

# **An Instruction Model for Modeling with simulations: How to help student build their own model with simulations**

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## **Introduction**

Researchers have defined simulation, a concept related to micro-world, as a model or simplified example of complex natural phenomena (Jonassen, 1996). Computer-based simulations in an instructional context mean using the computer to build models, or to model real-world phenomena in order to help students gain insights into the behavior of complex systems. Interacting with an instructional simulation can enable learners to gain a better understanding of a real system, process or phenomenon through exploring, testing hypotheses, and discovering explanations for the mechanisms and processes (Burton et al., 1984; Goldenberg, 1982; Lunetta & Hofstein, 1991; Mellar & Bliss, 1993; Raghavan & Glaser, 1995). This interactivity may provide opportunities for students to modify their mental models, by comparing the outputs of the model with their expectations (Jackson et al., 1996), and to engage or motivate students to explore and couple actions with effects which will lead to understanding.

Simulations not only allow learners to construct and manipulate screen “objects” for exploring underlying concepts, they also provide learners with the observation and manipulation tools necessary for exploring and testing hypotheses in the simulated world (Jonassen, 1996). However, there is not universal evidence of the effectiveness and efficiency of computer simulations. Some studies have shown positive effects (Brant, Hooper & Sugrue, 1991; Choi & Gennaro, 1987; Faryniarz & Lockwood, 1992; Grimes & Wiley, 1990; Mills, Amend & Sebert, 1985), but others have failed to find any advantages (Carlsen & Andre, 1992; de Jong, de Hoog & de Vries, 1992; Rivers & Vockell, 1987). Causes for discrepancies in these research findings are numerous but three major areas stand out: inadequate pedagogical support, shortcomings in the simulation design, and inadequate learning skills. For example, de Jong et al. (1994) suggested that simulation ineffectiveness is due to learner’s inability to overcome the difficulties of interacting with a simulation on their own. Pedagogical support, such as reinforcing productive conjectures, discussing successful learning strategies, and relating phenomena to the discipline, could be missing. Learner difficulties could be due to concepts embedded in the simulation that are too abstract or a design of the simulation that is not meaningful to

learners. Learners may not know how to use problem-solving strategies such as the generation and testing of hypotheses, model-based reasoning and meta-cognition.

The role of computer-based modeling and simulations becomes more important in the learning and teaching of science due to the explosion in science information and in its accessibility through the World Wide Web. Computer simulation can help students to understand invisible conceptual worlds of science through animation, which can lead to more abstract understanding of scientific concepts. Quantitative data can be manipulated and visualized to form qualitative mental pictures or descriptions. Such complex experience can help students to identify patterns within simulations, formulate explanations for phenomena in terms of models and theories. Increasing computational speed and multimedia capabilities lead to development of more powerful modeling and simulation tools. We have developed hundreds of physics related java simulations on our server (<http://www.phy.ntnu.edu.tw/ntnujava/>). Our java simulations are very popular around the world. However, we found out simulation or modeling software alone will not make the above claims come true in the real classroom. Teachers need pedagogical support in order to make the above dream realized.

Modeling is to use a “conceptual world” to “model” a “real world”. How to help student build their own physics model? How to implement simulation or modeling tools into the classroom in order to create an effective learning outcome? We all agree that modeling is not easy. Because we would like to build models that not only describe the behavior or results observed, but also explain why that behavior and results occurred as they did. And a good model also allows us to predict future behaviors or results that are yet unseen or undiscovered. Many questions need to be answered: how to generate representation or models, how to validate or test them, how to apply them to other situations, and what are their limitations. We present a theory-based Technology-Enhanced Learning (TEL) model that takes a situational cognitive approach, integrates the use of multimedia/modeling tools into instruction, and supports the development of students’ conceptual understanding. Although this model was developed for instructional purposes, by focusing on students’ cognitive processes it also becomes a learning model.

### **TEL Model: An Instruction Model for Modeling with simulations**

Our model essentially integrates the work of Karplus and Thier (1967) on the Learning Cycle, and of White and Frederiksen (1998) on the Inquiry Cycle. The Learning Cycle was first proposed during the curriculum reforms of the late 1950s and early 1960s (Abraham, 1998; Karplus & Thier, 1967; Lawson, 1995; Renner & Stafford, 1972). It was

developed as a way of translating the inquiry process used by scientists to advance students' active understanding. The Learning Cycle characterized scientific inquiry as consisting of three phases: exploration, invention, and discovery (Karplus & Thier, 1967). In the exploration phase, students gain hands-on laboratory or field experience during which they observe and make measurements in order to understand specific scientific concepts. In the invention phase, students discuss and explain their findings from the exploration phase. In the discovery phase, they apply the concepts they learned in the invention phase to verify the limitations of their understanding. White and Frederiksen (1998) proposed the Inquiry Cycle, which explicitly presents key components (question, prediction, experiment, model, and application) of scientific inquiry to students. In a process of scaffolded inquiry, students first formulate a question and then generate a set of competing predictions and hypotheses related to that question. They then plan and carry out experiments using both computer models and real-world materials; next, they analyze data and form a model to explain their findings. Finally, they apply their model to various situations in order to test the limitations of the model, and may generate a new question for the next inquiry cycle.

