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The Effect of a Computerized Simulation on Middle School Students' Understanding of the Kinetic Molecular Theory

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Abstract The objective of this study was to evaluate the effect of a dynamic software simulation on the understanding of the kinetic molecular theory by 7th graders. Students in the control group ($n = 62$) studied a curricular unit that addressed the differences in arrangement and motion of molecules in the three phases of matter. The experimental group ($n = 71$) studied the same unit combined with a few computer lessons using a software simulation. The results indicate that the students in the experimental group scored significantly higher than those in the control group. Nonetheless, while both groups of students improved their understanding of the kinetic molecular theory, the overall achievements were very low. These findings suggest that the simulation improved the understanding of the 7th graders; however, it was insufficient in itself to promote meaningful learning. Statistically significant gender differences were not observed. This paper concludes with a discussion of the educational implications of this study.

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Introduction

The essential ideas brought forth by the kinetic molecular theory are that all matter is made up of tiny particles and that these particles are in perpetual motion. Whereas this idea may seem simple, its ramifications are complex (Feynman 1977; Berkheimer et al. 1988). It is impossible to understand most of modern science without a good understanding of the kinetic molecular theory: Most of modern chemistry is devoted to developing our understanding of particles and their interactions. The kinetic molecular theory also plays a key role in physics, biology, and geology.

Because of the centrality of the kinetic molecular theory in science, it is included in the middle school curriculum almost universally and serves as a basis for learning other, more advanced ideas in middle school as well as in high school. Nonetheless, while the topic has been taught for many years, research repeatedly indicates that students of all ages have difficulties appreciating the particulate nature of matter (Novick and Nussbaum 1978; Osborne and Cosgrove 1983; Brook et al. 1984; Nussbaum 1985; Ben-Zvi et al. 1986; Johnston and Driver 1989; Stavy 1990; Lee et al. 1993; Johnson 1998a, 1998b). Even after relevant instruction, students hold alternative conceptions that are based on their everyday life experiences and intuitions. Middle and high school students have difficulties explaining daily common phenomena in molecular terms. For example, many secondary school students are strongly committed to the idea that matter is continuous or simply *includes* particles. Also, students of all ages attribute macroscopic properties to particles and have difficulties appreciating the intrinsic motion of particles, especially in solids. [Summaries of relevant research can be found in Benchmarks for Science Literacy (American Association for the Advancement of Science [AAAS] 1993), Driver et al. (1994), Johnson (1998a)].

It has been argued that meaningful learning of the particulate model of matter is exceedingly demanding and should be postponed (Fensham 1994). Other studies attribute the lack of understanding the particle ideas to curriculum and instruction, rather than to the students (Johnson 1998a; Kesidou and Roseman 2002; Stern and Roseman 2004). In fact, it has been shown that carefully designed instruction can help students as young as 6th graders develop understanding of atoms and molecules, although several deficiencies in students' understanding remain despite this approach (Lee et al. 1993).

Scientific models are used routinely in science education for different purposes, such as to promote the learning of abstract ideas in science, to promote the appreciation of the role of models in the development of scientific ideas, and to promote the ability to do science when students create their own models (Justi and Gilbert 2002). The premise of this study is that multiple representations—such as diagrams, analogies, models, and simulations—can make abstract ideas in chemistry intelligible to students (Champagne et al. 1985; Strike and Posner 1985; Feltovich et al. 1989; Clement 2000; Justi and Gilbert 2002). Different representations emphasize different aspects of an idea and provide a variety of opportunities for the idea to integrate with other students' ideas and become embedded in a student's knowledge system. For these reasons, students' experiences with models can help them to develop their own mental models of scientific concepts (Treagust et al. 2002) and apply these models in novel contexts.

The use of representations in chemistry and physics education is widespread and numerous studies have shown that pictorial materials, analogies, models, or simulations may help students envision, and subsequently construct molecular concepts (Harwood and McMahon 1997; Noh and Scharmann 1997; Barnea and Dori 1999; Barnea 2000; Barnea and Dori 2000; Harrison and Treagust 2000; Wu et al. 2001; Dori et al. 2003; Dori and Belcher 2005; Dori et al. 2007). Many of these studies emphasize the advantages of computer-based visualization tools in contrast to other modes of representation: Whereas molecular diagrams or ball-and-stick models frequently used in the chemistry classroom can highlight some aspects of the kinetic molecular theory (e.g. the arrangement of particles), computerized simulations are interactive and dynamic in nature and can therefore represent additional aspects, such as molecular motion in a variety of conditions. For example, when used with eleventh graders and undergraduate chemistry students, computer simulations were helpful in improving students' understanding of chemical representations and concepts (Wu et al. 2001; Dori et al. 2003). Regardless of the kind of model used, students tend to see models as an actual copy of the reality and therefore should be engaged in considering the nature, scope and limitations of each model (Thagard 1992; Harrison and Treagust 1996; Gilbert et al. 1998; Justi and Gilbert 2002).

The objective of this study was to evaluate the effect of a dynamic software simulation on the understanding of the kinetic molecular theory by 7th graders. This topic is taught in Israel at the seventh grade and as many as three quarters of the science lessons (that is, about 70 lessons) during that school year are devoted to this topic. This massive investment in curricular time and the importance of this topic for subsequent learning, justify further efforts to study and improve student learning.

