

# The Effectiveness of Simulation in Science Learning on Conceptual Understanding : A Literature Review

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## Abstract

Conceptual understanding, which permits one to transfer an explanation of a phenomenon with different ways is clearly a goal in science learning. One way to achieve conceptual understanding is using simulation. The purpose of this review is to analyze the effectiveness the impact of the use simulation on conceptual understanding in science learning. Based on the literature review, significant aspects of how such simulation influence on conceptual understanding is identified. The finding indicated that simulations work to improve understanding the concept of science, not only students' understanding but also pre-service teachers' understanding.

**Key words:** Simulation, Conceptual understanding, Science learning

## 1. Introduction

The Indonesian government has been making a series of alterations to the national curriculum during the 2000s, attempting to move from a content-based curriculum to a competency-based and from teacher-centered rote learning to student-centered active methods. The emphasis was on moving the focus of education away from the memorization of facts and theoretical knowledge towards students being able to achieve competencies (MoEC, 2013). There are four core competencies which mandatory for all educational levels and all subjects including science, i.e., spiritual, social, knowledge and skills competencies, respectively. In particular of knowledge competencies, conceptual understanding is an inseparable part of science concept. Conceptual understanding is one of the competencies in science learning in Indonesia. This competency is a part of science graduation standard indicated in MoEC article number 20, the year 2016. Thus, conceptual understanding is needed by students for learning science successfully.

Students' conceptual understanding in Indonesia is low. Based on the result of TIMSS' in the year 2015, showed that there were only 32% in the overall of Indonesian students who had the correct answer for a question which demands conceptual understanding ability on science (Martin et al., 2015). These facts indicated that majority of Indonesian students' conceptual understanding needs to be achieved. One way to achieve students' conceptual understanding in science learning is using computer simulation. With the rapid development of information and communication technology (ICT), the use of a computer technology in science education has become commonplace. The using of a computer in education highly recommended by the Indonesian government, as indicated in National Education System Law number 20 the year 2003. Furthermore, government policy in the Indonesian curriculum mentioned that computer has potential to support learning, and it should be used in each subject especially in the science subject.

Computer simulation has an overwhelming potential for the enhancement of the teaching and learning of science concept. Research into the use of computer simulations has a long history, as Smetana & Bell (2012) pointed out in their review. Computer simulations provide interactive, authentic and meaningful learning opportunities for learners because simulations facilitate the learning of abstract concepts since students would have the chance to make observations and get instant feedback (Bell & Smetana, 2008). Science simulations can give real environments structured according to principles in the domain. Spatial, temporal, and causal phenomena can be represented that may be otherwise unobservable and not directly manipulable because they are too large

(hurricanes), or too small (chemical reactions), too fast (earthquakes), or too slow (plant growth) (Quellmalz et al., 2012).

The purpose of discussing simulation literature review was to investigate the different ways simulation has been incorporated into classroom and the conditions under which simulation works on conceptual understanding. The simulation literature review is vast and varied, and researchers have tried to categorize in different ways to bring a similarity to their study. The potential advantages of using simulation have led researchers to explore the effectiveness of simulation to achieve students conceptual understanding. To have a good understanding of the how information is processed, students would be able to learn much more efficiently and systematically. The following question guide this study is why science simulations work on conceptual understanding?

## 2. Method

This paper is an integrative review of the literature. This review includes published research addressing the benefits of simulations in science learning. To investigate this review, we carried out a database search articles (ERIC, Scopus, and google scholar) that related to the effectiveness of computer simulations in science learning. To ensure that relevant articles were not missed, then followed up the database search with a manual search in several journals (Journal of Research in Science Teaching, Science Education and International Journal of Science Education).

The steps taken to investigate the effectiveness of simulations on conceptual understanding are: (1) identified the primary research outcome for each article and arranged the papers accordingly, (2) analyzed the definition of conceptual understanding in science learning, (3) identified the problem to achieve conceptual understanding in science learning, (4) categorized the studies by looking the advantages and disadvantages of simulation in each article, (5) Analyzed the reasons why science simulations are effective on conceptual understanding, (6) Finally, conclusion is presented in this review.

