DESIGNING A TECHNOLOGY-ENHANCED LEARNING ENVIRONMENT TO SUPPORT SCIENTIFIC MODELING

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ABSTRACT

Modeling of a natural phenomenon is of value in science learning and increasingly emphasized as an important component of science education. However, previous research has shown that secondary school students encounter difficulties when engaging in modeling activities and need substantial support in order to create meaningful scientific models. Therefore, the purpose of this article is to present the design of a technology-based modeling tool (Air Pollution Modeling Tool, APoMT) that supports students to engage in scientific modeling. The design of APoMT is based on theories and guidelines of scaffolding. APoMT decomposes a modeling process into manageable tasks, supports an increasingly sophisticated modeling process by integrating multiple variables into students' models, provides multiple representations to help students visualize data and relationships, and embeds expert guidance to help learners apply science content to modeling. An implementation study shows that combining APoMT with well-designed learning lessons could effectively support students' development of conceptual understandings and modeling abilities (Wu, 2010).

Keywords: technology-enhanced learning, modeling, scaffoldings

INTRODUCTION

Modeling of a natural phenomenon is of value in science learning and increasingly emphasized as an important component of science education (National Research Council, 1996). Modeling engages students in meaningful learning activities such as making a plan, identifying variables, building relationships, and testing their model (Sins, Savelsbergh, & Van Joolingen, 2005). However, secondary school students encounter a number of difficulties in creating and using models for science learning. For example, students are unable to relate their models to the phenomenon being modeled because of their limited content knowledge (de Jong & van Joolingen, 1998). Additionally, some students cannot recognize mismatches between modeled outcomes and expected behaviors of the system represented in a model (Hogan & Thomas, 2001). Previous research has shown that students need substantial support in order to create meaningful scientific models. One source of support is from a well-designed technological tool (Fretz et al., 2002). Compared to the support provided by teachers and peers, tool support is more consistent and persistent; it exists all the time and can be employed in various settings (e.g., inside and outside classroom). Therefore, the purpose of this article is to present the design of a technology-based modeling tool (Air Pollution Modeling Tool, APoMT) that supports students to engage in scientific modeling. The design guidelines are informed by theories of scaffolding (Puntambekar & Hübscher, 2005; Quintana, et al., 2004; Wood, Bruner, & Ross, 1976).

The following sections start with a description of models and modeling. Innovative features of the Air Pollution Modeling Tool (APoMT) are described. Then theories and studies about scaffolding are discussed, and a set of design guidelines is showed after the discussion. Finally, the design of APoMT is presented and how the design follows the guidelines is explained.

Models and Modeling

A model is a simplified representation of a system that focuses attention on specific aspects or components of a system, such as ideas, objects, events or processes (Gilbert, 1991). These specific aspects can be either complex or on a different scale to that which is normally perceived. Models, therefore, can reveal the hidden structures or processes that are fundamental to an understanding of a system or a phenomenon (Harrison & Treagust, 2000).

Models also integrate conceptual knowledge to explain the phenomenon and use components of the model (i.e., objects, variables, factors or relationships) to elaborate on interactions within the system (Gobert & Buckley, 2000). For example, when creating a model of water quality, students need to identify variables of related concepts, such as dissolved oxygen, conductivity, and pH value, build causal relationships among them, and test the accuracy of these relationships. Thus, constructing a scientific model involves various learning activities that could enhance students understandings of scientific concepts, and in this article, this model construction process is defined as modeling.

Innovations of a Modeling Tool

Several software tools have been designed to engage students in modeling processes. For example, Fretz et al. (2002) showed how Model-It supported students to externalize their scientific ideas and create their own models. PowerSim allowed students to create and run a model about dynamic systems (Sins, et al., 2005). However, none of these technological tools were developed based on a real scientific model. Additionally, very few modeling tools in previous research provided simulated data for students to test the accuracy of their models. Thus the technology-based modeling tool presented in this article, APoMT, contains two innovative features as follows.