We focused on the 'basic particle theory' as defined by Johnson (1998a), namely, the idea that matter is composed of invisible particles that are in constant motion. More advanced ideas concerning the structure of atoms and the distinction between atoms and molecules were beyond the scope of our study.

We were also interested in studying whether the computerized simulation affects the genders differently. Whereas international comparisons such as TIMSS 1999 did not reveal significant differences between genders at the middle school level, the proportion of boys that passed with honors was significantly greater than that of girls (29% vs. 21%) (Mevarech and Liberman 2001). In addition, it was found that Israeli boys' attitude towards learning science was significantly better. Some researchers suggest that these results could be partly explained by the assessment format used: When mostly multiple-choice format was used (for example, in TIMSS 1999), boys performed better whereas when open ended questions were used (for example, in PISA 2002) girls performed better. Nevertheless, boys performed better than girls in an open ended national test administered at the middle school level in Israel (Mevarech and Liberman 2001).

Specifically, the research addressed the following questions: (a) How did the computerized simulation used in our study affect the understanding of 7th grade students of the kinetic molecular theory and their ability to explain phenomena in molecular terms, and (b) Was the effect of the computerized simulation genders related?

Methodology

Context of the Study

'Materials' is one of the seven main topics that constitute the Israeli syllabus for middle school (grades 7–9). It includes the kinetic molecular theory as well as related concepts, such as elements and compounds (Israeli Ministry of Education 1996). Several curricular units that treat the kinetic molecular theory are available in Israel.

Ideally, the effect of the software simulation should have been studied using the curriculum that best support student learning. 'Vacuum and Particles', a unit that explicitly addresses students' difficulties is available in Israel (Nussbaum 1996). A longitudinal study conducted on 1,302 middle school students showed that over 80% of the students who used 'Vacuum and Particles' underwent conceptual change regarding the particulate nature of matter in contrast to far less students in the control group who studied 'Into the Matter' (Margel et al. 2001).

Unfortunately, the teachers in our sample lacked the appropriate background and experience relevant to that unit, and consequently did not feel comfortable using it. Instead, during the time of the study our teachers were using the popular unit 'Into the Matter' (Dori 1989). This unit provides multiple phenomena for each scientific idea and opportunities for students to practice the ideas they had learned. However, it rarely guides students' thinking about their experiences and, most importantly, it does not attempt to address the well-documented students' difficulties regarding particles (Shauli 2002, Unpublished MSc thesis).

Our preliminary classroom observations indicated that teachers differed greatly in the way that they implemented the unit 'Into the Matter' probably due to the lack of explicitness of the unit. To address this issue, a chapter from 'Matter and Molecules', a research-based unit developed in Michigan State University (Berkheimer et al. 1988) was translated into Hebrew and was used to replace the equivalent chapter from 'Into the Matter'. Throughout the unit students are asked to explain phenomena and predict new phenomena. In each explanation, students are prompted to refer to the macroscopic level (substances) and the microscopic level (particles). It had been shown that this approach helped students as young as 6th graders develop understanding of atoms and molecules (Lee et al. 1993).

The specific chapter from that unit was selected based on its emphasis on molecular motion and thermal expansion, which corresponded well to the concepts best depicted by the computerized simulation. 'Matter and Molecules' is very prescriptive in nature and consequently, it indeed helped to minimize the differences among teachers in instruction. A sample activity from 'Matter and Molecules' is included in Appendix A.

Table 1 Distribution of the students among schools and groups

Teacher	School	Experimental group	Control group
Teacher 1	A	$n = 26$	$n = 18$
Teacher 2	B	$n = 21$	$n = 20$
Teacher 3	B	$n = 24$	$n = 24$

Research Sample

The subjects of this study were three teachers and 133 seventh grade students at two middle schools located in the northern part of Israel. Classes were randomly selected as control classes ($n = 62$) and experimental classes ($n = 71$). Only students that responded to the pre-test and the post-test were included in the study. Each teacher taught one experimental and one control group. Table 1 shows the distribution of students between the two schools.

Research Design

The sequence of activities consisted of the following:

(a) The first chapters of the unit 'Into the Matter' were taught for 30 class periods. These chapters presented concepts such as matter, properties of matter, mass, volume, and phases of matter. In addition, the idea that matter is made up of small particles was introduced.
(b) A pre-test questionnaire was administered.
(c) The chapter, 'Heating and Cooling, Expansion and Contraction' from the 'Matter and Molecules' curriculum was taught for seven class periods to the control and experimental groups. The students in the experimental classes received, in addition, three class periods using the computerized simulation, 'A Journey to the World of Particles' (Milgrom et al. 1997).
(d) A post-test questionnaire was administered.
(e) Five students from the experimental group and five students from the control group were interviewed.

Curricular Components

These included (a) the chapter 'Heating and Cooling, Expansion and Contraction' from 'Matter and Molecules', (b) the software simulation 'A Journey to the World of Particles', and (c) interactive software that compares the simulation to particles (Comparison software).

