, it could be used to be an integral part for practical experiment for providing a sense of direction and making more conceptual reflection of learning science concepts.

Keywords: Computer simulation, inquiry, mental model, contact angle, hydrogen bonding

Introduction

From the past to nowadays, researchers, educators, or developers in science education devoted to find various interesting ways that can lead to student not only have excellent memorable knowledge in scientific facts, laws, and principles but also integrate new confronted knowledge into existing conceptual framework appropriately and transfer what they learned to new situation or other context within everyday life, accounting to meaningful understanding construction. The way of using everyday life is considered to be an important pedagogical tool for motivating students and making science leaning more relevance. In a constructivist perspective analyzing everyday life problems or authentic situations has been seen as a matter of understanding concepts well [2]. Anderson [1] stated that the meanings of scientific concepts are deepened if they are applied to everyday phenomena and that solving everyday life problem scientifically is a way to challenge students' everyday conceptions. In order to understand the world, the students have to grasp a comprehension by themselves and the comprehension requires the construction of mental models of it in their mind. According to support student's construction of accurate mental model of scientific phenomena, computer simulation has been used extensively as a visual representation tool to advocate presenting dynamic theoretical or simplified models of real-world components, phenomena, or processes, enlarging students to observe, explore, recreate, and receive immediate feedback about real objects, phenomena, and processes. Computer-simulated experiment has been inevitably infused into science classroom as an integral part of processing scientific inquiry in the classroom, affording inquiry learning activities. There are several educational values that computer simulation adds into science learning activities [11]. Therefore, this study was intended to explore impact of simulation-based inquiry on student's mental model transformation.

1. Literature Review

1.1 Open-inquiry Science Learning

In recent years, more and more evidence indicates that structured inquiry, highly structured laboratory practices that provide questions, theory, experimental and analytical procedures, is not sufficient in developing scientific thinking [23]. This type of investigation produces a robotic style of thinking that is less effective than teaching deductive reasoning, detailed in-depth thought processes, and logic [19]. According to the evidence, engaging learners into more flexible of scientific inquiry through conducting laboratory experiment is more emphasizing in recent science education. Therefore, science teachers who have a critical role in implementing inquiry-based learning, especially in case of open-ended inquiry, need to know and practice to build up increasingly open-inquiry science learning process for students. Recently, the meaning of open inquiry is quite not clear yet and inquiry practitioners are still discussing about its characterizations. Buck, Bretz, and Towns [4] described open inquiry in a way that can be used by both secondary school practitioners and university researchers as an investigation where instructor provides the inquiry question or problem and basic background, but the remaining characteristics are left open to the student, in where learners have to develop their own procedure, analysis, communication, and conclusions to address an instructor provided question.

1.2 Computer Simulation on Student Learning

Visual representation technologies have become increasingly important amongst science educators [7]. Simulation is a computer-based visualization technology which can imitate dynamic systems of objects in a real supporting to the quality of making sense by vision. Computer simulation has been used extensively as a visual representation tool to simplify dynamic theoretical models of real world phenomena or processes. Researchers found its potential that it works with remedial by producing change to student's misconceptions [3]. Computer simulation also improves scientific process skills [8], and the performance of gaining more qualitative knowledge [21], more coherent understanding of the concepts [18, 22], and more advanced mental model [5]. Conclusively, Computer simulation is mentioned widely that it could be used to facilitate the construction of mental model and the development of conceptual understanding.

1.3 Mental Model and Understanding

Understanding cannot be transmitted from person to person, for example, teacher to student or student to student. To understand the world, students have to grasp a comprehension in which requires the construction of accurate mental models by themselves. Newton [16] mentioned that understanding is a product of mental processes, with having a mental model, which infer relationships between elements of information, and also have a generative character. Hence, the process of understanding calls for the construction of mental model.

Mental models are always under construction, and based on existing and new coming knowledge, ideas, conceptions, and experiences. During the learning process, the development of mental model varies as students' experience increase and their superior performances reflected that how well they develop their own mental model [12]. In facts, not everyone has developed performance at the same level. Several researches were reported that novices differ from experts in that novices have more primitive, incomplete, unconnected, and erroneous mental model but experts have more abstract, elaborate, stable, interconnected, and integrative mental model [13]. Student who can come with highly developed mental models would produce more accurate and efficient results in performing complex tasks [20]. However, novice mental models are able to become more complete and accurate as their gaining more experience [15].

2. Method

2.1 Study Participants

The participated students comprised 116 college students (18-20 years old) in science major enrolled in Principle of Chemistry II course. They were classified into two groups with respect to level of scientific prior knowledge and there are 49 and 67 students for Higher Prior Knowledge (HiPK) and Lower Prior Knowledge (LoPK) groups, respectively. All students have sufficient computer experience with learning. The students have been covered with the intermolecular forces experiments in chemistry laboratory before undertook the CA-SIM. In addition, one professor and four graduate students were invited to participate in a survey to indicate an expert's mental model level.