The first innovation is to build a modeling tool based on a real scientific model. According to theories of situated learning (Lave & Wenger, 1991), engaging students in activities that are similar to what scientists do is a very important part of learning. A real scientific model provides a context for students to participate in authentic science and gives students access to experts' knowledge base. Because APoMT focuses on a topic of air quality, integrating a model used by atmospheric scientists into APoMT could help students understand the transport and dispersion of air pollutants in the ambient air. One of the professional models commonly used by atmospheric scientists is AERMOD (http://www.epa.gov/scram001/dispersion_prefrec.htm). AERMOD can simulate the flow of air pollution in the atmosphere and estimate the concentration of air pollutant, but it does not have an interface for high school students to visualize and manipulate the simulations. Thus APoMT was designed based on AERMOD, includes major variables for students to manipulate and test, and contains interfaces to run, generate and visualize simulations.

Secondly, very few modeling tools provide real or simulated data to help students evaluate the accuracy of their models. For example, in Model-It (Fretz, et al., 2002), students could create as many irrelevant variables or relationship as they want, and the tool provided no data for students to test their modeled results. To improve the accuracy of students' models, therefore, it is necessary to provide students with simulated data. Rather than retrieving ready-made data from a database, APoMT directly runs the equations and simulations provided by AERMOD. This innovation could support students to build accurate relationships between variables and create a better model. Students could also use this feature to compare the simulated results to their predictions.

In summary, APoMT is a modeling tool with innovative features. By using APoMT, students could visualize a phenomenon (e.g., how pollutants disperse in the air), pose questions that take them beyond the original phenomenon (e.g., how topographical factors, weather conditions, and atmospheric stability affect the transport and dispersion of air pollutants), and develop explanations for these questions based on simulated results. Consequently, APoMT transforms modeling into a process that affords students the opportunities to engage in meaningful learning and allows them to transform their understandings of a phenomenon into objects, variables and a series of relationships between variables (Fretz, et al., 2002).

Theories and Design Principles of Scaffolding

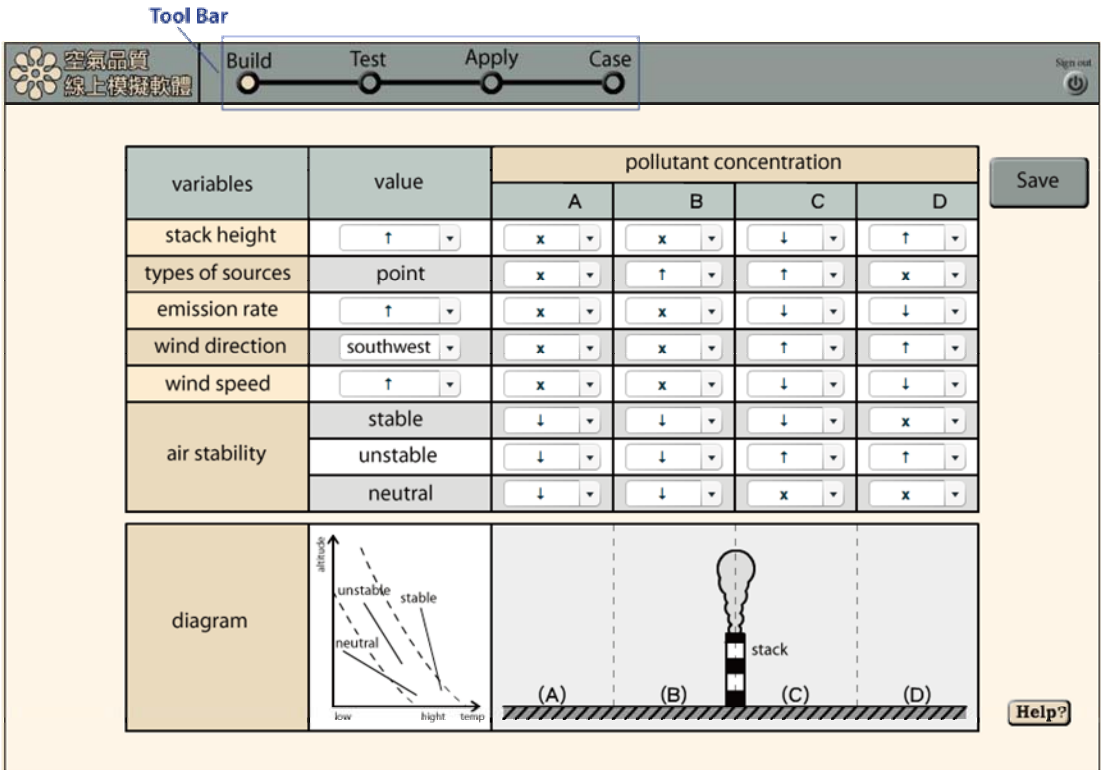
Although modeling is important for science learning and allows students to participate in desirable learning activities, several studies showed that secondary school students encounter difficulties when creating and using models (de Jong & van Joolingen, 1998; Hogan & Thomas, 2001). To design effective support for modeling, our research team draws on theories of scaffolding (Wood, Bruner, & Ross, 1976), and defines scaffolding as a process of providing decreasing amounts of support to help students "bridge the gap between their current abilities and the intended goal of instruction" (Rosenshine & Meister, 1992, p. 26) that allows students "to participate at ever-increasing levels of competence" (Palincsar & Brown, 1984, p. 122). Scaffolding is referred to as support provided within a learner's zone of proximal development (Vygotsky, 1978) that is the vital developmental area between what a student could do alone, and what he or she could do with the assistance of a more capable other.

