Chapter 13
How Does Level of Guidance Affect Understanding When Students Use a Dynamic Simulation of Liquid–Vapor Equilibrium?

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Introduction

Learning chemistry involves understanding chemistry phenomena at three levels; macroscopic (the phenomena we can see, feel, and hear), symbolic (chemical formulas and equations), submicroscopic (the individual atoms and molecules), and the connections between them (Johnstone 1993). Because molecules are not visible and the concepts can be abstract, it is difficult for novices to visualize and make connections involving the submicroscopic level. Instructors desire to provide their students with appropriate guidance in learning these abstract concepts. But how much guidance is required? Too much guidance could even inhibit learning (Spencer 1999). This chapter discusses misunderstandings students have of molecular behavior in a simple system: liquid–vapor equilibrium. Approaches to helping students understand these concepts are introduced and the role of guidance discussed. Types of guidance strategies found to be effective are then outlined, followed by a research study in which some of these strategies were used. Finally, implications for instruction are presented.

Theoretical Background

Helping Students to Understand Physical Equilibrium

Understanding physical equilibrium at the submicroscopic level has been shown to pose problems for many learners (Haidar and Abraham 1991; Kelly and Jones 2007).

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Even tertiary students do not easily make connections between observable physical change and submicroscopic explanations (Lekhavat and Jones 2009). Learners also have misconceptions about physical processes. For example, many precollege students believe that water splits into hydrogen and oxygen when it evaporates (Osborne and Cosgrove 1982). Gopal et al. (2004) found that the tertiary students they studied tended not to refer to the submicroscopic level when describing the processes of evaporation and condensation. They also exhibited weaker understanding of condensation than of evaporation and tended to believe that the level of an open container of water would remain constant during evaporation. Azizoğlu et al. (2006) found that students preparing to become teachers held many misconceptions about phase equilibria, even after 6 weeks of instruction. For example, many of the students believed that the vapor pressure of a liquid depends on the volume of its container and that the freezing point is independent of pressure. Canpolat et al. (2006) found additional misconceptions in their study of students preparing to become teachers. For example, the students tended to believe that vaporization does not begin until a liquid boils and that different liquids boiling at atmospheric pressure have different vapor pressures at their boiling points.

Computer animations and simulations have been shown to help students visualize submicroscopic phenomena and thus enhance the learning of chemistry (Ardac and Akaygun 2004; Burke et al. 1998; Gil and Paiva 2006; Kelly and Jones 2007; Sanger et al. 2000; Tezcan and Yilmaz 2003; Williamson and Abraham 1995; Xie and Tinker 2006). Molecular animations and simulations may also help students better understand the submicroscopic nature of physical equilibria. However, visualizations of molecules can be difficult for novices to interpret (Jones et al. 2005). Therefore, students may need additional guidance to benefit from the visualizations. Supplementary materials such as worksheets, assignments, questions, and exercises have been recommended to enhance learning from simulations and animations (Jong and Joolingen 1998; Robinson 2000). This study aimed to investigate the effect of level of guidance provided by worksheets used by students as they interact with a simulation of liquid–vapor equilibrium.

The Role of Guidance

The use of guidance provided during instruction has been investigated over the years (Ausubel 1964; Craig 1956; Mayer 2004). Some researchers have suggested that learners benefit most when the level of guidance provided is minimal, because learners construct most of the information by themselves (Bruner 1961; Steffe and Gale 1995). On the other hand, some have argued that direct instructional guidance on the concepts and procedures should increase learning (Mayer 2004; Sweller 2003). Positive effects of direct instructional guidance on learning have been supported by some controlled experimental studies (Moreno 2004; Tuovinen and Sweller 1999).

The reduced cognitive load experienced by learners has been cited as justification for providing guidance during instruction (Hmelo-Silver et al. 2007; Kirschner et al. 2006; Van Merriënboer et al. 2003). Cognitive load has been defined as the amount of mental activity required by working memory while performing a particular task (Sweller 1988). A difficult task, or one that requires recalling and combining a variety of content information, will have a higher cognitive load than a simpler task (Paas and van Merriënboer 1994; Sweller et al. 1998). Kalyuga et al. (2003) suggest that a learner's prior knowledge determines the cognitive load the individual will experience. The cognitive load of the learner when studying a particular content area then decreases as the expertise of the learner increases. For example, novice students may solve equilibrium problems by setting up tables of data in order to determine how to set up a quadratic equation, but an expert might simply set up the quadratic equation directly.