2.2 The Contact Angle Simulation (CA-SIM)

In order to design the learning environments for supporting the construction of cognitive schema, the instructional model of Open Learning Environments (OLEs) [10] was utilized to form and create key elements of the CA-SIM. The instructional message design principles in according to Cook [6] were used to design messages, which is directly delivered to student, of each key element for reducing cognitive loaded during the construction. In respect on the design of the CA-SIM, the context of everyday phenomena such as phase change of water and water contact angle property of wettability, which represented both macroscopic and microscopic views, was used to situate student learning into the domain of hydrogen bonding concepts and induce student to transfer their leaned concepts to different contexts. The manipulative tools enable student to change parameters and visualize dynamic effects graphically. The tools also afford student in order to verify, test, extend their own understanding, and promote restructuring of mental model. Resources which included both static and dynamic pattern provided scientific background and related information covering the contexts. Scaffoldings such as conceptual, procedural, and strategic scaffoldings were used to provide key concepts and reflections on understanding, introduce how to utilize available tools, and identify what are needed data that they should experience, respectively. An example of the CA-SIM displayed in Figure 1.

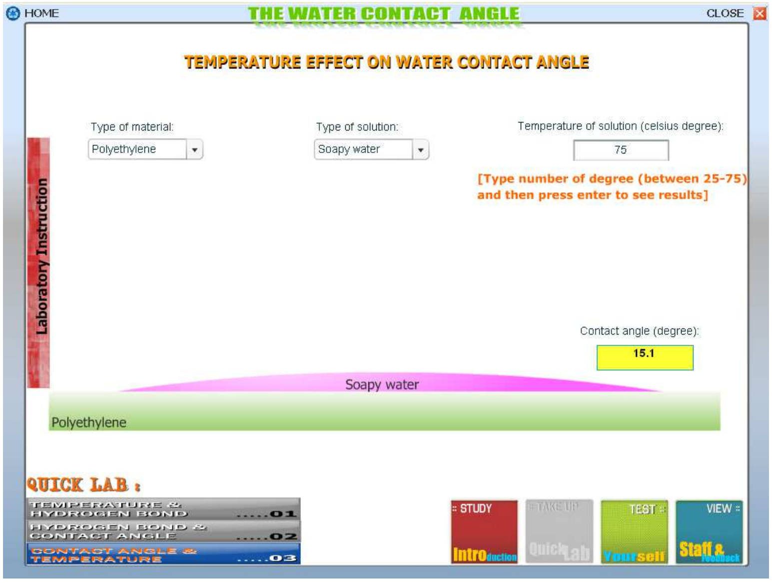

Figure 1. An illustrative interface example of the CA-SIM

2.3 Data Collection

For investigating construction of mental model in this study, a mental model survey form was administered to examine HiPK and LoPK's mental models at before and after their interaction with the CA-SIM. The mental model survey form was used to determine students' conceptual understanding in mental model expression. Ad hoc drawing and describing approach was used to develop the form for surveying the students' mental models. In this survey, they were assigned to use only a given black ink pen for drawing their mental model and reasoning at the pre-test. After completed learning action with the CA-SIM, the mental model survey form was administered to them again with a given red ink pen for drawing and reasoning their mental model and they were assigned to use a given red ink to complete their previous mental model in the pre-test.

2.4 Data Analysis

A rubric scoring was used to interpret and evaluate their mental model for three concepts; the relationship of temperature and hydrogen bonding, temperature and contact angle, and hydrogen bonding and contact angle, at two knowledge representation levels; observable (OBS) and molecular (MOL) levels (maximum and minimum scores of each level = 3 and -3, respectively). For each concept at each level, their scored mental models were calculated and transformed into the conception net values, where a student's net OBS and MOL values equal "number of OBS and MOL scientific conceptions" minus "number of OBS and MOL misconceptions". Based on the net values of students' conception, central tendency of and dispersion of the net values were used to spatially visualized their conception values by using mean center and standard deviation ellipse.

3. Results

Visually, the biplot result was used to show that both OBS and MOL misconceptions for HiPK and LoPK were considerably diminished and eliminated after their interacting with the CA-SIM. This indicated that the CA-SIM effectively helped them to revise their mental model at OBS and MOL. The mean score of experts' OBS and MOL conception values were also displayed in Figure 2 as a reference level to visualize the students' mental model development. The result also shows that some of both HiPK and LoPK can reach to experts' mental model level. Arrow vectors were used to indicate change of their OBS and MOL conception values from the pre-test to the post-test, which resulted from the revision of their mental model. Ceiling effects were found on OBS conception values of HiPK and LoPK post-test because many students in both groups reached the maximum score at OBS after having interaction with the CA-SIM. However, the biplot graph in Figure 2 provides empirical evidence that the CA-SIM environment was effective to increase HiPK and LoPK scientific conceptions at both OBS and MOL levels by correcting their mental models.