Scaffolding can be provided by a variety of sources and appear in many forms ranging from print-based materials to modeling behaviors enacted by the teacher. These scaffolding materials or procedures often begin with simple exercises that allow learners to participate in difficult tasks or activities early on in their inquiry. Through a series of closely monitored steps, difficulty is gradually increased as students become more involved with their learning, and finally the support by the teacher is withdrawn (Wood, et al., 1976). The scaffolding instruction allows students to gain appropriate experiences and skills to increase their cognitive capabilities toward the task.

Software tools can also have supports or functions that play a role of scaffolding. Through inductive and theory-based analyses, Quintana et al. (2004) proposed a scaffolding design framework for science learning and synthesized previous research on learning technologies into a set of guidelines. Among the seven guidelines, four of them are very relevant to designing scaffolding in a modeling tool: (1) use representations and language that bridge learners' understanding, (2) organize tools and artifacts around the semantics of the discipline, (3) use representations that learners can inspect in different ways to reveal important properties of underlying data, and (4) provide structure for complex tasks and functionality (p. 345). For example, based on the third guideline, a modeling tool can provide multiple representations to help students visualize data and relationships between variables. According to the fourth guideline, a tool can offer representations or visuals that demonstrate structures or sequences of modeling so that students can easily organize their modeling process. The following section describes how the design of APoMT follows the guidelines.