(a) 'Heating and Cooling, Expansion and Contraction': The development of 'Matter and Molecules' involved two cycles of research and development. It led to significant improvement in student learning although some difficulties remained (Lee et al. 1993). This unit takes account of students' prior knowledge, provides a wide variety of macroscopic experiences accompanied by molecular explanations, and systematically guides student interpretation on their experiences. Nonetheless, it does not include dynamic representations such as animation or computer simulations to illustrate the different motions of solid, liquid, and gas molecules (detailed evaluation of the instructional strategies in 'Matter and Molecules' according to AAAS' Project 2061 criteria can be found in http://www.project2061.org/tools/textbook/mgsci/Mat_Mol/MMOL_ps.htm). An example of an activity from the unit is provided in Appendix A.

(b) Computerized simulation: 'A Journey to the World of Particles' consists of interactive software that was developed at the Hebrew University in Jerusalem. It presents 'particles' in the three phases of matter, and shows their constant motion and the interaction among them. Students are able to observe and track an individual particle in a variety of conditions (temperature, pressure, etc). In addition, students can modify parameters such as temperature, pressure, volume, or the number of particles and observe the consequences of doing so. Students can make predictions and then observe what happens to the particles during diffusion, thermal expansion and contraction. Using the simulation, the teachers can demonstrate various phenomena and provide (or ask students to provide) microscopic explanations. As with all other simulations, 'A Journey to the World of Particles' has some limitations; it represents reality well in some aspects and not very well in others. For example, the particles in the simulation are about 1 cm each and the spaces between them are relatively small (in the gaseous phase) and large (in the liquid phase). All particles in the simulation are round and seem identical, regardless of the substance they construct. In addition, particles of all substances appear as individual atoms and never as molecules. Of the 23 activities included in this software, the students in our study were involved in the three activities that were focused on the behaviour of particles in the three phases of matter during temperature changes. Since 'Matter and Molecules' and 'Into the Matter' included mostly diagrams of molecules, the only dynamic representation of molecular motion took place during the computerized simulation. These three activities covered three class periods.

Upon observations, we noticed that the three teachers in our study did not differ greatly in the way they implemented the computerized simulation. The three lessons that were selected were structured and this contributed to minimizing the differences. Each of the three lessons is accompanied by computerized worksheets that include questions that guide students' observations. Occasionally, students get feedback on their responses (see Fig. 1).

(c) Comparison software: Middle and high school students tend to see models as an actual copy of reality and not as conceptual representations (Grosslight et al. 1991). Involving students in considering which aspects of the actual phenomena are represented by the model and which are not may address this potential pitfall (Thagard 1992; Harrison and Treagust 1996; Gilbert et al. 1998; Justi and Gilbert 2002; Stern and Roseman 2004). With this in mind, a comparison software was developed and used in our study. This interactive software attended to the differences between particles and their representation, in terms of size, velocity, shape, number of particles in a cubic centimetre, and dimensions (the simulation is two-dimensional whereas particles are not).

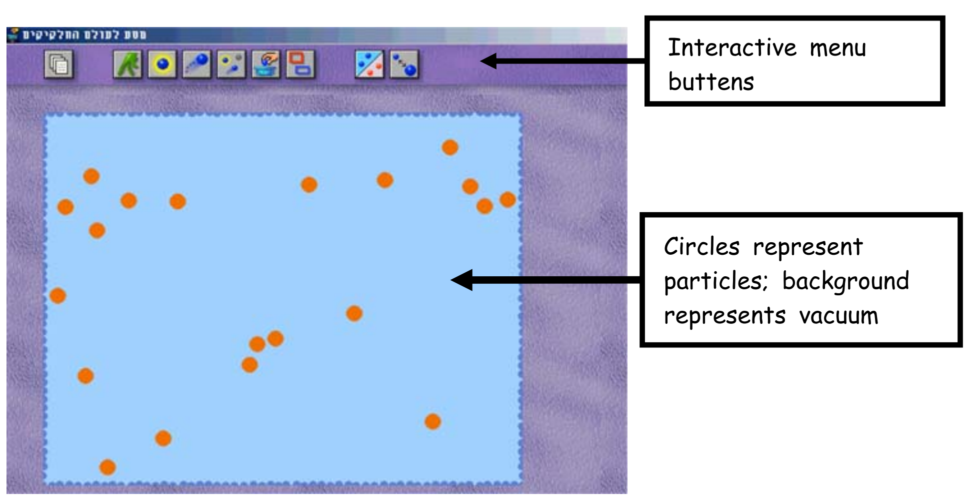

Fig. 1 A sample screen from the computerized simulation, 'A Journey to the World of Particles'

Sources of Data

Students responded to written diagnostic questionnaires at the beginning and three weeks later, at the end of the instruction. Examples of questions from the pre- and post-questionnaires are included in Appendix B. The questions, mostly open ended, were adapted or modified from Novick and Nussbaum (1978), Berkheimer et al. (1988), and US curriculum materials (identified by Stern and Ahlgren 2002). The pre-test included four questions. Two aimed at the pre-requisite ideas that matter is particulate (rather than continuous) (question 4, Appendix B) and that particles are in constant motion (question 2, Appendix B). The other two questions assessed students' initial ideas regarding the effect of temperature on particles (questions 1 and 3, Appendix B).