## 3. Results and Discussions

### 3.1 What is “Conceptual Understanding”?

The word concept has many different meanings to science educators. Concepts are the construction of the human mind (Lawson et al., 2000; Konicek-Moran and Keeley, 2015). Concepts are similar to mental representations which in their simplest forms (Carey, 2000), such as energy, force, evaporation, respiration, heat, erosion, and acceleration. They are abstraction developed in the minds of people who tried to understand what was happening in their world. Concepts may also consist of more than one word or a short phrase (Konicek-Moran and Keeley, 2015), such as conservation of energy, food chain, or closed system. Concepts imply meaning behind natural phenomena such as phases of the moon, transfer of energy, condensation, or cell division. When we use a concept, there are usually some understandings of what associated with it.

Cognitive scientists state that concepts are themselves complex representational structures (Carey, 2000). Moreover, concepts can be constructed directly by generalizing from experience of many instances. In some cases, examples of concepts are difficult to demonstrate or make real. For instance, it is hard to show example concepts such as ‘atom’ or ‘molecule.’ So that, a concept such as ‘molecule’ may be more readily established, instances are illustrating by constructing representations or models. Within a particular representational structure, concepts help students to clarify more complex ideas. Concepts could thus act as building blocks of more complex or even abstract representations.

Instruction to promote conceptual change requires time and effort on the part of learning (Adadan et al., 2010) and also carefully designed (Vosniadou et al., 2001). However, the practice of science instruction has emphasized of memorizing a lot of science concept (Chin, 2004). Students who are excellent at memorizing facts and definitions often engage in what may be called literal understanding (Konicek-Moran and Keeley, 2015). Students with this understanding, could explain any page in a textbook or reproduce any graph or picture at a moment notice exactly as it appeared in the book. These students might not have been able to understand basic concepts that provide explanatory evidence for ideas about phenomena. For instance, the concept of evaporation. Students rely on their memorization term of evaporation, but the students lack the conceptual understanding of what happens after the water evaporates. The students use the words evaporation, yet not understand where the water went or where it came from to explain a natural phenomenon. The important learning process is students think through all arguments on their “own” and “construct” further knowledge upon already understood concepts.

Meaningful science learning requires conceptual understanding rather than memorization (Adadan et al., 2010). Meaningful learning requires knowledge to be constructed by the learner, not transmitted from the teacher to the students (Jonassen, et al., 1999). Students who have conceptual understandings of certain concepts construct well-connected and hierarchically arranged conceptual frameworks (Mintzes & Wanderse, 1998). When students have an understanding of a concept, they can (a) think about

it, (b) use it in areas other than in which they earned it, (c) state it in their own word, (d) find a metaphor or an analogy for it, or (e) build a mental or physical model of it (Konicek-Moran and Keeley, 2015). In other words, the students have made the concept their own.

### 3.2 Conceptual Understanding in Science Concept

Science is a field that involves the study of science phenomena, and students are continuously required to identify the hidden concepts, define adequate quantities and explain underlying laws and theories using high-level reasoning skills (Konicek-Moran and Keeley, 2015). Thus, students are involved in the process of constructing qualitative models that help them understand the relationships and differences among the concepts of science phenomena.

The main goal of science education is teaching for conceptual understanding (Konicek-Moran and Keeley, 2015). Conceptual understanding of science concept is a complex phenomenon (Nieswandt, 2007). It combines an understanding of single concepts such as sunlight, Chlorophylls, water, carbon dioxide or of a more complex concept such as chemical energy, which following certain rules and models, combines multiple individual concepts (e.g., photosynthesis), resulting in a new concept. Learning a new concept is integration into an existing knowledge framework (conceptual growth) or fundamental reorganization of existing knowledge to fit the new concept into the framework (conceptual change) (Treagust & Duit, 2008). The increasing availability of science simulation in classrooms has prompted the investigation of their influence on processes of conceptual development and conceptual change. The ability of simulations to portray phenomena and allow users to interact with the dynamics of a model system creates an arguably unique way of helping learners conceptualize (Windschitl, 1996). Some research on students' conceptual understanding and conceptual change in science education have been done previously (Hsu et al., 2008). A significant amount of previous research has demonstrated the effectiveness of computer simulations in student learning. A good number of these studies have focused on the acquisition of specific conceptual change. For example, Trundle & Bell (2010) found that simulations have been used to promote conceptual change in lunar concept. Additionally, Windschitl & Andre (1998) found that using a computer simulation as an instructional tool can work on college students' conceptual change. Simulations offer many attributes that are potentially useful for promoting conceptual understanding. Because simulations present simplified versions of the natural world, they can focus students' attention more directly on the targeted phenomena (de Jong & Van Joolingen, 1998).