We propose the TEL model for designing learning activities in order to foster students' acquisition of synthetic knowledge through the integration of technology into their learning environment. The TEL model includes five cognitive phases, with a description of the mode of technology-implementation corresponding to each phase (see Figure 1). The five phases are: (a) *contextualization*: students will confront an authentic and meaningful situation; (b) *sense-making*: students will visualize and represent the dynamic mechanics of the complex situation and simplify it; (c) *exploration*: students will plan and carry out their experiments or, given access to information on databases, explore scientific principles or relationships among variables; (d) *modeling*: students will form hypotheses or build models to explain their findings; (e) *application*: students will get the opportunity to apply concepts to different situations and identify the limitations of their models.

In following this cycle, teachers first provide an authentic situation to engage learners in the generation of a question or comprehension of scientific phenomena (contextualization and complexity); then, learners are better able to make sense of the underlying mechanics of the complex situation through scientific visualization. A set of exploratory learning activities (exploration) guides learners to test their hypotheses and formulate a model (decontextualization and simplification) to explain their observations and findings. Finally, they apply what they have learned to a variety of situations in order to reflect the limitations of their model, think how to improve their model and plan for the next exploration (reflection-exploration).

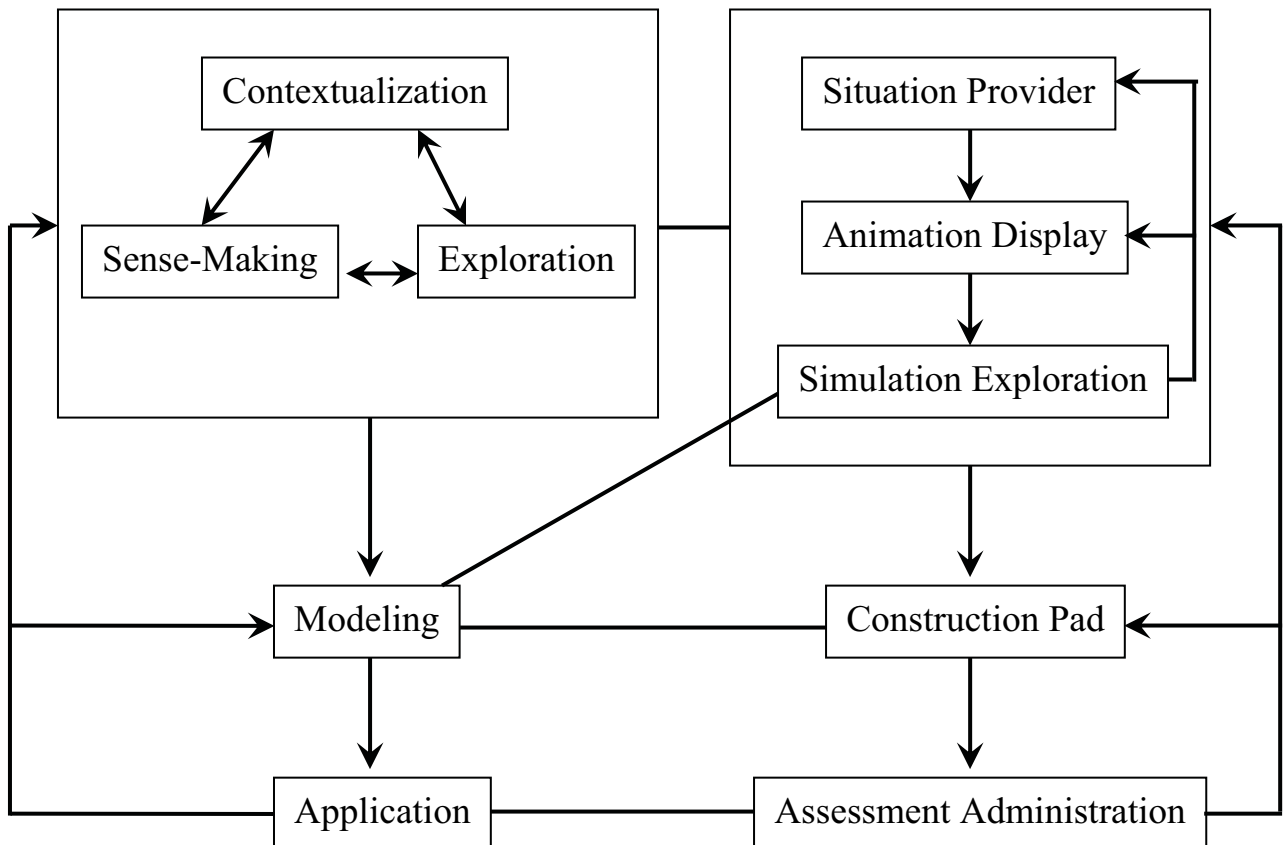


Figure 1: The Framework of the Technology-Enhanced Learning Model

The quality of computer technology's effects greatly depends on the setting in which the computer-related activity takes place, on the user's goal(s), and on his or her mindful engagement in the activity. To be effective, instructional methods and the media that deliver them must guide learners to effectively process and assimilate new knowledge and skills. Figure 1 shows one suggested way of applying the TEL model from the technology-implementation point of view: Situation Provider → Animation Display → Simulation Exploration → Construction Pad → Assessment Administration. The detailed descriptions of each TEL phase and the use of these components are as follows:

### **Contextualization**

To motivate students and focus their attention on specific scientific phenomena, therefore, the first phase of the TEL model is contextualization. In this phase, teachers may use pictures or videos to evoke students' prior knowledge and experience of a given phenomenon. In this phase, students are encouraged to describe their observations about the phenomenon, gain an intuitive comprehension of it, and connect it to their personal experiences. The computer or other medium will provide a real-life situation in the **contextualization phase** which motivates students. Students can achieve cognitive comprehension by watching videos or pictures to evoke their prior knowledge and experience of a given phenomenon. Most often real-life situations are too complex for

novice students to be able to extract key elements from the picture or video. Group discussion or scaffolding is required to help students know: what the problem is, why it is important, what key factors/concepts related to their tasks are, and how they can solve their problem. Videos or pictures used in the contextualization phase should emphasize the need to engage students in meaningful and purposeful activities, to help students see science as important, vital, and integral to their everyday lives, and to have them pay attention to “science in action” in their own life. Static pictures are useful for comparison or detailed analysis, while video is better if we want a dynamic learning process. An animation starting from real life phenomena, with the unnecessary parts faded out and the image reduced to key elements, can be very helpful to beginners. It is important to facilitate social interaction between and among students after either a film or static pictures are shown.