Kirschner et al. (2006) compared constructivist, discovery, problem-based, experiential and inquiry-based teaching. In their analysis the authors argue that unguided or minimally guided instructional approaches are less effective and less efficient than instructional approaches that provide extensive guidance. They claim that guided instruction helps learners engage in cognitive activities, produces expert-like skills, and provides minimum cognitive load. They also argue that minimally guided instruction may put too high a burden on working memory (the items kept in mind when solving a problem) and the accumulation of information in long-term memory.

Schmidt et al. (2007) did not agree with the manner in which Kirschner et al. (2006) equated problem-based learning (in which groups of learners are presented with a complex problem and must work out how to solve it) with minimally guided instruction. In their commentary, Schmidt et al. (2007) argued that problem-based learning also allows flexible adaptation of guidance and is compatible with the organization of learners' cognitive structures. Hmelo-Silver et al. (2007) also disagreed with Kirschner et al. (2006) and suggested that problem-based learning and inquiry learning are not minimally guided, rather highly scaffolded; therefore, cognitive load is reduced. In scaffolded instruction extensive guidance is provided at the start, but then is gradually withdrawn as learners develop competence (Reiser 2004).

One method of providing guidance is the use of written materials such as process worksheets and worked examples (Van Merriënboer 1997; Kirschner et al. 2006). According to Kirschner et al. (2006) such worksheets provide students with an outline of the phases they go through when solving the problem and also hints that they may need to complete each phase successfully. Worksheets have been used to help chemistry students to remedy their misconceptions and to attain better conceptual understanding of fundamental concepts such as chemical equilibrium (Costu and Unal 2004), phase changes (Costu et al. 2003), and acids and bases (Ozmen and Yildirim 2005), as well as to improve science process skills (Karsli and Sahin 2009). In this study, worksheets having different levels of guidance were provided along with a computer simulation in order to investigate the amount of guidance necessary for comprehension of liquid–vapor equilibrium.

Guidance Strategies

A variety of guidance strategies that emphasize different aspects of the learning process have been identified and incorporated into learning environments, including computer-based learning environments. Jackson et al. (1994) described three guidance strategies implemented in their dynamic computer modeling environment:

(1) *Grounding in experience and prior knowledge:* They believe that the learning environment should allow learners to create models based on their prior experiences and knowledge so that the models are meaningful for them.
(2) *Bridging representations:* They argue that analogies, examples, and multiple visuals should be used as a bridge to connect new representations to learners' current understanding.
(3) *Coupling actions, effects, and understanding:* They propose that the interactive learning environment provide a coupling between the learners' actions and mental representations, because learners test their mental models while they are interacting with the simulation.

The investigators concluded that the guidance strategies they used helped students run and revise the model artifacts in the simulation and their own mental models.

Another type of guidance system, "Knowledge Integration Environment (KIE)," is a framework used with an online platform of resources and software that is used to help students improve their understanding of science (Bell et al. 1995; Linn 1996). KIE Activities include guidance to support students as they integrate their ideas (Bell and Davis 2000). The guidance provided in the KIE learning environments includes four main principles or strategies:

(1) *Making science accessible:* Encouraging students to build on their scientific ideas as they develop more powerful scientific principles; and to revisit their scientific ideas regularly.
(2) *Making thinking visible:* Modeling students by illustrating how links and connections are made, scaffolding them to explain their ideas, and providing multiple visual representations from media.
(3) *Helping students learn from each other:* Encouraging students to listen and learn from their peers; and designing social activities to promote productive social interactions.
(4) *Promoting lifelong science learning:* Encouraging students to reflect on their scientific information and to continue to engage in knowledge integration. (Bell and Davis 2000; Linn 2000).

Bell and Davis (1996), Hannafin (1999), and Cagiltay (2006) identified guidance strategies for electronic learning environments and suggested the following four main types of strategies:

(1) *Conceptual Guidance:* Guiding the learners in what to consider by identifying key conceptual knowledge related to a problem or revealing conceptual organization.
(2) *Procedural Guidance:* Guiding students in what to do by emphasizing how to utilize available resources and tools.
(3) *Strategic Guidance:* Providing logistical support to accomplish the activity by helping students to identify and select needed information, evaluate available resources, and relate new to existing knowledge and experience.
(4) *Metacognitive (reflective) guidance:* Providing guidance in how to think during learning and reflect on the goal(s). Metacognitive guidance may emphasize specific ways to think about a task.

In another study of guidance provision in a computer-mediated learning environment, Ping and Swe (2004) described the guidance strategies used by teachers to engage students in computer-mediated lessons. In their study, Ping and Swe (2004) identified four categories of guidance:

(1) *Orienting activities* to direct student attention to key variables, concepts, and visual cues.
(2) *Peer interactions* to facilitate cognitive thinking and metacognitive skills.
(3) *Prompts* to promote knowledge integration.
(4) *Modeling* to guide students to generate questions and elaborate thinking.