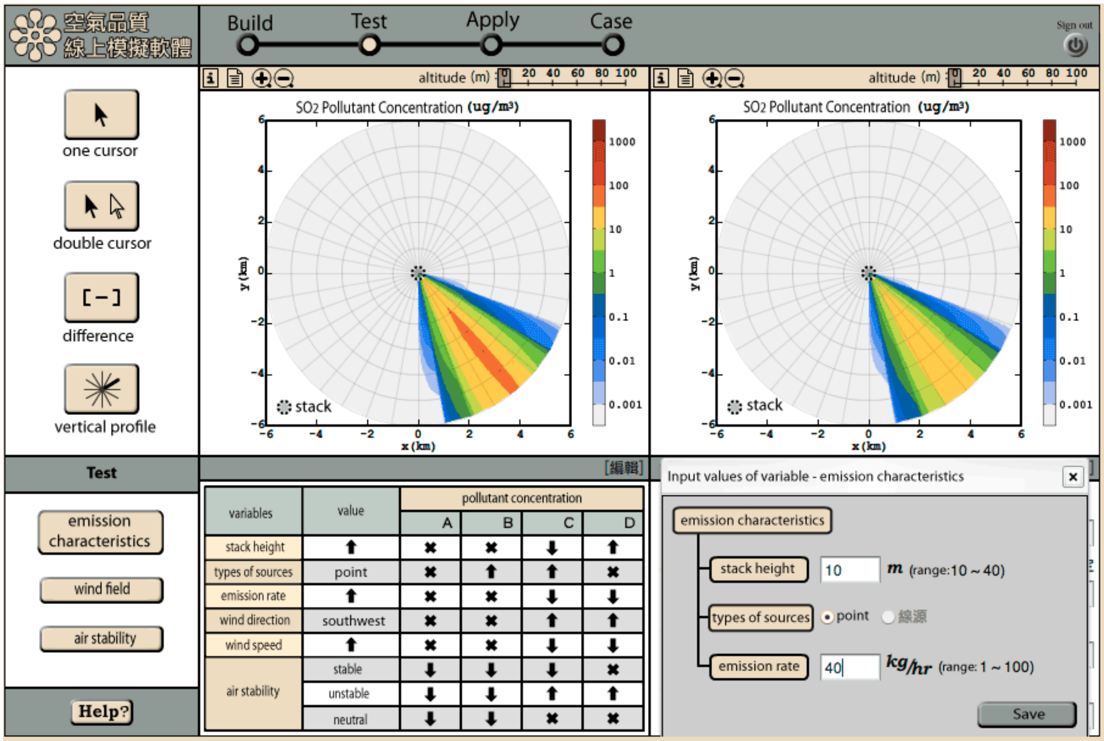
Design of APoMT

APoMT decomposes the modeling processes into four modes: Build (Figure 1), Test (Figures 2 and 3), Apply, and Case (Figure 4). Two common features are embedded in every mode: Tool Bar and Help. Students could move back and forth among the modes by clicking on the buttons in the "Tool Bar" at the top of the window. The Tool Bar also provides a visual organizer that allows students to have access to functionality (Guideline 1). In addition of the Tool Bar, another common feature across different modes is "Help." This embedded feature serves a role of expert guidance to help learners use the tool, understand the purposes of each mode, and apply science content to modeling (Guideline 1).



variables	value	pollutant concentration			
		A	B	C	D
stack height	↑	x	x	↓	↑
types of sources	point	x	↑	↑	x
emission rate	↑	x	x	↓	↓
wind direction	southwest	x	x	↑	↑
wind speed	↑	x	x	↓	↓
air stability	stable	↓	↓	↓	x
	unstable	↓	↓	↑	↑
	neutral	↓	↓	x	x
diagram					

Figure 1. Interface of Build mode in APoMT



variables	value	pollutant concentration			
		A	B	C	D
stack height	⬆	✖	✖	⬇	⬆
types of sources	point	✖	⬆	⬆	✖
emission rate	⬆	✖	✖	⬇	⬇
wind direction	southwest	✖	✖	⬆	⬆
wind speed	⬆	✖	✖	⬇	⬇
air stability	stable	⬇	⬇	⬇	✖
	unstable	⬇	⬇	⬆	⬆
	neutral	⬇	⬇	✖	✖

Input values of variable - emission characteristics

emission characteristics

stack height: 10 m (range:10～40)

types of sources: ● point ○ 線源

emission rate: 40 kg/hr (range: 1～100)

