The Effect of Classroom Practice on Students Understanding of Models

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Abstract

Science instruction focused around modeling can help learners develop deep understanding of subject matter and the nature of science. Despite its importance, students typically do not develop an understanding of modeling, and many teachers lack strategies for supporting their students in the practice. This research examines a teacher and her students' developing an understanding of models and modeling by taking part in an 8-weeks 6^{th} grade chemistry unit that focuses on the particle nature of matter, models and modeling. The unit was developed as part of IQWST: a middle school inquiry-based curriculum development project. The curriculum closely integrates content learning goals with scientific practices. Modeling learning goals as well as meta-knowledge of models and modeling were highly specified. To assess the effect of teacher practice and the change in students' meta-knowledge of models and modeling, various types of data were collected: Pre and post students and teacher interviews, videotapes of lessons, students artifacts, and open-ended pre-post assessment items that involved the use of models. Preliminary findings suggests that students improve their modeling practices and understanding of the meta-knowledge associated with the practice. Links can be drawn between students' improvement and instruction. Some changes in the teachers' perception of modeling as a classroom practice are also observed.

Introduction

The research presented in the paper examines a teacher and her students' developing understanding of models and modeling by taking part in an 8-weeks 6^{th} grade chemistry unit that focuses on the particle nature of matter, models and modeling. The curriculum closely integrates content learning goals, with scientific practices. Modeling learning goals as well as meta-knowledge of models and modeling were highly specified. We were mostly interested in finding links between specific classroom practices and students' improvement in the practice and in understanding modeling meta-knowledge (MMK). We were also interested in learning about the teachers' conceptions of modeling, as revealed in pre post interviews and in her actual teaching.

The practice of scientific modeling is central both to science and science learning. Scientists continually build and refine explanatory models (Stewart, Cartier, & Passmore, 2005). A scientific model is an abstract and simplified set of rules, representations and relationships that embody *portions* of scientific theories and principles, and that enable users to generate explanations and predictions about natural phenomena. Models may be broadly classified into two types (Gilbert & Boulter, 1998): Conceptual and physical models. Internal conceptual models refer to an individual's mental representation of the explanatory mechanism underlying a natural phenomenon. Physical models can be thought of as the external representation of a conceptual model. For example, to represent particles in motion, one could draw ball-and-stick diagrams with arrows, assemble gumdrop and toothpick models to shake in a plastic bag, or develop an animation using moving dots to represent particles in motion. These are physical representations of an individuals' conceptual model.

Given the prominence of scientific modeling to the science community, scientific modeling should also be prominent in science education in schools. Research indicates that science instruction focused around modeling can help learners develop deep understanding of subject matter and the nature of science (Gilbert & Boulter, 1998; Schwarz & White, 2005). Despite its importance, studies shows that students, even at university level, typically do not develop an understanding of modeling (Grosslight et al. 1991; Carey & Smith, 1993; Gilbert 1997; Stephens et al., 1999 Schwarz.& White, 2005). Some recent research suggest that curricular sequences involving explicit teaching of modeling, help students understanding of scientific models. Saari (2003) showed a change in 7th grade students' understanding of models from an everyday view to a more scientific view, after a 3-weeks intervention aimed at teaching students the general ideas of modeling by teaching them how to use models in learning the states of matter. Mikelskis-Seifert & Leisner (2005) showed that focusing on modeling was effective both for developing understanding of content (particle conception) as well as understanding of models. Long-term tests suggested that the effect was stable. In the NRC report "Taking Science to School: Learning and Teaching Science in Grades K-8" (NRC, 2007) the authors based their recommendations to teach science as practice on accumulating evidence that young students are actually capable in conducting complex scientific inquiry practices.

The use of models in science teaching usually focuses on the content of the models being taught and learned, while the nature of the models themselves is not always explicitly discussed. Students are usually not actively involved in the practice of modeling (Van Driel & Verloop, 1999, Harrison and Treagust 2000). While some commercially available materials ask students to use models, few directly address the nature of models, support teachers' use of models, nor support the students' use of models. Thus there is a need to develop materials that support this, and a need to learn how best to support both students and teachers.

The common hypothesis is that engaging in the practice of modeling (using, constructing, revising, and communicating about models) not only supports the understanding of content knowledge but also supports the development of some understanding of conceptual or epistemological knowledge that underlies the practice of modeling, we call such understanding meta-modeling knowledge (MMK). MMK includes understanding the purpose of scientific models, their nature, and the criteria for evaluating them (Schwarz & White, 2005). We clarify and elaborate on these ideas in the next section. Supporting modeling and the understanding of modeling meta-knowledge (MMK) needs to be done systematically, over time, and not as single disconnected experience. Different types of models should be used simultaneously and their strengths and limitations should be discussed (Harrison and Treagust 1996; Van Driel and Verloop, 1999). Also, it should be taught in a wide variety of contexts (Harrison and Treagust 2000; NRC, 2007).