The post-test included six questions. Students were asked to summarize the main ideas that they learned (question 6, Appendix B) and to predict and explain different phenomena related to thermal expansion. In addition, one question (question 5, Appendix B) was included to probe whether, due to the simulation's limitations, the students maintained naïve ideas that specifically resulted from these limitations: Particles of different substances appear identical in the simulation, and therefore the students were asked whether they thought this is true and why. The post-test included both familiar contexts (for example, explanation of smell) to judge student comprehension of what was taught, while other questions included novel contexts (for example, explanation of phase change of water) to judge transfer of what has been learned. The questions that were included in the pre- and post-tests were different because there was concern that the three-week period between the questionnaires was too short, and students may have remembered the pre-test questions and may have approached their teachers for the answers. To avoid allowing the students to answer correctly by repeating a memorized answer without true comprehension, different questions were included in the post-test. Nevertheless, the questions in the pre- and post-tests, while using different task contexts, addressed the same key science ideas. For example, students were asked to explain thermal expansion of mercury in a non-digital thermometer in the pre-test whereas in the post-test they were asked to explain thermal contraction of a balloon filled with water. Also, in both tests students were asked to explain the effect of temperature on smell; however, in the pre-test the example used was that of an apple pie whereas in the post-test the example was that of perfume.

Responses were scored according to scoring rubrics that were first suggested by the researchers and later finalized based on students' actual responses. Four experienced middle school teachers reviewed the questions included in the pre- and post-test and later verified the scorings. An example of a scoring rubric is included in the following section. The results were processed by SPSS using standard statistical methods.

Semi-structured personal interviews were designed to probe beyond students' initial responses. The interviews lasted approximately 15 min. A total of 10 students—five from the experimental group and five from the control group—were interviewed at the end of instruction. The interviewees were chosen according to their score and responses to the post-test. The questionnaires that received the lowest scores typically included unanswered questions or responses that indicated clearly that the student did not understand the kinetic molecular theory. Therefore, it was felt that more could be learned about student thinking if we were to probe the ideas of the students that demonstrated partial understanding or better. As a result, only students who scored above 60 in the post-test were chosen for the interview. During the first part of the interview, the students were shown two simple phenomena (e.g. a soap bubble stretched across the open end of a test tube before and after heating the test tube) and were asked to draw the particles and explain the phenomenon in molecular terms. During the second part of the interview, students were asked to clarify their written explanations.

Results

Scoring

Each of the questions included in the pre- and post-test was scored according to a pre-determined scoring rubric. In designing the rubrics, the elements that represented a satisfactory response were identified. For example, a satisfactory explanation of the way a non-digital thermometer works (question 1, pre-test; Appendix B), included the following five elements:

1. The liquid in the thermometer is made up of particles;
2. Increased temperature means greater particle motion;
3. Increased particle motion results in more molecular collisions;
4. As a result of the increasing collisions, the particles are more far apart and the liquid expands;
5. The scale on the thermometer corresponds to the expansion and contraction of the liquid.

The scoring considered the total number of elements that were included in each response. For instance, the thermometer question granted 5 points for the inclusion of each of the five elements, totalling a maximum score of 25 points. Responses were not penalized for the inclusion of naïve (incorrect) ideas. As an illustration, the following response received 7 points:

Table 2 Average scores of pre- and post-tests according to group and teacher (Maximal score is 100)

Group	Time	Teacher 1		Teacher 2		Teacher 3		Difference
		M	SD	M	SD	M	SD	$\chi^2_{(2)}$
Experimental $N = 71$		$n = 26$		$n = 21$		$n = 24$		
	Pre	30.12	14.75	28.81	17.83	28.91	19.00	0.16
	Post	55.81	23.67	66.52	17.99	54.58	27.09	2.71
Control $N = 62$		$n = 18$		$n = 20$		$n = 24$		
	Pre	31.61	14.46	23.95	16.03	24.38	15.25	1.73
	Post	47.17	19.67	37.00	15.71	33.50	15.23	5.65

Table 3 Average scores of pre- and post-tests according to group (Maximal score is 100)

Time of measurement	Experimental group $N = 71$		Control group $N = 62$	
	M	SD	M	SD
Pre	29.32	16.96	26.34	15.42
Post	58.56	23.69	38.60	17.46

> Mercury rises in response to heat. Since we know how many degrees are there in 1 centimetre, we can measure the temperature in the room or in our body

This response does not refer to particles but indicates macroscopic understanding of the phenomenon: Five points were given for demonstrating an understanding of the correspondence between the scale on the thermometer and the height of the liquid (element #5). Additional 2 points were granted for the partial (macroscopic) understanding that the heating causes the mercury to expand.

Pre- and post-tests scores

The three teachers each taught one experimental class and one control class. Thus, the experimental group and the control group consisted of three classes each (see Table 1). The average scores of the pre-tests and post-tests according to group and teacher are presented in Table 2.