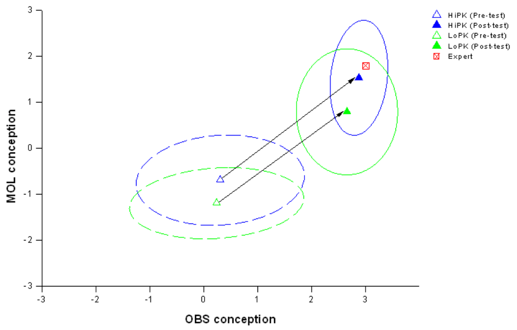

Figure 2. Mean center and standard deviation ellipse of HiPK, LoPK and Expert mental model score at OBS and MOL

Inferential statistics was used to examine significantly difference for HiPK and LoPK mental model scores both manner of within and between groups. The statistical analyses provide empirical findings that HiPK and LoPK had the different cognitive ability of the studied scientific phenomena in mental model. This situation resulted to gaining of mental model development of both groups from the learning with the CA-SIM. The CA-SIM learning environments effectively influence in leading HiPK and LoPK to increase OBS and MOL mental model scores.

Table 1. Overall mean and S.D. of HiPK and LoPK mental model scores and comparison the differences of pre- and post-test and of HiPK and LoPK mental model scores

Group	n	Mental model scores			
		Pre-test Mean(S.D.)	Post-test Mean(S.D.)	$t_{independent\text{-}samples}$($p$-value,$d_{IGD}$)	$t_{paired\text{-}samples}$($p$-value,$d_{CD}$)
HiPK	49	a_1=0.31(1.53) b_1=-0.69(0.96)	a_3=2.88(0.53) b_3=1.53(1.23)	$a_{(1,2)}$=0.23 (0.820,0.04^{s}) $b_{(1,2)}$=3.12 (<0.005*,0.59^{m})	a_{3-1}=11.29(<0.005*,2.23^{l}) b_{3-1}=11.73 (<0.005*,2.01^{l})
LoPK	67	a_2=0.24(1.60) b_2=-1.19(0.76)	a_4=2.66(0.93) b_4=0.79(1.35)	$a_{(3,4)}$=1.62 (0.108,0.31^{s}) $b_{(3,4)}$=3.02 (<0.005*,0.57^{m})	a_{4-2}=11.19 (<0.005*,1.84^{l}) b_{4-2}=11.12 (<0.005*,1.79^{l})

Note: a and b There are OBS and MOL mental model score, respectively.
* This is significant difference at p<0.05
^{s}, ^{m}, and ^{l} There are small, medium, and large effect size.

4. Discussion

Considering with the result, mental model at observable and molecular level for both groups of HiPK and LoPK students were developed considerably after they learned interactively with the CA-SIM. The students increased more conceptual accuracy on their observable and molecular mental models. Thus, this finding could be argued that the CA-SIM has significant influence to transform students' mental models from simple to being complex mental models by changing alternative conceptions, which embedded within individual mental model, into scientific conceptions. As a statement of Rhodes [17], he pointed out that computer simulation and modeling helped students understand complexity of natural phenomena and, especially, test the limits of their understanding with others. Thus, we believed that the students have opportunities to change and restructure their own existing mental model and then transform and re-model the phenomena to be more acceptable mental model. Support for this argument was mentioned by [14] that conceptual change is archived by any of acquisitions of new information and then reorganizing existing knowledge, the notion of conceptualization stability, and this effect also caused to mental model variability.

Furthermore, the result showed its impact that the simulation helped all students develop good mental model on the observable level of the studied phenomenon, however none of the groups had fully developed mental model at the molecular level after learning with the CA-SIM. This evidence could be argued that the CA-SIM has a potential limitation for helping mental model construction process. Haag and Kaupenjohann [9] mentioned that simulations have limited predictive capacity and it is difficult to validate them. Therefore, students could construct different of knowledge and this situation results to conceptual dispersion [14]. However, the CA-SIM has impact on varying degrees of mental model and it has potentially united effect on student's observable mental model more than molecular mental model. Correspondingly, Haag and Kaupenjohann also reported that dynamical simulation offers a remarkable potential for consensus mental model building.

5. Conclusion

To enhance conceptual understandings on hydrogen bonding, a designed interactive computer-simulated experiment was created to provide a unique learning environment, which reduces cognitive load and induces the construction of cognitive schema, for supporting meaningful learning of the concepts. This study result verified the potential of computer simulation that it helped students to correct their mental models by comprehending their own conceptual understandings. This empirical finding revealed the benefit of OLEs-oriented computer simulation for inquiry-based learning in science concept that it could be directly utilized for eliminating students' alternative conceptions and enhancing the construction of meaningful conceptual understanding. Other way, it also could be used as integral part for practical experiment to provide a sense of direction and make more conceptual reflection on learning science concepts.

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