The teacher has a key role in helping students make sense of this kind of practice and abstract ideas associated with it. Justi & Gilbert (2003) claim that there are some central ideas in modeling that cannot be figured out without the help of a teacher. They define the specific knowledge teachers must have in order to support their students in practicing modeling: (1) comprehensive understanding of curricular models they have to teach; (2) understanding of what a model is per se; (3) when, how and why to introduce modeling meta-knowledge perspectives; and (4) an ability to develop good teaching models.

However, research indicates that many teachers have partial and even poor understanding of modeling, that they lack strategies for supporting their students in the practice, and ignore important uses of models such as promote thinking ('models as thinking tools' and making predictions (Justi & Gilbert, 2002; Harrison, 2001; Van Driel & Verloop, 2002).

Context of study: modeling in IQWST project

The Investigating and Questioning our World through Science and Technology (IQWST) is an inquiry-based curriculum development project spanning 6th, 7th and 8th grade. The curriculum closely integrates content learning goals, with the following scientific practices: modeling, design investigations, data gathering, organization and analysis, and constructing evidence-based explanations (Krajcik, McNeill, Rieser, 2007). This research focuses on one of the scientific practices: modeling. Following are the modeling learning goals for the IQWST units (Rogat, Schwarz, & Reiser, 2006):

- *Constructing models:* Students will construct models consistent with prior evidence to explain or predict phenomena.
- *Using models:* Students will use models to explain or predict other related phenomena.
- *Evaluating models:* Students will compare and evaluate the ability of different models to accurately represent and account for patterns in phenomena, and to predict new phenomena.
- *Revising models:* Students will revise models to increase their explanatory and predictive power (e.g., taking into account additional evidence or aspects of a phenomenon).
- *Communicating models*: Students will be involved not only in constructing models and "turning them in" to teachers, but will use models to communicate with, and to persuade their peers.

Modeling meta-knowledge (MMK)

Engaging in the practice of modeling involves to some degree the development of conceptual or epistemological knowledge that underlies the practice (i.e. purpose of scientific models, their nature, and criteria for evaluating models).

Purpose of models: Students should know that scientists construct models to explain or predict natural phenomena. Models are helpful in thinking about processes that are difficult or dangerous to observe or too abstract to easily understand. Students should also know that constructing and using models can help clarify and advance scientific understanding.

Nature of models: This learning goal has three aspects. First, students should know that a model is a simplified representation of a phenomenon in the real world. Related to this idea, students should know that models are not exact replicas of objects, events, or processes, and as such have characteristics not shared with what is represented. Second, students should know that different models may represent the same phenomenon and thus multiple model may exist to explain a given phenomena. Third, students should know that a range of types of models exist, including physical (e.g., a scale model of an airplane in a wind tunnel, used to investigate wing shapes); conceptual (e.g., molecules of a gas are analogous to tiny elastic balls bouncing off one another); and mathematical/computational (e.g., interacting predator and prey species in a computer simulation)..

Evaluation criteria for models: Students should know that models are based on previous evidence and theories. Models must be evaluated based on how consistent they are with evidence about relevant phenomena, and how consistent they are with other models and theories.

Revision of models: Students should know that models can be revised if they fail to explain or predict phenomena in the world accurately and consistently.

Acknowledging the difficulties teachers face regarding both content knowledge and inquiry practices, IQWST materials were designed to be educative for teachers by including teaching strategies, teaching alternatives, science background information for the teacher, common student conceptions, required prerequisite knowledge, and ideas for monitoring student understanding (Ball & Cohen, 1996; Davis & Krajcik, 2004). Educative features address both content knowledge and scientific practices. The curriculum designers specifically defined and outlined learning goals and learning progressions related to modeling, and underlying conceptual understanding of modeling within the context of the IQWST materials (Rogat, Schwarz, & Reiser, 2006).

How can I smell things from a distance?

This study focuses on the enactment of a 6th grade chemistry unit entitled "How can I smell things from a distance?" This 8-weeks, project-based unit helps students develop an understanding of the particle nature of matter – one of the big ideas of science – through experiencing and explaining a variety of phenomena. In order to contextualize chemistry concepts and scientific inquiry in students' everyday experiences, the unit focuses on the phenomenon of how they smell odors.