The authors included question prompts as a guidance strategy, since these prompts were designed to promote connections between the new ideas and prior knowledge and experiences.

In this study the level of guidance in the worksheets that learners completed as they worked through a computer simulation was manipulated using the four types of strategies (*conceptual, procedural, strategic, and metacognitive* guidance) recommended by Bell and Davis (1996), Cagiltay (2006), and Hannafin (1999). Specifically, in one type of worksheet (A), extensive conceptual guidance was introduced by directing the students' attention to key concepts and variables; procedural guidance was provided by asking questions in a stepwise manner; metacognitive (reflective) guidance was provided by adopting the strategy of predict-observe-explain; and prompting questions were also included to promote knowledge interaction and reflection. In the second type of worksheet (B), none of the guidance strategies were used; instead, only an open-ended (unguided) three-part problem was provided. Worksheet B could be described as providing a problem-based learning environment.

These strategies were chosen for this study because each of these strategies focuses on a particular understanding the students may lack. In addition, even though these strategies were designed for online environments and response systems, they were easy to adopt and apply to the worksheets accompanying online instruction.

Purpose of the study

This study was part of a larger investigation of student mental models of physical equilibrium (Akaygun 2009). The research question examined was, "How does the level of guidance provided in worksheets that accompany a simulation of liquid–vapor equilibrium affect understanding of the dynamic nature of equilibrium?"

Method

Participants

Study participants were 191 first-semester general chemistry students at a medium-sized public research university in the western United States. Students were in 11 different laboratory sections taught by six different teaching assistants. Participants were randomly assigned to work with either a guided or open-ended worksheet while working on a computer simulation. At the end of the computer lesson, the novices completed the equilibrium post-test and a personal evaluation questionnaire (PEQ). After the implementation of the study, selected volunteers were interviewed as they worked through the simulation. Approval for the study was obtained from the university's institutional review board.

Instruments and Materials

Liquid–Vapor Equilibrium Simulation

A simulation of liquid–vapor equilibrium based on research data from the literature and from observations of student work was developed by the authors of this chapter (Akaygun and Jones 2007). The simulation was programmed in Adobe Flash by the CADRE design group in Sydney, Australia. A motion algorithm that simulates the Brownian motion of polar particles was used to calculate the separations, orientations, and interactions of water molecules in the liquid phase. In the gas phase the relative rates at which the molecules evaporate at two different temperatures were calculated and used to create a realistic simulation. One of the screens from the simulation is shown in Fig. 13.1.

As seen in Fig. 13.1, the simulation shows simultaneous macroscopic and submicroscopic views of water in an open and a closed flask that are placed side by side. The simulation allows students to observe the processes occurring in the liquid, at the surface, and in the vapor by clicking the corresponding regions in the flasks. The molecular view for the surface includes a counter displaying the number of evaporating and condensing molecules that was designed to help

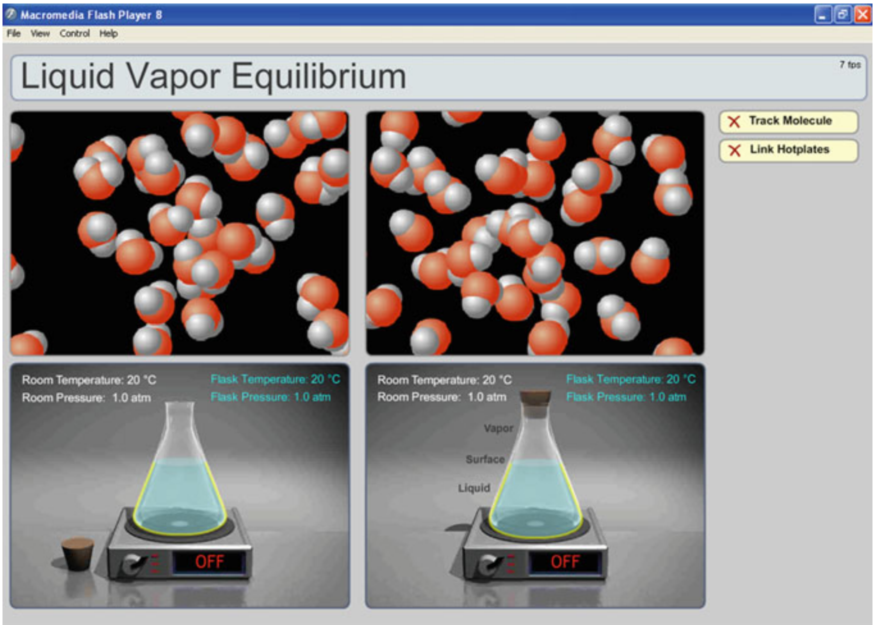

Fig. 13.1 A screen shot from the liquid–vapor equilibrium simulation, which shows simultaneous processes in the open flask (*left*) and the closed flask (*right*)