Conceptual understanding of science concept is also described as students' ability to apply the learned scientific concepts to scientific phenomena in an everyday life situation (Nieswandt, 2007). This includes the capacity to recognize new information, construct explanation and make connections among scientific phenomena. For instance, scientific phenomena of photosynthesis and respiration. Students should able make the connection between photosynthesis and cellular respiration, which is an inverse relationship both are opposites of each other.

According to Alao & Guthrie's (1999) definition of conceptual understanding by emphasizing breadth and depth of knowledge. Breadth is related to the extent of knowledge that is distributed and represents the major sectors of a specific domain, and depth related to the knowledge of scientific principles that describes the relationship between concepts. For instance, students with a breadth of knowledge will be able to make connections between photosynthesis and respiration, while students with depth knowledge will able to explain in details how photosynthesis process works.

The problem in conceptual understanding is students difficult to make the connection with complex science phenomenon in an everyday life situation. Complexity makes difficulty due to ideas and concepts existing at three different levels: macro and tangible, micro, and representational or symbolic (Johnstone, 1991; Treagust & Chittleborough, 2001). For instance using 'water' concept; this concept can be taught at the macro level where students can observe the characteristic of water. The teacher can also explain the concept at the micro level, for example, students are taught that water consists of molecules of hydrogen and oxygen. At the representational level, these molecules can be represented as a symbol  $H_2O$ . An example of complex science phenomena "water concept" can be seen in Figure 1.

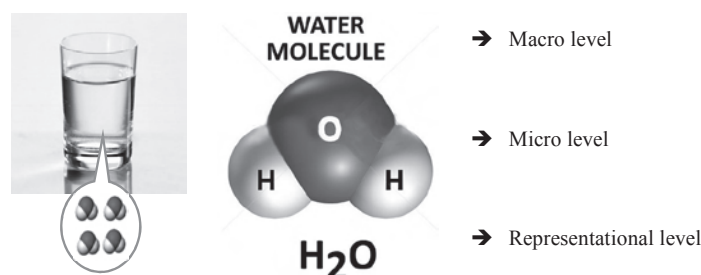


Figure 1. example of complex science phenomena "water concept"

### 3.3 Why is science simulation effective on conceptual understanding?

Technological advances increasingly brought digital instructional technologies into the science classroom. One of the technological advances is the computer simulation. Computer simulations are computer-generated dynamic models that present theoretical or simplified models of real-world components, phenomena, or processes (Bell et al., 2008). In line with this, simulation as a representation or model of an event, object, or some phenomenon (Thompson, Simonson, & Hargrave, 1996). Simulations are used to model that which is not easily observed in real life or are used in teaching situations where simulation offers advantages (Scalise et al., 2011). Computer simulations are programs that allow the learners interact with a computer representation of either (a) a model of the natural or physical world, or (b) a theoretical system (Weller, 1996). Simulation provides learner-centered environments that allow students to explore systems, manipulate variables and test hypotheses (Windschitl, 1998). Further, these programs can be used as demonstrations by teachers, or they can be used directly by the students to explore various phenomena that would not be readily available under normal situations. Simulations also provide learners with realistic experiences from which to gain and manipulate knowledge to understand better the relationship between the concepts being investigated. Simulations can combine animations, visualizations, and interactive laboratory experiences.

By combining animations and visualizing science concepts, simulations can support the development of insight into complex phenomena (Akpan, 2001). Simulations can be used in class when equipment is not available, or when it is not practical to set it up (Wieman et al., 2010). Another application of simulations is for doing experiments that would otherwise be impossible to do. Variables can easily be changed in simulations in response to students' questions, where this is not always possible with real equipment. Students can practice laboratory techniques before engaging in lab experience with real equipment (Akpan, 2001). They can also practice with simulations at home to repeat or extend classroom experiments for additional clarification. The studies that compared the application of simulations with traditional learning seem to indicate that traditional learning can be successfully improved by using simulations. Within traditional instruction, learners can be a useful add-on, for instance serving as pre-laboratory exercise or visualization tools. Chang, et al. (2008) proved that learning by using simulation in optical lenses topic leads to a significantly greater improvement in learning outcomes in comparison with traditionally laboratory practices.