The large standard deviations indicate that the populations were not normally distributed therefore, the non-parametric Kruskal–Wallis test was used instead of the standard analysis of variance (ANOVA). There were no significant differences found between the pre-test scores of the three experimental classes and between the three control classes. This allowed us to pool the results from the three experimental classes into one experimental group and the three control classes into one control group. The resulting distribution of the pooled groups was close to normal and ANOVA analysis was used to analyse the data. Table 3 presents the average scores of the two groups.

The students in the experimental and control groups all improved their understanding of the kinetic molecular theory. The improvement was more substantial in the experimental group than in the control group: Whereas the students in the experimental group improved their scores by 29 points on average, students in the control group gained only 12 points. Furthermore, the students in the experimental group scored significantly higher in the post-tests than the students in the control group. The pre-tests scores of students in both groups were found to be significantly different than the post-test scores using repeated measures ANOVA (F (1,131) = 95.84; $p < 0.001$), indicating that both groups improved their scores. Also, statistically significant variance was found for groups (F (1,131) = 21.33; $p < 0.001$), indicating that the average post-test scores of the experimental group was higher than that of the control group. Most importantly, the interaction between time of measurement and group (F (1,131) = 16.05; $p < 0.001$) showed significant variance thereby showing that the improvement (or net gain) of the experimental group was significantly higher than the improvement of the control group. Overall, statistically significant variance was not found between the pre-test scores of the control and experimental groups. However, both groups significantly improved their scores, though the improvement in the experimental group was significantly higher.

A more detailed analysis set out to examine whether the experimental group's students scored higher on specific questions or on all the questions in the post-test. A comparison was done between the scores of the experimental and the control groups for each of the questions in the post-test. The one-way ANOVA analysis is presented in Table 4.

The results indicate that the average scores of the students in the experimental group were consistently higher than those of the students in the control group (across all questions). With the exception of one question (question 3), these differences were statistically significant. Question 3 focused on the molecular explanation of condensation. Given that phase changes in general and condensation in particular were not explicitly addressed during instruction, the low scores on that question (among both groups) were reasonable.

Table 4 Average scores of post-tests according to group and question

Question	Issue addressed by the question	Maximal score	Experimental group		Control group		*F* value
			M	SD	M	SD	
1	Smell	16	11.61	6.24	6.5	4.71	27.75***
2	Melting	16	9.87	6.14	6.09	5.55	13.96***
3	Condensation	16	7.18	7.43	6.34	6.21	0.501
4	Thermal expansion	20	14.58	6.18	11.69	5.15	8.61**
5	Difference between the simulation and reality	18	10.29	5.69	6.89	5.32	12.79***
6	Main ideas in the unit	14	7.96	4.42	4.40	4.12	14.89***

** $p < 0.01$; *** $p < 0.001$

Table 5 Average scores of pre- and post-test according to group and gender (Maximal score is 100)

Time of testing	Experimental group $N = 71$				Control group $N = 62$			
	Boys $N = 28$		Girls $N = 43$		Boys $N = 27$		Girls $N = 35$	
	M	SD	M	SD	M	SD	M	SD
Pre	25.12	17.21	32.00	16.44	27.56	16.82	25.40	14.42
Post	57.89	24.15	59.00	23.66	39.52	17.32	37.89	17.77

Question 5, as noted above, was included to probe whether students in the experimental group maintained naïve ideas due to the limitations of the simulation. Although the experimental group was not expected to score higher on question 5, our analysis shows that students in the experimental group scored significantly higher than those in the control group on that particular question.

The students' scores according to group and gender are presented in Table 5. The differences between boys and girls using repeated measures ANOVA were not statistically significant.

In conclusion, our findings demonstrate the following:

1. Students in both groups significantly improved their understanding of the kinetic molecular theory.
2. This improvement was significantly higher in the experimental group than in the control group. The experimental group's students scored higher on all questions in the post-test.
3. There were no significant gender related differences found.

These results suggest that the use of the computerized simulation improved the understanding of the kinetic molecular theory among the 7th graders, as was evidenced by their improved ability to apply this abstract idea to respond to the post-test questions.

Nonetheless, while both groups of students improved their understanding of the kinetic molecular theory, the overall achievements were very low. This finding will be discussed below.

Interview Analysis

During the interviews, the students received the opportunity to clarify and elaborate on their own written responses and to apply the kinetic molecular theory in additional contexts. Generally, the ideas expressed by the students during the interviews concurred with the ideas that they expressed in writing. For example, one of the students from the control group predicted that an inflated balloon that is cooled would contract (question #3, post-test). The following explanation was provided in writing:

> The balloon will get cooler and eventually shrink because the particles are getting smaller

During the interview, the same student was shown a soap bubble stretched across a test tube before and after heating the test tube. The student was asked to explain (at the molecular level) the expansion of the heated soap bubble. The explanation was similar to his written response:

S: 'The air inside the test tube is made up of particles... When you heated it, the particles of air rose up and pushed the soap bubble'
I: 'Why do you think the particles rose up when the temperature increased?'
S: 'Because...[pause] they became bigger'
I: 'So when the temperature rose, the particles inside became bigger?'
S: 'Yes. The particles got bigger and didn't have enough space. This is why they rose up.'

While the interviewees from the experimental group and those from the control group attained similar scores, there were more students from the control group who expressed the naïve idea that particles are still and start to move only upon heating. This difference might be attributed to the computerized simulation—which explicitly shows that particles are *constantly* moving. However, we did not interview an adequate number of students to arrive to a definite conclusion.