Save

Figure 2. Interface of Test mode in APoMT

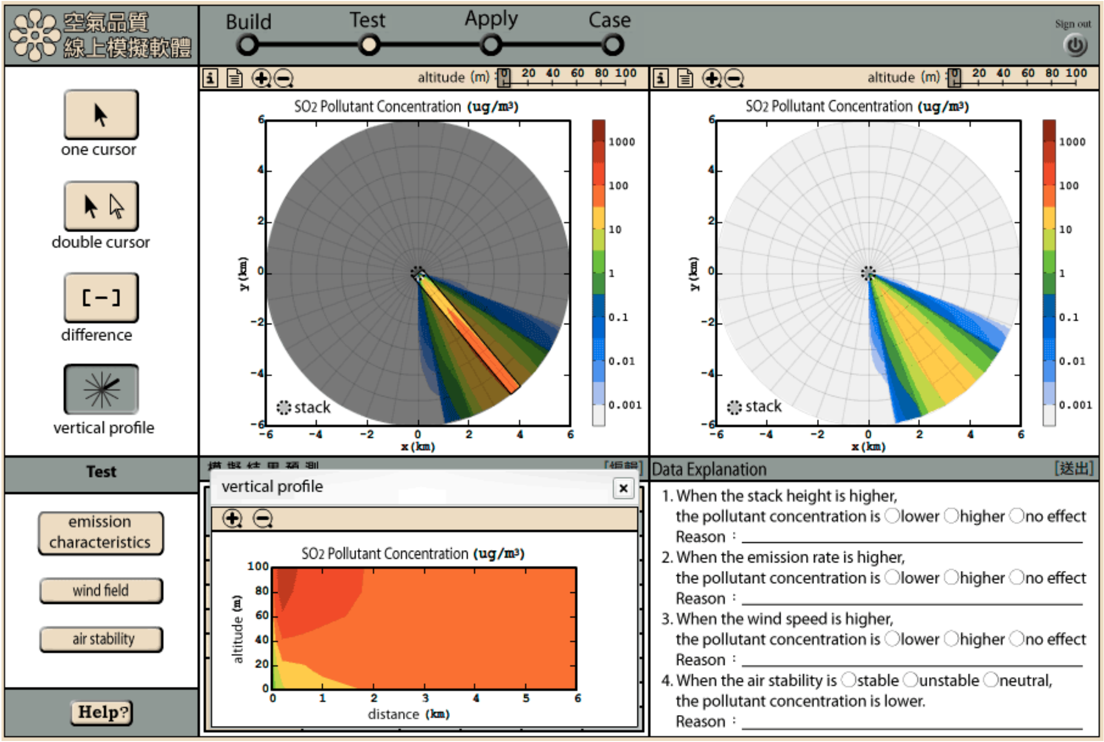
Table 1 Design Guidelines of Scaffolding and APoMT Features

Design Guideline	APoMT Features
(1) Use representations and language that bridge learners' understanding	• Provide a visual organizer that allows students to have access to functionality (Tool Bar). • Embed expert guidance to help learners use the tool, understand the purposes of each mode, and apply science content to modeling (Help).
(2) Organize tools and artifacts around the semantics of the discipline	• Organize the tool modes around a possible sequence of how scientists construct a model (Four modes). • Make a modeling process accessible and explicit to students (Four modes).
(3) Use representations that learners can inspect in different ways to reveal important properties of underlying data	• Offer a representation that can be inspected to reveal relationships among variables and underlying properties of data (Variable Table in Build mode). • Allow students to directly manipulate different representations (Test, Apply, Case modes). • Provide multiple representations to help students visualize data and relationships (Test, Apply, Case modes).
(4) Provide structure for complex tasks and functionality	• Constrain the space of activities that makes a complex modeling process more feasible and manageable (Four modes). • Restrict a complex task by allowing students to test only one variable each time (Test mode). • Support an increasingly sophisticated modeling process by using ordered task decompositions (Test, Apply, Case modes)

The four modes are organized around a possible sequence of how scientists construct a model (Guideline 2); the sequence makes a scientific modeling process accessible and explicit to students and guide students to plan their investigations of pollutant dispersions for model construction (Guideline 2). Additionally, each mode constrains the space of activities that makes a complex modeling process more feasible and manageable (Guideline 4). Table 1 outlines the design guidelines of scaffolding and APoMT features that are designed based on the guidelines.