The use of simulations in the classroom have a positive finding on conceptual understanding (Ramasundarm et al., 2005; Abdullah & Syarif, 2008; Plass et al., 2012; Nowak et al., 2013; Sarabando et al., 2014). The use of simulation also helps students to understand difficult science concepts (Plass et al., 2012; Webb, 2012; Sarabando et al., 2014). The Summary of studies the advantaged and disadvantages of simulation can be seen in Table 1.

The first reason why using simulation concerns the need to understand the complex phenomenon in science. For instance DNA, molecular structure, atom, or molecule. Hmelo, Holton, and Kolodner (2000) suggested that structures are often the easiest aspect of a complex system to learn; in molecular genetics especially, understanding the structure of molecules such as DNA and RNA is crucial to comprehending their functions. Simulations, in this case can help to organize the small pieces of information into large pieces of information, reducing the amount of memorization required by increasing the logical connections between ideas (Tversky et al., 2002). Simulation allows learners to view and interact with models of phenomena and processes (Plass et al., 2012).

Visualization of phenomena through simulation can contribute to student's understanding of science concept at the molecular level by attaching mental images to these concepts (Abdullah & Syarif, 2008). Lambert and Walker (1995) stated that a mental model is an understanding and interpretation of individual's concept existing, which is formed and reformed by experiences, beliefs, values, socio-cultural histories, and prior opinions. Mental models affect how interpreting new concepts and events. Many topics in science require students to generate their mental models and students are aware that physical representations can help them to create their mental models and understand new concepts (Treagust et al., 2002). To solve this problem, teachers routinely use of models and representations to assist students in constructing their mental model for instance use simulation. By using the simulation, they can see a concrete situation that helps them to build a mental model. Mental models, like prior knowledge, influence students' perceptions of phenomena and students' understanding (Buckley, 2000). Using simulations, students can represent their understanding of science phenomena and mental model construction (Abdullah & Syarif, 2008; Quellmalz et al., 2012; Nowak et al., 2013). Similarly, simulation is the most suitable method when the learning objective requires a restructuring of the students' individual mental models (Landriscina, 2009). Restructuring own mental model can help students to increase the conceptual understanding of science concept.

The second reason why using simulation concerns the need to understand the learned scientific concepts to scientific phenomena in an everyday life situation. Some scientific phenomena in science occur very fast and take place in multiple locations; for instance, cell division. Simulation can facilitate the development of students' evaluation skills to understand the phenomena at the molecular level (Sanger, Brecheisen, & Hynek, 2001). Starting, stopping, and replaying a simulation can allow focusing on specific parts and actions. A simulation that allows zooming and control of speed are even more likely to be facilitating (Tsui &

**Table 1.** Summary of studies the advantages and disadvantages of simulation

<b>Simulation in Science Learning</b>		<b>Studies</b>
<b>No</b>	<b>Advantages</b>	
1	Simulation works to improve understanding concept of science, not only students' understanding, but also pre-service teachers' understanding.	Liu & Hmelo-Silver, 2009; Ryoo & Linn, 2012; Bell, Maeng, & Binns, 2013; Nielsen & Hoban, 2015
2	The use of simulation helps students to understand difficult science concepts	Plass et al., 2012; Webb, 2012; Sarabando, et al., 2014
3	Simulation can make abstract science phenomena more accessible and visible to students.	Muller, Sharma, & Reimann, 2008; Stieff, 2011; Ryoo & Linn, 2012
4	Simulation can animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in the textbooks	Marbach-Ad, Rotbain, & Stavy, 2008; Ryoo & Linn, 2012
5	Simulations help students visualize the phenomenon that might otherwise be difficult to depict	Chang, Quintana, & Krajcik, 2010
6	Simulations can help students to generate their own mental models and understand new concepts	Buckley, 2000; Treagust et al., 2002; Abdullah & Syarif, 2008; Landriscina, 2009; Quellmalz et al., 2012; Nowak et al., 2013;
7	Simulation works to increase student engagement to learn science	Davies 2002; Shellman and Turan, 2006; Honey & Hilton, 2011
8	Simulation allows users to experience and interact with an environment similar to the real world	Matveevskii & Gravenstein, 2008; Ruggeroni, 2001
<b>Disadvantages</b>		
1	Lack of realism (in a real environment, people can feel and taste, while in simulation this cannot happen)	Sadideen et al., 2012
2	Students have time flexibility to think and react in problem-based scenarios: there is no stress for quick thinking as in real situations	Byrne et al., 2010
3	Compared to laboratory experiments, simulations have the disadvantages that they are only able to show outcomes that are pre-programmed, and can only be manipulated to a limited extent. Moreover, they do not do much to develop the skill of handling lab equipment	Karlsson, Ivarsson, & Lindström, 2013