### *Sense making*

Although pictures and videos are powerful tools for contextualizing learning in a meaningful situation, they usually contain irrelevant information that could distract students’ attention from the scientific content embedded in a given phenomenon. Therefore, the second phase of the model supports students’ ability to make sense of their observations and intuitive comprehension, and to use various representations to guide the direction of their thinking (Bell, 1997; Quintana et al., 2002). Research on educational technology has suggested several design features to help students make connections between their intuitive comprehension and scientific representations (Edelson et al., 1999; Quintana et al., 2002; White, 1993; Wu et al., 2001). These features include providing representations that reveal underlying scientific concepts (White, 1993), giving students the ability to manipulate and link multiple representations (Wu et al., 2001), and providing representations and language that build on students’ intuition in describing complex concepts (Bell, 1997). Scientific phenomena often involve dynamic processes in time or variations in space. Computer-generated animations representing a dynamic natural phenomenon can be used to help students conceptualize the underlying scientific process, conjecture the rules or theorems that lie behind the phenomenon and even build their own models or theories to explain the scientific process. Animation provides a qualitative or visual representation of scientific processes. By representing the phenomena in an animation, we allow students to induce the possible causes of recurring phenomena in the **sense-making phase**; this is the capacity for induction. A well-designed animation containing these features could help students make sense of what they observe from pictures or videos, and guide them in visualizing the scientific concepts embedded in a particular phenomenon.

### ***Exploration***

During the sense-making phase, students develop an initial understanding of a phenomenon and generate simple rules or hypotheses to explain what they have observed. To develop a deeper understanding of scientific concepts, they have to explore the concepts and test their explanations (Roth, 1997). In the third phase of the model, therefore, students are provided with more opportunities to form and test their hypotheses. Simulations can offer such opportunities. Features such as allowing students to manipulate the quantities of variables and observe changes (de Jong & van Joolingen, 1998), linking conceptual information (e.g. equations) to representations (e.g. graphs) (Kozma et al., 1996), and providing situations in which students can test their ideas could encourage students to explore concepts. By exploring the simulation students form hypotheses, test them and develop a scientific model in the **exploration phase**. This is an essential feature of scientific inquiry. Interacting with simulations, students can also construct relationships between variables, which in turn will help them move to the next phase, that of constructing a scientific model. Quantitative relations between key factors/variables can be simulated with computational tools. Exploration of the simulation helps students to discover the relationships among variables.