In Build mode, the tool provides a Variable Table (Figure 1) that is designed to help students identify major variables and predict how the variables affect the pollutant concentration in different locations. For example, for a variable of the stack height, students could choose a "up arrow" which means "when the stack height increases" and then decide whether the pollutant concentration in location A, B, C, or D would increase (↑), decrease (↓) or not change (×). Build mode allows students to make prediction about relationships between variables and reveals students' own models before they collect simulated results. Following the third guideline, the design of this mode includes a representation (Variable Table) that can be inspected to reveal relationships among variables and underlying properties of data.

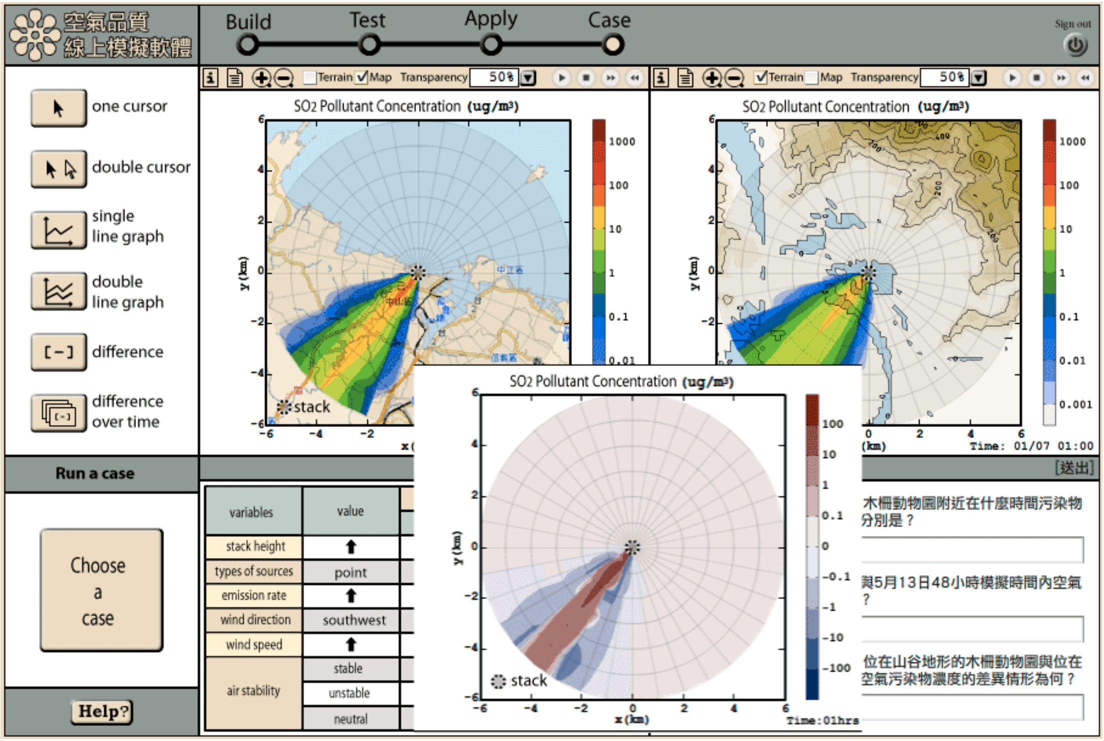
After making predictions, in Test mode (Figures 2 and 3), students could examine their models and test their hypotheses about how a variable might affect air pollution dispersion. To restrict the complexity of the task (Guideline 4), this mode allows students to manipulate only one variable from the variable list while other variables are controlled. Students can input a variable value in a pop-up window and run a simulation. Students can test different values with the same variable and observe how changes to variable values affect the pollutant dispersion patterns. The simulated results are generated by a professional modeling system, AERMOD, and shown by color-coded displays (Figure 3). The colors indicate estimated concentrations of an air pollutant (SO_2) at different altitudes (0-100 meters). Students can also visualize the dispersion of the pollutant from a different perspective; the Vertical Profile shows a cross-section of how a flow of pollutants moves from the stack to several kilometers away. After running simulations, students conclude their observations in the Data Explanation box and compare their conclusions with prediction early made in the Variable Table. The simulations are malleable representations that allow students to directly manipulate different variables and to have multiple views of how variables have impact on the pollutant concentrations (Guideline 3). Additionally, this mode provides multiple representations to help students compare differences and visualize data and relationships (Guideline 3).