Treagust, 2004; Tverssky et al., 2002). Simulations may be used to show students scientific phenomena that cannot be observed easily in real time. For example, they can allow students to see things in slow-motion, such as lightning or speeded up, such as earth revolution. They are used to model phenomena that are invisible to the naked eye, such as cell division. Simulation utilizes in situations that require several repetitions of an experiment, for example rolling a ball down a slope while varying mass, the angle of inclination, or the coefficient of friction.

The third reason why using simulation concerns the need to understand emphasizing breadth and depth of science knowledge. Simulations can bridge this breadth and depth of students knowledge because simulations have the potential to make learning abstract concept more concrete (Ramasundarm et al., 2005). Simulations can make abstract science phenomena more accessible and visible to students. For example, understanding science phenomena such as the circulatory system are difficult for some reasons. It is a complex interactive system that ranges in scale from the heart or blood vessels visible through the skin to blood cells circulating in capillaries much smaller than the human visual range. Simulation has the potential to make abstract scientific concepts, such as circulatory system, more accessible and visible to students. Muller, Sharma, & Reimann (2008) explained that simulations allow learners to represent visually and dynamically important concepts that would otherwise be invisible. They can provide detailed representations of unobservable science phenomena (Stieff, 2011; Ryoo & Linn, 2012). They can also animate dynamic changes in scientific processes that are difficult to infer from static illustrations found in the textbooks (Marbach-Ad, Rotbain, & Stavy, 2008; Ryoo & Linn, 2012). In particular, simulations or animations can help students visualize the phenomenon that might otherwise be difficult to depict (Chang, Quintana, & Krajcik, 2010). Thus, the benefit from simulations are making science abstract concept more accessible, visible, and can help students to understand science concepts. When students are unable to observe or experience abstract science phenomena directly, simulation can play a crucial role in helping them understand those phenomena.

Simulations work to improve understanding the concept of science, not only students' understanding but also pre-service



teachers' understanding. For example, Bell & Trundle (2008) stated that well-designed simulation combined with appropriate instruction effective in improving preservice teachers conceptions of moon phases. In addition, simulation also influences preservice teachers' and middle school students' learning to develop a deep understanding of a complex science system (Liu & Hmelo-Silver, 2009). Furthermore, creating simulation also enabled pre-service science teacher to develop more elements to contribute to their understanding of science concept (Nielsen & Hoban, 2015; Bell, Maeng, & Binns, 2013). Creating simulations enabled the preservice teachers to develop more elements to contribute to their understanding of science concept. Creating the multiple representations presented many opportunities to have their alternate conceptions and elements that underpinned the concepts challenged, discussed, negotiated, and revised. Importantly, the stop-motion construction process was halted several times enabling preservice teachers to check, review, and revise information (Hoban & Nielsen, 2014). Thus the development process enables an ongoing interplay between existing knowledge. Further, in the process of developing simulations as a teaching resource, has potential to help them consider relationships between different representational and develop more sophisticated understandings.

The another benefits from the simulation do not only work on conceptual understanding but also to increase student engagement to learn science. Shellman and Turan (2006) have reported an improvement in students participation, motivation, and preparation for simulation exercises. Moreover, simulations have potential to advance multiple science learning goals, including motivation to learn science, understanding of the nature of science, science process skills, scientific discussion and argumentation, and identification with science and science learning (Honey & Hilton, 2011). Supporting this idea, Davies (2002) suggest that for successful students engagement with simulations, the learning must be authentic and meaningful, students should work on group projects where they can share their understanding.

Remember that simulations are tools to support science learning. As with other educational tool, the effectiveness of simulation is limited by the ways in which they are used. Absolutely, instructional strategies proven to support meaningful learning should be adhered to when using simulations. Students should be actively engaged in the acquisition of knowledge and encouraged to take responsibility for their own learning. Science content should be placed in the context real world.

#### 4. Conclusion

The literature review suggests that simulation may play important roles in the science classroom and science instruction. Simulation gives learners opportunity to observe a real world experience, and they can interact with it. Through using simulations, learners can experimentally get an understanding of difficult to grasp concepts in science learning. Findings from this article showed that simulation work on conceptual understanding in science learning.

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