the students to visualize the dynamic nature of the equilibrium condition. The molecular view for the vapor displays another counter showing the number of molecules condensing on the wall of the flask, so that students may compare condensation rates in the open and closed flasks. In addition, the simulation was designed to show the processes at two different temperatures: 25 and 60 °C. The simulation is available online as the second item listed at http://artsci.drake.edu/honts/molviz/page2/page2.html.

Worksheets

Handouts containing instructions on navigating the simulation and a set of detailed questions to be answered as the students worked with the simulation. Worksheet A was designed to be more structured and to provide more guidance by using the strategies described in the previous section of this chapter (Fig. 13.2). Worksheet B was designed to provide less guidance. It contained the same set of instructions as Worksheet A but, instead of questions, had only a three-part open-ended problem to solve using the liquid–vapor equilibrium simulation (Fig. 13.3). Follow-up questions to be answered when finished with the simulation were the same for both worksheets (Fig. 13.4).

Part A – Liquid Phase

1) Predict what is happening at the macroscopic and molecular level for the liquid water in an *open* and a *closed* flask at 25ºC. Write down your predictions in the table given below
2) Repeat question 1 for 60ºC.
3) Turn the hot plate to 25ºC for the *open flask*, click on the lower part of the flask so that the edges of the flask are highlighted with a yellow line. Describe what you observe at macroscopic and molecular levels in the table given below.
4) Turn the hot plate to 25ºC for the *closed flask*, click on the lower part of the flask so that .the edges of the flask are highlighted with a yellow line. Describe what you observe at macroscopic and molecular levels in the table given below.
5) Repeat questions 3 &4 for 60ºC

	Liquid Phase	25ºC		60ºC	
		Open Flask	Closed Flask	Open Flask	Closed Flask
Macroscopic	Prediction				
	Observation				
Molecular	Prediction				
	Observation				

6) Now, click on the "link hot plates" button and compare the flasks. Was there a difference in the following between the two temperatures; 25ºC and 60ºC?

Fig. 13.2 A page from Worksheet A shows the extensive guidance provided to students using this worksheet

Mission: You are given open and closed flasks at two different temperatures, 25ºC and 60ºC. Investigate these flasks at liquid, surface and vapor phase by considering the characteristics of the systems and

a) propose *one main difference* between the open flask system and closed flask system at the molecular level; i. e. behavior of the molecules in the two types of flask systems
b) label one (or both) of them according to this difference.
c) justify your reasoning for this main difference.

Fig. 13.3 The problem presented in Worksheet B shows the minimal guidance provided to students using this worksheet

3) Does the molecular structure of the water molecules change when the molecules move from the liquid to gas phase?
   a) No, they don't change.
   b) Yes, the molecules decompose into individual atoms
   c) Yes, the molecules combine to form new molecule

4) Do molecules expand as they move from liquid to gas phase?
   a) Yes
   b) No

5) How does the rate of evaporation compare to the rate of condensation in the *open* flask?
   a) The rate of evaporation is equal to the rate of condensation.
   b) The rate of evaporation is greater than the rate of condensation.
   c) The rate of evaporation is smaller than the rate of condensation.

Fig. 13.4 Sample follow-up questions used on both worksheets

Conceptual Pre-and Post-test on Liquid–Vapor Equilibrium (Pre-test)

True/false and multiple choice questions on liquid–vapor equilibrium (Fig. 13.5). The questions were designed to assess misconceptions identified in the literature and discovered in previous research (Akaygun and Jones 2007). The same questions were used on both tests; only the order of the items was changed.

Personal Evaluation Questionnaire (PEQ)

A questionnaire containing open-ended questions to evaluate the effectiveness of the study through personal comments.

Procedure

During the 10th week of the semester, at the beginning of their laboratory period, participant volunteers completed a demographic form and the Pre-test on Liquid–Vapor Equilibrium, which took approximately 10 min. Next, the participants were randomly assigned to work with either Worksheet A (guided) or Worksheet B (open-ended) as they completed the liquid–vapor computer simulation (35–45 min).

The study took place in a computer lab where students worked individually on desktop computers. Each participant was assigned a code, which was used throughout the study. No introductory material or lecture was provided; students had only their previous understandings on which to rely. Depending on the type of worksheet, students answered either guided (type A) or open-ended (type B) questions while they were working and answered follow-up questions at the end.