The driving question, "How can I smell things from a distance?" provides the anchoring context for all of the lessons, and is revisited throughout the unit (Krajcik & Blumenfeld, 2006). The driving question organizes and motivates activities throughout the unit by providing a real world context in which students can attach abstract ideas. The unit goals are to help students understand the particle nature of matter and emphasizes scientific modeling as an important practice for students.

The scientific principles students learn and the inquiry practices in which they engage are instrumental to understanding and answering the driving question. Students complete a number of investigations, each time revisiting the application to smelling odors. Each cycle helps learners delve deeper into the science content to understand the particle nature of matter. Grosslight et al. 1991 suggested that in the case of the modeling of unobservable objects (such as atoms and molecules), a higher level understanding of modeling needs to be obtained. Most students are unable to discover the abstract ideas for themselves, since they consider models as concrete copies. Therefore, throughout the "smell" unit, students experience various phenomena, construct models (physical models – through drawing and 3D manipulatives), and use them to explain their observations. Small groups and whole class discussions are utilized to help students discuss, critique, and revise their models. Students also use their models to make predictions. MMK is explicitly discussed and students are provided with opportunities to reflect and test their ideas regarding models.

The first learning set focuses on helping students understand that all matter is made of particles. Initially, students create models of how they think they can smell substances from a distance. Students create drawings along with written explanations (models) to demonstrate their ideas. Students learn that all matter has mass and volume. They observe the three states of matter and focus on the gaseous state. They create models of air (matter in the gaseous state), and use their models to explain characteristics of gases. Initially, students can have different types of models (continuous, mixed or particulate) (Merrit, Shwartz, Rogat & Krajcik, 2007), and should gradually acknowledge the particle model as the one that accounts for all phenomena studied in class since other alternative models eventually fail to account for all the phenomena they experienced. The main features of this model are: Substances are made of particles; in the gaseous state there is empty space between the particles, (the particles are not attached to each other); the particles are moving constantly. By the end of learning set 1, students should be able to explain that an odor is a substance in the gaseous state, and that it is made of particles that move in the empty spaces between other particles that make up air. Particles in the gaseous state move in linear paths, until they bounce off other particles, they move in all directions and some of those particles reach their noses. The particle model created in the first learning set emphasizes the similar features of all substances. In the last lesson of this learning set, students observe that two liquids, which appear to be the same, are distinguishable by the fact they turn indicator paper different colors. This serves as a transition to learning set 2 that focuses on why different substances have different odors.

The second learning set emphasizes the differences among substances. Students learn that every substance has unique properties, and that different substances can be distinguished by those different properties. Students are introduced to the terms *element*, *atom* and *molecule*. Students use these terms (rather than only "particles") to refer to the particles in their model.

Their particle models of matter are revised once again to incorporate new ideas and to explain why different substances have different smells. This learning set is linked to the driving question by the fact that the arrangement of atoms (in different molecules) determines the odor of a substance. By the end of this learning set, students should be able to explain that different substances smell differently because they are made of different molecules. Different molecules can be made of either the same or different types of atoms, but those atoms are in different arrangements.

The last learning set uses the particle model to explain states of matter and phase changes. In this learning set, students use the particle model to represent the three states of matter, to explain what happens at melting and boiling points, and to explain the relationship between temperature and the movement of molecules at each state. By the end of this learning set, students understand that "state of matter" characterizes a bulk of particles in terms of distances between particles, movement, and arrangement. Explaining state of matter and phase changes by using the developed model also demonstrates to the students how scientists use models—they use models to explain phenomena. By doing so, the model itself is revised and refined—including aspects that were not part of the original model.

The teacher materials included specific teaching strategies to help the teacher facilitate the modeling activities and discussions. It also included some background knowledge about the uses of models in science and the nature of models.

Purpose of the Study

This research examines the effect of classroom practice, teacher's instruction, and students' developing understanding of models and modeling by taking part in an 8-week chemistry unit that focuses on the particle nature of matter, models and modeling.

Research Questions: The questions that guided the design and data collection are:

1. What were the teachers' conceptions of modeling before teaching the unit?
2. Do teachers' conceptions of modeling change as a result of teaching this unit?
3. What is the teachers' main goal when teaching specific modeling activities? Is it more a content focused goal or a practice (modeling) focused goal?
4. How important is the process of modeling to the teacher? What are teachers' beliefs regarding the benefit of modeling to their students?
5. What modeling practices do students develop over time? What practices are difficult for students to learn? How do the practices support each other?
6. What knowledge about modeling do students develop? (i.e. purpose of models, uses of models, limitations of models, and the use of multiple models).
7. Can direct links be drawn between classroom practice to students understanding of models and modeling as demonstrated in their artifacts?