Conclusions

The kinetic molecular theory has been included in middle school curricula worldwide for many years; nonetheless, numerous studies have demonstrated that even following relevant instruction, it is one of the most difficult scientific theories to accept. Some research suggests that representations—especially dynamic representations—can help make these abstract ideas intelligible for students.

A systematic evaluation of middle school curriculum materials in the USA revealed that most of the currently available materials are inadequate to foster meaningful learning (Kesidou and Roseman 2002; Stern and Roseman 2004). For instance, these materials do not take account of students' prior knowledge and do not provide adequate, comprehensible representations. Representations in textbooks are often inaccurate, inadequate in number, or incomprehensible. They typically consist of illustrations and diagrams and therefore fail to represent the dynamic aspects of the kinetic molecular theory. Furthermore, in depth analysis of these illustrations reveals that they are often misleading and might even reinforce students' naïve ideas (Kesidou and Roseman 2002; Johnson 1998a). An analysis of the representations included in two Israeli middle school materials—'Into the Matter' (Dori 1989) and 'Vacuum and Particles' (Nussbaum 1996)—shows somewhat similar findings. These representations—mostly illustrations—are inadequate in number and are typically not accompanied by explanations or questions that could help guide students' interpretations of the illustrations (Shauli 2002, Unpublished MSc thesis). To address this issue, the developers of 'Vacuum and Particles' explicitly recommend using the computerized simulation that was used in this study to enhance understanding.

In the study described in this paper, students who were provided with a molecular software simulation demonstrated significantly better understanding of the particulate model of matter than students who were not provided with this simulation. These results suggest that the computerized simulation improved the understanding of the particulate nature of matter among our 7th graders. These findings are in accord with previous research that showed that dynamic molecular animations, rather than static illustrations, could be a powerful tool in promoting the learning of chemistry and physics ideas (Wu et al. 2001; Dori et al. 2003; Dori and Belcher 2005).

Whereas this may seem encouraging, the achievements of both groups were very low. The average post-test scores were approximately 58 for the experimental group and 39 for the control group. In order to learn whether long-term learning had taken place, the post-test questionnaire was administered a second time, a year post instruction. There were only 41 students available at the latter date (15 from the control group and 26 from the experimental group). The teachers reported that during the year that had gone by, the students from the experimental group explicitly referred to the computerized simulation several times, suggesting that these students may have retained the kinetic molecular theory ideas better than the control group. Nonetheless, the average scores were low in both groups and interestingly, the average was somewhat higher among the control group (44 among the students from the experimental group and 49 among those from the control group). It is our belief that students in the experimental group may have indeed remembered the uncommon experience of working with the interactive software but that this experience did not confer better learning in the long run.

Since the computerized simulation used in our study was not intended as a stand-alone curriculum but rather as supplementary material, it is unlikely that this or any other supplementary software alone will be sufficient to promote meaningful learning. The computerized simulation is but one instructional strategy and many studies done over the past few decades clearly show that learning of abstract ideas in science requires the use of sound and diverse instructional strategies. Among these are the role of prior knowledge, the use of relevant phenomena for making scientific ideas plausible, conditions that facilitate the transfer of knowledge, and the importance of guiding students' interpretation of their learning experiences (e.g. Lee et al. 1993; Smith et al. 1993; NRC 2000; Kesidou and Roseman 2002). 'Into the Matter', a popular curricular unit, was used in our study during the majority of the curricular time devoted to the kinetic molecular theory. Unfortunately, this unit does not guide students' thinking about their experiences nor does it attempt to address students' prior knowledge regarding particles. Whereas a chapter from 'Matter and Molecules'—a research-based unit that prescribes sound pedagogical strategies was used in our study—teachers were not aware of the rationale of these strategies and only one chapter from this material was used throughout instruction. We therefore believe that the low achievements in our study result primarily from the lack of sound teaching strategies and not from the learners' abilities.

Admittedly, some disagreements among science educators exist with respect to the appropriate grade placement for teaching the kinetic molecular theory (Stern, 2003). One may argue that using the same curricular components with older students may result in better learning because of their higher cognitive developmental level. However, we were unable to do so, since the kinetic molecular theory is taught at the 7th grade level in the majority of schools in Israel.

Clearly, teachers play a key role in mediating even the best available curriculum and in modifying the curriculum to meet their particular students' needs. The three teachers in our sample lacked the appropriate background relevant for the effective use of a conceptual change-based unit that is available in Israel. Consequently they did not feel comfortable using it. Most importantly, based on their long experience with their own curriculum and with middle school students, these teachers were confident that only 'fine tuning' was necessary to improve students' learning. Moreover, the teachers were disappointed to discover that their students did not demonstrate better understanding of the particulate nature of matter despite the fact that as much as three quarters of the school year were devoted to this topic. The questions that were used in the pre and post-test asked the students to apply the kinetic molecular theory to predict and explain phenomena. Such questions are rare in today's classroom practice and this may lead teachers to overestimate what their students actually know (Stern and Ahlgren 2002). While much research is yet needed in order to identify effective ways to promote a need for change among teachers, communicating with teachers the results of studies such as the current study may be a first step in this direction.