1) Circle True or False for each of the following explanations of what happens when liquid water evaporates to form a gas.

True / False: Water molecules expand in size.
True / False: Water molecules separate into H and O atoms.
True / False: Attractions between individual water molecules are broken.
True / False: Molecules move further apart.

2) Assume that water is being heated from 25°C to 90°C in a *closed* flask. Circle True or False for each of the following statements about this process.

True / False: Steam molecules get smaller in size since they get trapped
True / False: The high pressure in the closed flask keeps the water molecules from moving much.
True / False: When the temperature stabilizes at 90°C, the rate of evaporation equals the rate of condensation.
True / False: More boiling occurs in a closed flask than an open flask because the closed flask has more heat content.

Fig. 13.5 Sample items from the post-test on liquid-vapor equilibrium. Each question was designed to assess misconceptions that had been identified in students

The students were observed while they worked on the simulation, but the instructors did not interact with the students. When students completed the simulation, they were given the Post-test on Liquid–Vapor Equilibrium (about 10 min) and the Personal Evaluation Questionnaire (about 5 min).

Four interviews were held approximately one week following the implementation of the study. Two participants were randomly selected from the participants who worked with worksheet type A and two were selected from those who worked with worksheet type B. The 20–25 min interviews were designed in a think-aloud format, in which the students were asked to explain what they thought while working with the simulation (Bowen 1994). The interviews were audio and video-recorded.

Results and Discussion

Demographics

Of the participants, 39 % were male and 63 % were female. The ethnicity of the participants was as follows: 83 % white, 7 % Hispanic, 4 % black, 3 % Asian, and 3 % others. The participants were found to be in various stages of their studies: 58 % freshmen, 24 % sophomore, 17 % junior, and 2 % senior. The majority of the students stated that they were pursuing a medical career or planned to enter a natural science field such as biology, physics, or chemistry.

Conceptual Pre- and Post-test on Liquid–Vapor Equilibrium

The average scores on the conceptual pre- and post-test on liquid–vapor equilibrium were compared by a paired-sample t test. The average scores of both groups improved significantly ($p < 0.05$), as shown in the third and fourth entries in Table 13.1.

As can be seen in Table 13.1, no significant difference ($p > 0.05$) between the Pre-test scores of the groups who worked with worksheet type A or B was found, indicating that the two groups of students held equivalent levels of prior knowledge. In addition, no significant difference ($p > 0.05$) was found between the Post-test scores of the same two groups. On the other hand, a significant improvement between the Pre-test and the Post-test ($p = 0.000$) was found in the scores of the students who worked with either type of worksheet. This result implies that the use of the simulation had helped the two groups to reach the same level of conceptual understanding, regardless of whether the more or less guided worksheet had been used. Despite the fact that both groups showed a significant improvement in

Table 13.1 Average scores on the pre- and post-tests (Max. Score = 26)

	Type of worksheet	N	Mean	*T*	d*f*	Sig. (two-tailed)
Pre-test	A	99	14.15	−1.025	189	0.307
	B	92	14.65			
Post-test	A	92	16.05	−1.624	189	0.106
	B	99	16.97			
Pre versus post-test	A	92	14.15 16.05	−5.101	91	0.000
Pre versus post-test	B	99	14.65 16.97	−6.387	98	0.000

understanding, the scores were still low (61.7 % for Group A and 65.3 % for Group B). Students may not have yet entirely mastered the concepts.

The responses to specific items in the Pre-test and Post-test of students who worked with each kind of worksheet were compared by a related-samples non-parametric sign test. The analysis showed that the responses of students to 13 of the 26 items improved significantly from the Pre-test to the Post-test ($p < 0.05$).

After completing the simulation students in both groups showed a better understanding of evaporation and were able to correct misconceptions such as, “Water molecules separate into H and O atoms during evaporation.” and “Steam molecules get smaller in size.” regardless of the type of worksheet being used.

A significant difference between the students who worked with worksheet type A or B was seen on only one item. Significantly more students who worked with worksheet type B (less guided) selected the correct answer on Item 2 in the Post-test, as shown in Table 13.2.