### ***Modeling***

A model can focus students' attention on the components of a phenomenon or a system (i.e. objects, variables, factors or relationships) and help them elaborate on interactions within the phenomenon (Gobert & Buckley, 2000; Ingham & Gilbert, 1991). Constructing a model can thus engage students in such learning activities as identifying variables, making connections among variables, and verifying the accuracy of the model (Fretz et al., 2002). In the **modeling phase**, then, students are encouraged to synthesize the context or network of the phenomenon's interrelationships and its possible explanations, and so develop a coherent understanding of the phenomenon they are investigating. The construction pad are learning/modeling tools that can assist students' modeling skill through symbolic representation. Furthermore, with tools like "easy java simulation" (Hwang & Francisco, 2003), they can form hypotheses, modify the relations between variables, compare the generated simulations and the real phenomena, test their own hypotheses and establish possible scientific models. They then may display their constructed scientific model in the modeling phase; this is schema-building. Learning tools used in this phase should provide students with a working space in which to develop, modify and connect ideas, reflect on their modeling process, and evaluate the accuracy of their model.

## ***Application***

Learning cannot be separated from the “act of knowing,” for “what is learned’ is an integral part of “how it is learned and used.” It is important to provide opportunities for students to apply their new concepts in related situations and allow them to verify or identify limitations in the scientific model they have created. Finally, in the **application phase** students should go through an evaluation process in order to know their learning efficiency and the applicability of their own generated model; this is reflection. One way to verify the accuracy of the students’ model is to apply it to different situations. In doing so, students should realize the errors and limitations of their model, transfer ideas from one setting to another, reinforce their ideas, and thus gain a new understanding of the phenomenon and relevant concepts. This application phase could also help students to overcome the “inert knowledge” problem by fostering the conceptual understanding that will come when the situation is relevant to what they have learned (Krajcik et al., 1999). To promote the application of knowledge, the designers of learning tools should consider including a database using similar situations, and provide scaffolds to support students in making comparisons among situations and in examining the applicability of their models.

“Research shows that it is not simply general abilities, such as memory or intelligence, nor the use of general strategies that differentiates experts from novices. Instead, experts have acquired extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environment” (Bransford, Brown, & Cocking, 2002, p.31). The main purpose of the Situation Provider and Animation Display is to develop students’ ability to notice the most important features or aspects of their problem. The Simulation Explorer and Construction Pad are designed to help students organize, represent, form hypotheses and interpret information based on the simulation. Here the learning process is just as important as the learning context.

One does not interact with the computer but with the specific software program run on it. The question is whether “the program” can provide (or can be designed to provide) the specific activities, goals, and conditions for cognitive involvement which are requisite. Both the content and the instructional methods that help people know this content should be considered when selecting appropriate software tools for science learning. The final goal of the TEL environment is to help students construct their own understanding instead of merely being passive receptors of instructional content. However, the short term goal during each phase of the TEL model could vary from information acquisition (receptive) to response strengthening (directive) to knowledge construction (heuristic).

## Conclusion

Usually, the learner regards the computer simulation as a black-box. After the learner performs an input-output analysis, he or she can state the functional dependency relations between input and output (Goodyear, 1992). The strength of a simulation is to force students to retrieve or discover relevant knowledge, experiences and problem-solving skills in authentic situations. Exploratory simulations require students to take more responsibility in learning processes (de Jong & Njoo, 1992; Thomas & Hooper, 1991). With the help of scaffolded support from instruction, students can generate mental models based upon their interactive experiences with simulations (Suits & Diack, 2002).

Taiwanese students are near the top when the math and science scores of student in industrialized nations are reported in TIMSS 2003 study. However, most of the students did not like physics at all. There are just working very hard under the pressure from their parents. Many young kids in the elementary school like science. However, most of them did not like science or physics during their high school years. We have created hundreds of physics related java simulations and posted them on the NTNUJAVA web site (<http://www.phy.ntnu.edu.tw/ntnujava/>) to help students gain deeper understanding of physics concepts. And we hope they can enjoy the fun of physics as we do. We did find students who can use computer simulations to visualize the mechanism behind complex systems, and to see into phenomena that are not accessible to direct observation, therefore enhancing their comprehension of the underlying physics concept. However, we also found students who only gain the visualization effect from the simulation. They did not really understand the physics principles which govern the simulated processes. So we developed the above model to help teachers to implement simulation/modeling tools into their classroom to help their student. The study of the model is underway. We will report our research findings based on this model in the near future.

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