Appendix A: Sample Activity from 'Matter and Molecules'

Try doing this experiment:

Fill two cups half full with water, one with hot water and one with cold water. Both cups should have the same amount of water.

Fill the syringe on your table with 15 ml of raspberry syrup. Inject the syrup to the bottom of the cold water cup. Be careful not to mix the syrup with the water. Repeat these steps with the hot water cup. Wait and watch for about 10 min.

While you are waiting try making some predictions:

1. How do you think what happens in the two cups will be the same?

____

2. How do you think what happens in the two cups will be different?

____

3. Explain your predictions.

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____

Appendix continued

Look at the two cups after 10 min and compare them. Were your predictions correct? Try describing and explaining what you see:

4. How are the two cups the same?

____

5. How are the two cups different?

____

6. Try to explain what happened to in the two cups. In your explanation, try to describe what happened to the <u>substances</u> (the water and the syrup) and what happened to the <u>particles</u>.

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An important difference between the two cups is that the water turned completely red.

7. In which cup did the syrup spread faster?

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8. What was the difference between the two cups that would make the syrup spread faster or slower? Explain your answer.

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Appendix B: Examples from the Written Questionnaires

Pre-test:

1. Explain how a non-digital thermometer (that contains mercury or some other liquid) works.

2. Explain how can you smell from a distant room, an apple pie while it is baking in the kitchen.

3. Explain why can you smell an apple pie as it is being taken out of the oven but you can't smell an apple pie that had just been taken out of the refrigerator.

4. The flask in the illustration contains air (The upper lid of the flask is sealed so that no air can escape or enter the flask from the upper lid). A pump, connected to the side of the flask, adds some air to the flask. Imagine that you could see the air in the flask. Draw the air in the flask before and after some air was added to it.

Post-test:

1. When garbage collectors go on strike, why is it that the smell from the trash is more troublesome in the summer than it is in the winter?

2. Imagine that you are a dwarf riding on <u>one</u> particle of an ice cube that has been removed from the freezer on a hot day. Explain what is happening to you.

3. A balloon that had been filled with water vapour is cooled until the vapour becomes liquid. What do you suppose will happen to the balloon? Explain why you think so. (Talk both about the substance and the particles.)

5. a. In what ways are particles of different substances (for example, hydrogen and oxygen) alike? In what ways are they different?

6. Describe how you would explain the main ideas of the unit to a student from a different school.

References

American Association for the Advancement of Science [AAAS] (1993) Benchmarks for science literacy. Oxford University Press, New York

Barnea N (2000) Teaching and learning about chemistry and modeling with computer managed modeling system. In: Gilbert JK, Boutler CJ (eds) Exploring models in science education. Kluwer Academic Publishing, Dordrecht, pp 307–323

Barnea N, Dori YJ (1999) High-school chemistry students' performance and gender differences in a computerized molecular modeling learning environment. J Sci Educ Technol 8:257–271

Barnea N, Dori YJ (2000) Computerized molecular modeling – the new technology for enhancing model perception among chemistry educators and learners. Chemistry Education Research and Practice in Europe, New educational technologies (NET) 1(1): 109–120. http://www.uoi.gr/conf_sem/cerapie/pdf/16barneaf.pdf

Ben-Zvi R, Eylon BS, Silberstein J (1986) Is an atom of copper malleable? J Chem Educ 63:64–66

Berkheimer G, Anderson C, Blakeslee T (1988) Matter and molecules. Michigan State University, Institute for Research on Teaching, East Lansing. Retrieved January 14, 2001, from http://ed-web3.educ.msu.edu/reports/matter-molecules/default.htm

Brook A, Briggs H, Driver R (1984) Aspects of secondary students' understanding of the particulate nature of matter. University of Leeds, Centre for Studies in Science and Mathematics Education, Leeds

Champagne A, Gunstone R, Klopfer L (1985) Instructional consequences of students' knowledge about physical phenomena. In: West L, Pines AL (eds) Cognitive structure and conceptual change. Academic Press, Inc., pp 61–90

Clement J (2000) Model based learning as a key research area for science education. Int J Sci Educ 22:1041–1053

Dori E (1989) Into the matter. Centre of science education. The Hebrew University of Jerusalem (In Hebrew)

Dori YJ, Belcher JW (2005) How does technology-enabled active learning affect students' understanding of scientific concepts? J Learn Sci 14(2):243–279

Dori YJ, Barak M, Adir N (2003) A Web-based chemistry course as a means to foster freshmen learning. J Chem Educ 80(9):1084–1092

Dori YJ, Hult E, Breslow L, Belcher JW (2007) How much have they retained? Making unseen concepts seen in a freshman electromagnetism course at MIT. J Sci Educ Technol 16(4):299–323

Driver R, Squires A, Rushworth P, Wood-Robinson V (1994) Making sense of secondary science. Research into children's ideas. Routledge, London

Feltovich PJ, Spiro RJ, Coulson RL, Anderson DK (1989) Multiple analogies for complex concepts: antidotes for analogy-induced misconception in advanced knowledge acquisition. In: Vosniadou S, Ortony A (eds) Similarity and analogical reasoning. Cambridge University Press, Cambridge, pp 498–531