Item 2: Circle True or False for each of the following explanations of what happens when liquid water evaporates to form a gas: Water molecules expand in size. (Answer: False)

This difference might be due to the fact that students who worked with the less guided worksheet spent more time working with the simulation than students who

Table 13.2 Average scores on question 1, item 2 of the conceptual liquid-vapor equilibrium pre- and post-tests

Item 2	Type of worksheet	N	Correct answers in pre-test (%)	Correct answers in post-test (%)	d*f*	Sig. (two-tailed)
Pre and Post-test	A	92	72	77	91	0.424
Pre and Post-test	B	99	71	88	98	0.004

Table 13.3 Comparison of scores of students who worked on different types of worksheets

	Type of worksheet	N	Mean	F (d*f* = 189)	Sig. (two-tailed)
Worksheet score	A	92	4.06	189	0.000
	B	99	2.43		
Follow-up questions	A	92	5.50	189	0.496
	B	99	5.66		

used the more guided worksheet, who divided their time between viewing the simulation and answering the questions in the worksheet. Students who had more time to focus on the simulation might have noticed features in the simulation that were not mentioned in the worksheets.

Student responses to the questions on the worksheets were evaluated and scored out of a total of 5 points in each case. Next, the students in each group were compared by independent sample t-test with respect to worksheet score and score on the follow-up questions, which were the same for both types of worksheets. The results of the t-test analysis are shown in Table 13.3.

The only significant difference found between the scores of students who used different types of worksheets was found to be in the worksheet score itself ($p = 0.000$). This difference merely indicates that the questions on the more extensively guided worksheet were easier to answer than the more open-ended questions. The scores of the two groups on the follow-up questions, which were the same for each worksheet, were not significantly different.

The students were asked to rate the difficulty of the worksheet and the simulation based on their performance, the mental effort they spent, and the frustration they experienced. Students in both groups rated the difficulty of their worksheets as "average." Students who had worked with the more guided worksheet (type A) also rated the difficulty of the simulation as "average." On the other hand, students who had worked with the less guided worksheet (type B) rated the difficulty of the simulation as "less than average." This response is the reverse of what would have been expected on cognitive load considerations alone, because the lower guidance of the open-ended worksheet should have resulted in a higher cognitive load.

Personal Evaluation Questionnaire

The Personal Evaluation Questionnaire consisted of open-ended questions designed to assess student opinions about the helpfulness of the simulation, aspects of the simulation and worksheet they liked or disliked, their suggestions for the improvement of the study, and what part of the simulation they found to be the most challenging. The responses of the students were coded and a frequency analysis was performed.

The responses of students who worked with the two types of worksheets were compared by Chi square analysis. The results of the analysis are shown in

Table 13.4 Attitudes of students toward the helpfulness of the computer lesson

Group	N	Helpfulness	Number	d*f*	Pearson Chi square	Sig (two-tailed)
Worksheet A (more guided)	92	Not helpful	21			
		Partially helpful	12			
		Helpful	59			
				2	11.888	0.003
Worksheet B (less guided)	99	Not helpful	6			
		Partially helpful	11			
		Helpful	82			

Table 13.5 Comparison of features of the computer lesson mentioned by students using different types of worksheets

Aspect	d*f*	Pearson Chi square	Sig (two-tailed)
Helpfulness	2	11.888	0.003
Reasons for helpfulness	9	17.376	0.043
Aspects liked	11	25.035	0.009
Aspects disliked	15	27.276	0.027
Suggestions	4	17.077	0.002
Most challenging part	7	8.871	0.262

Table 13.4. As seen in Table 13.4, significantly more students who had worked with Worksheet B (less guided) said that the computer lesson was helpful than students who had worked with Worksheet A (more guided).

Significant differences in the attitudes toward the computer lesson were found between the groups of students when compared by Chi square analysis, as summarized in Table 13.5.

Reasons students gave for the helpfulness of the lessons, the aspects they liked or disliked, and the suggestions they made for improving the lesson differed significantly between the two groups. Table 13.6 lists the major categories of comments in which differences were seen between students in the two groups.

When suggesting how the simulation was helpful students in Group B, who worked with a less guided worksheet, were more likely to refer to conceptual understanding in their comments; they were more likely to focus on the visualization rather than on the questions and procedures. This finding implies that students who work with open-ended worksheets may focus more on the conceptual aspect of simulations, whereas students who work with more guided worksheets may focus more on the interactivity of simulations and on the worksheet questions.

Comments on the aspects liked suggest that students who worked with a more guided worksheet liked the visual, graphical, and the design aspect of the simulation more than students who worked with a less guided worksheet. On the other hand, students who worked with a less guided worksheet liked the conceptual

Table 13.6 Differences in comments made by students in the two groups

	Group A (92)	Group B (99)
How the simulation was helpful		
It made the molecular processes visible	15	29
It was hands-on or interactive	31	13
It helped in understanding the concepts	36	47
Aspects of the simulation liked		
Easy to understand	0	8
Helped in understanding the concepts	2	4
A specific feature, such as the molecule counter	3	9
Ability to compare the different phases	4	13
Its interactivity	36	30
The ability to visualize the concepts	38	30
Aspects of the simulation disliked		
A specific feature, such as not being able to zoom out	2	8
The graphics	3	6
The time length of the lesson	20	8
Suggestions were made for improvement of		
The simulation	10	35
The worksheet	22	13
The implementation	27	20

aspect and the specific features that emphasized the conceptual aspects more than students who worked with a more guided worksheet. It may be that as the amount of guidance provided by the worksheets decreased, students spent less time answering specific questions and more time exploring the simulation; they may have focused more on the conceptual aspects of the simulation and have valued them more than the other group.