1. When the stack height is higher,
the pollutant concentration is ○lower ○higher ○no effect
Reason：
2. When the emission rate is higher,
the pollutant concentration is ○lower ○higher ○no effect
Reason：
3. When the wind speed is higher,
the pollutant concentration is ○lower ○higher ○no effect
Reason：
4. When the air stability is ○stable ○unstable ○neutral,
the pollutant concentration is lower.
Reason：

Figure 3. Interface of Test mode in APoMT

Apply mode is also designed for students to manipulate variables, to visualize simulated results, and to describe their findings. However, different from Test mode in which students could change only one variable each time, Apply mode allows students to manipulate all variables at once and is designed to support a more sophisticated modeling process. The transition from Test to Apply mode could make model testing become a more feasible and manageable task to students (Guideline 4). In this mode, students could integrate what they learned about the effects of individual variables in Test mode, manipulate multiple variables at the same time, and observe possible interactions among variables. Additionally, this mode allows students to visualize how the pollutant concentration changes within 48 hours (Guideline 4) and to answer open-ended questions in the Data Explanation box.



variables	value
stack height	⬆
types of sources	point
emission rate	⬆
wind direction	southwest
wind speed	⬆
air stability	stable
	unstable
	neutral

木柵動物園附近在什麼時間污染物
分別是？

與5月13日48小時模擬時間內空氣
？

位在山谷地形的木柵動物園與位在
空氣污染物濃度的差異情形為何？

Figure 4. Interface of Case mode in APoMT

To further support students' modeling processes, six cases are provided in Case mode. Each case includes a location and relevant information (e.g., data of different variables, weather conditions, topographical situations, and maps) about the location. In this mode, students are asked to generalize their conclusions, apply their models and concepts learned to different cases, make prediction about the pollutant dispersion in different locations, and decide where would be the best location to build a thermal power plant. Students could choose a case, employ their models to make predictions about the case, run simulations, and compare the simulated results to their predictions (Figure 4). To support an increasingly sophisticated modeling process, one more variable, topography, is included in this mode (Guideline 4). Students could choose a Terrain view or a Map view to see whether the location is near large cities, whether pollutants would move into an urban or rural area, and whether any mountain or hill close to the location would cause an increase in the pollutant concentration. Additionally, line graphs and graphical illustrations (Figure 4) are provided for students to compare the pollutant concentrations in different locations and to visualize how the pollutant concentration changes over time (Guideline 3).

CONCLUSION

Modeling is one of the important ways for scientists to construct scientific knowledge (Dunbar, 1998). Although several modeling tools were built, very few of them have been developed based on a real scientific model and provided simulated data for students to test the accuracy of their models. Therefore, this article presents the design of APoMT that follows design guidelines of scaffolding. The tool decomposes a modeling process into manageable tasks, supports an increasingly sophisticated modeling process by integrating multiple variables into students' models, and provides multiple representations to help students visualize data and relationships. In the past year, an implementation study was conducted and shows positive results (Wu, 2010). In the study, we designed five learning lessons with the use of APoMT and examined students' conceptual understandings and modeling abilities after the lessons. The results indicated a significant improvement in conceptual understandings. In addition, students performed better on modeling abilities, such as planning, identifying variables, and testing models. These findings suggest that combining APoMT with well-designed learning lessons could effectively support students' development of conceptual understandings and modeling abilities.

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