Fensham P (1994) Beginning to teach chemistry. In: Fensham P, Gunstone R, White R (eds) The content of science: a constructivist approach to its teaching and learning. Falmer, London, pp 14–28

Feynman R (1977) The Feynman lectures on physics, vol 1. Addison Wesley, Reading

Gilbert JK, Boulter C, Rutherford M (1998) Models in explanations, part 1: horses for courses? Int J Sci Educ 20:83–97

Grosslight L, Unger C, Jay E (1991) Understanding models and their use in science: conceptions of middle and high school students and experts. J Res Sci Teach 28:799–822

Harrison AG, Treagust DF (1996) Secondary students' mental models of atoms and molecules: implications for teaching chemistry. Sci Educ 80:509–534

Harrison AG, Treagust DF (2000) Learning about atoms, molecules, and chemical bonds: a case study of multiple-model use in grade 11 chemistry. Sci Educ 84:352–381

Harwood WS, McMahon MM (1997) Effects of integrated video media on student achievement and attitudes in high school chemistry. J Res Sci Teach 34:617–631

Israeli Ministry of Education (1996) Science and technology curriculum for Junior High Schools. Jerusalem, Israel (In Hebrew)

Johnson P (1998a) Progression in children's understanding of a 'basic' particle theory: a longitudinal study. Int J Sci Educ 20:393–412

Johnson P (1998b) Children's understanding of changes of state involving the gas state, part 2: evaporation and condensation below boiling point. Int J Sci Educ 20:695–709

Johnston K, Driver R (1989) A case study of teaching and learning about particle theory. University of Leeds, Centre for Studies in Science and Mathematics Education, Leeds, UK

Justi RS, Gilbert JK (2002) Modelling, teachers' views on the nature of modelling, and implications for the education of modellers. Int J Sci Educ 24:369–387

Kesidou S, Roseman JE (2002) How well do middle school science programs measure up? Findings from Project 2061's curriculum review. J Res Sci Teach 39:522–549

Lee O, Eichinger DC, Anderson CW, Berkheimer GD, Blakeslee TD (1993) Changing middle school students' conceptions of matter and molecules. J Res Sci Teach 30:249–270

Margel H, Eylon B, Scherz Z (2001) A longitudinal study of Junior High School students' perceptions of the particulate nature of matter. In: Science and technology education: preparing future citizens. Proceedings of the IOSTE symposium in Southern Europe (1st, Paralimni, Cyprus, April 29–May 2, 2001)

Mevarech Z, Liberman G (2001) Gender gaps in mathematics and science: facts, reasons, and actions. A report prepared by the chief scientist in the Ministry of Education (In Hebrew)

Milgrom I, Tassa R, Ben Atar O, Shani M (1997) A journey to the world of particles. Centre of science education. The Hebrew University of Jerusalem (In Hebrew)

National Research Council (2000) How people learn: brain, mind, experience, and school. National Academy Press, Washington

Noh T, Scharmann LC (1997) Instructional influence of a molecular-level pictorial presentation of matter on students' conceptions and problem-solving ability. J Res Sci Teach 34:199–217

Novick S, Nussbaum J (1978) Junior high school pupils' understanding of the particulate nature of matter: an interview study. Sci Educ 62:273–281

Nussbaum J (1985) The particulate nature of matter in the gaseous phase. In: Driver R, Guesne E, Tiberghien A (eds) Children's ideas in science. Open University Press, Milton Keynes, pp 124–144

Nussbaum J (1996) The structure of matter: vacuum and particles. Weizmann Institute of Science, Rehovot (In Hebrew)

Osborne RJ, Cosgrove MM (1983) Children's conceptions of the changes of state of water. J Res Sci Teach 20:825–838

Smith EL, Blakeslee T, Anderson CW (1993) Teaching strategies associated with conceptual change learning in science. J Res Sci Teach 30:111–126

Stavy R (1990) Children's conception of changes in the state of matter: from liquid (or solid) to gas. J Res Sci Teach 27:247–266

Stern L (2003) Analysis of students' assessments in curriculum materials: fidelity to national standards. J Res Sci Teach 40:827–834

Stern L, Ahlgren A (2002) Analysis of students' assessments in middle school curriculum materials: aiming precisely at benchmarks and standards. J Res Sci Teach 39:889–910

Stern L, Roseman J (2004) Can middle-school science textbooks help students learn important ideas? Findings from Project 2061' curriculum evaluation study: life science. J Res Sci Teach 41:538–568

Strike K, Posner GS (1985) A conceptual change view of learning and understanding. In: West L, Pines AL (eds) Cognitive structure and conceptual change. Academic Press, Inc., New York, pp 211–231

Thagard P (1992) Analogy, explanation, and education. J Res Sci Teach 29(6):537–544

Treagust D, Chittleborough G, Mamiala T (2002) Students' understanding of the role of scientific models in learning science. Int J Sci Educ 24:357–368

Wu HK, Krajcik JS, Soloway E (2001) Promoting understanding of chemical representations: students' use of a visualization tool in the classroom. J Res Sci Teach 38:821–842