Significantly different aspects were disliked by the two groups of students. The finding that more students in Group A disliked the amount of time required for the lesson might be related to the observation that students in Group A spent more time answering their questions and less time exploring their own interests than the students in Group B. Students in Group B were more likely to indicate disliking a specific feature of the simulation or the graphics of the simulation. This finding may be related to the observation that because students in Group B spent less time answering worksheet questions than students in Group A, therefore, they may have paid more attention to the features of the simulation.

The students in the two groups also made significantly different suggestions for improving the lesson. Once again the students in Group B appeared to be more focused on the simulation itself, while students in Group A were more focused on the worksheet questions and on the implementation of the study. Students who used less guided worksheets may have spent more time with the simulation and may have paid more attention to the specific features of the simulation, focusing more on conceptual understanding than students who had worked with the more guided worksheet. On the other hand, students in Group A may have spent more

Table 13.7 Some student quotes showing attitudes toward the computer lesson

Aspect	Student quotes
Helpfulness	Group A: "No, not enough time"
	"Yes, it gives you a visual representation of what is going on a molecular level"
	Group B: "Yes, because it was nice to visualize the information"
	"Yes, it made the topic easier to understand"
Aspects liked	Group A: "Animation was cool"
	"Visual"
	Group B: "The pictures of molecules helps get involved"
	"Being able to control different aspects"
Aspects disliked	Group A: "Too many questions and repetitive charts"
	"Time consuming"
	Group B: "The numbers of the temperatures didn't match"
	"Top three buttons were rather slow/unresponsive"
Suggestions	Group A: "More things to click"
	"Making less questions to answer"
	Group B: "The molecules should have been smaller so a larger area could be seen"
	"I thought overall the lab was set up very well providing all the necessary info. One suggestion is maybe providing molecular speeds of the molecules"

time with their worksheets and thus were more focused on the guiding questions than on the simulation itself. Some student quotes, which show their attitudes toward the computer lesson, are given in Table 13.7.

Classroom Observations and Interviews

Students in each section were observed as they worked with the simulation. Because students were randomly assigned to the two groups, it was difficult to measure exactly how much time students in the two groups spent on the lesson. However, observers noted that the students who took the longest time tended to be in Group A.

Findings from the interviews conducted support the findings from the classroom observations and the Personal Evaluation Questionnaire. The two students who had used the open-ended Worksheet B both indicated that they had liked the worksheet. One mentioned that it helped her make her own decisions, but still provided the basic guidance needed; the second student mentioned that she found it easy to use. Both of these students found the simulation easy to use, but the first student added that she needed to think and figure out why things were happening as she used the simulation. The two students who had used the more guided Worksheet A also indicated that they had found the worksheet helpful. However, one mentioned having difficulty making the connection between the questions and the molecular motion in the simulation. The other student indicated that, although the worksheet questions were easy to answer, she found completing them to be a long and frustrating process.

Conclusions

Students in both groups showed significant learning gains after working with the simulation, as seen in Table 13.1. When performance on specific items on the Pre- and Post-test was examined, in 13 of the 26 items students exhibited significantly better understanding of evaporation and condensation. For instance the majority of students in both groups overcame the misconception of "separation of water molecules into H and O atoms" when evaporating.

The only difference in achievement between the students who worked with the two worksheets was seen for the misconception that water molecules expand in size during evaporation, a misconception addressed only in a follow-up question on both worksheets. Only students who worked with the less guided worksheet (Group B) did significantly better on this item on the Post-test (Table 13.2), suggesting that students using the open-ended worksheet may have paid more attention to aspects of the simulation not mentioned on the worksheet, while students in Group A may have been more focused on the worksheet questions.

Overall, as described in Tables 13.1 and 13.3, no significant difference in average scores on the Post-test or follow-up questions were found for students who had used the two types of worksheets. This finding might indicate that even the minimal guidance of open-ended Worksheet B was sufficient to help students learn the concepts needed to answer the questions on the Post-test and the follow-up questions at the end of each worksheet (Costu and Unal 2004). On the other hand, the effects of the different levels of guidance provided by the worksheets might not have been revealed by the assessments used in the study. The different types of worksheets might have had an effect on other aspects of learning and it would be worthwhile to investigate other possible effects of varying the amount of guidance provided to students.

In this study students were able to improve their understanding of liquid–vapor equilibrium after viewing a simulation accompanied by worksheets having two different levels of guidance. These findings suggest that when students learn other chemistry concepts with simulations and animations the accompanying worksheets can be either highly guided or open-ended. Students in this study had positive attitudes toward the computer lesson, regardless of the level of guidance. However, students using the less guided worksheets had more positive attitudes toward their worksheets than did students using the more guided worksheets. In addition, the responses to the Personal Evaluation Questionnaire suggest that the students using the open-ended worksheet were more focused on the concepts that they were learning. The fact that students who used the open-ended worksheet found the computer lesson to be more helpful than students who used the highly guided worksheet suggests that worksheets used with computer lessons should have a minimum of guidance. Students might have enjoyed discovering the simulation through their interaction with the computer instead of being directed (and perhaps distracted) by the questions on the worksheet. In addition, most of the students who worked with the highly guided worksheet stated that the worksheet was time-consuming or lengthy; hence, they made suggestions for the modification of the worksheet or the implementation rather than the simulation itself.

Student attitudes toward the computer lesson varied significantly for students using worksheets with different levels of guidance. Significantly more students who worked with the less guided worksheet thought the simulation was helpful (Table 13.4). In addition, their reasons for finding the simulation helpful were also significantly different. Students who worked with the less guided worksheet were more likely to report that the simulation helped them conceptually understand the processes, whereas students who worked with a more guided worksheet were more likely to report that the simulation was helpful due to being hands-on (Table 13.6). Similarly, the aspects liked, disliked, and suggestions for improvement were significantly different between the groups in that students who had worked with the less guided worksheet wrote comments that focused more on the chemistry concepts, whereas students who worked with the more guided worksheet focused more on the graphical-visual aspects of the simulation. It may be that as the students spent more time and effort exploring the simulation in an open-ended fashion, they were paying more attention to the chemistry concepts than students who mostly focused on answering the larger number of questions in the more guided worksheet.

Because no significant difference was found between the level of guidance and the Post-test scores, minimal guidance in an open-ended format may be sufficient guidance for students using computer simulations of molecular behavior. No evidence was found that strategies recommended for reducing the cognitive load of instruction (Bell and Davis 1996; Cagiltay 2006; Hannafin 1999; Kirschner et al. 2006) were helpful in this case. In fact, differences in attitude between students using more guided and less guided worksheets suggest that students using the less guided worksheet focused more on the conceptual basis of the computer lesson. Further investigation of the type of questions and answers might reveal whether any other variables might have been affected by the difference in guidance.

Implications for Teaching

The findings of this study suggest that it may be preferable to use either minimal guidance in simulation worksheets or to provide scaffolding in which students move from more guided to less guided questions in the same lesson. When the level of guidance is high learning can become a tedious experience and student attention can be distracted from conceptual understanding as they struggle with answering a large number of questions.

1. Run the simulation by connecting the hot plates so that both open and closed flasks are simultaneously at the same temperature.
2. Observe and compare the following:
a) the motion of the molecules in the *liquid* phase in *open* and *closed* flasks.

b) the motion of the molecules at the *surface,* in *open* and *closed* flasks.

c) the motion of the molecules in the *gas* phase, in *open* and *closed* flasks.

d) the number of *evaporating* & *condensing* the molecules from the surface, in *open* and *closed* flasks.

e) the *rate of evaporation* & *condensation* in *open* and *closed* flasks.

Fig. 13.6 A page from a sample worksheet with a transitional level of guidance that could be provided to students using the liquid–vapor simulation

In this study students may have been able to learn the content primarily from the simulation, with a need only for minimal guidance. For more difficult topics and when simulations are not available, an ideal situation might be a true scaffolded approach, with the first session closely guided, the second transitional, and the third open-ended. In other words, in such an approach a single worksheet may contain three sections: Highly guided, transitional, and lightly guided. The highly guided questions in the beginning of the worksheet may be designed by applying conceptual and procedural guidance (Bell and Davis 1996; Cagiltay 2006), in which detailed directions, tables/charts, and concrete cases are given. In the transitional section the level of guidance/scaffolding could be gradually decreased by providing supports such as cues, hints, and coaching comments. Finally, minimally guided questions may be presented so that students can organize their cognitive structures by using understandings gained from the guidance provided earlier (Schmidt et al. 2007). An example of worksheet questions for the application in this chapter that uses an intermediate level of guidance is shown in Fig. 13.6.

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