Methodology

Population: One 6th grade teacher enacted the chemistry unit in two classes, at a middle school in a mid-western college town. The teacher is an experienced science teacher (teaching 10-15 years), most confident teaching earth sciences, and that her last science course for college credit was completed 6-10 years ago. Each class had about 30 students stemmed from various ethnic and socioeconomic backgrounds and differing academic abilities.

Data Collection: To track teacher practice and the change in students' practice of modeling and meta-knowledge of models, the following types of data were collected:

- Student Interviews: We interviewed six students prior and after the unit (i.e. pre/post interviews). The 3-part interview addressed meta-knowledge aspects of models: model type, model use, model change, model limitation, and multiple models. Part I asked students to recall what they know about models without any specific prompts. Part II presented students with four visual representations (a toy car, a globe, a flat topographical map, and a hand-drawn food chain diagram) and asked several basic questions about models: 1) is this a model?, 2)why or why not?, 3) if so, how would you use it as a model? 4) does it have limitations?, 5) could it be changed? Part III presented students with three models of the same phenomena (adapted from Penner et al. 1997) and asked students five questions (which one would you consider a model, why and why not, which would be the best model for a certain purpose, can you have more than one model and why, and what makes a good model).
- Teacher interviews: We interviewed the teacher before and after the unit. The teacher was asked what does she think a 6th grader, and an 8th grader may perceive as a good model, and why; as well as other questions regarding the use of models as a teaching tool, and the importance of the process of modeling. In addition, the interview used the same models that were presented to students during interviews. The teacher was asked which of the presented models she would use as good examples of what a model is, and why.
- Videotapes of lessons: Specific lessons in which models were created, presented, communicated, critiqued and revised were video-taped: 1) lesson one following the anchoring activity in which students drew and discussed their model; 2) lessons four-five in which students revised their models to account for various phenomena; and 3) lesson fifteen in which students created their last model of how smell travels and compare their own model from day 1 to the model drawn in the last lesson.
- Analyzing various students' artifacts and answers to reflection questions throughout the unit. The specific items will be presented in the results section.
- Pre-post test assessment items that involved the use of models in order to explain a specific phenomenon were analyzed.

Data Analysis: Students' models and pre post-tests were analyzed to determine to which extent do these items/artifacts reflect the practice of modeling and the modeling meta-knowledge. In order to analyze students' artifacts (e.g., students' constructed or revised models and also answers to reflective questions) a content analysis of the item was carried out in order to decide which aspect of the practice or MMK are best reflected by the specific artifact. Then, a sample of students' artifacts was analyzed to help the researchers come up with specific criteria. The criteria are presented along with the results.

Students' pre-post interviews and classroom videos were analyzed using qualitative methodologies (Miles & Huberman, 1994). The overall approach includes:

1. Segmenting each episode/ students' answer to a question in interview into small units (sightings), and categorizing each unit by its content. This process helps in surfacing and identifying categories for the coding scheme, additional to the theory-driven categories.
2. Developing a coding scheme and coding the sightings. The coding scheme incorporates meta-modeling knowledge features, with how this knowledge is generated in a specific sighting.
3. Mapping and reorganizing the data according to the chosen categories.
4. Looking for the foci, and for general trends.
5. Proposing assertions based on the accumulated data.

Results

The teacher

In this section we report on a teacher's perception of modeling as an instructional strategy prior to and after teaching our unit. We also include a description of the instructional strategies employed by this teacher to support students' use and understanding of models as observed in classroom videos of modeling activities. A major finding was that the main change detected was an increased appreciation for the value of modeling as a instructional strategy to help students learn science content. The teacher also provided some insight into students' challenges and success stories with this unit.

Previous perceptions of models

Analysis of instruction along with teacher pre and post interviews reveals that the teacher holds view that is closer to the scientific perception of models and modeling. She perceived the classroom modeling similar to scientific use of models: *"I would say that we create models that represent our thinking and we also use other people's models, so in that way I would say it's similar to what scientists use".* In pre unit interview the teacher said that the difference between classroom models and scientific models was the simplicity of classroom models.

In previous units (mainly earth science) she used models in ways that could promote some MMK development.

For example, her understanding of the idea that models are not replica of reality is illustrated by the following quotes:

" I always say to them, 'Ok, I'm going to draw China' and I throw like a rectangle up on the board and they laugh, but for us that's a model that works. They know that they can throw some boundaries on there, like the Himalayas, and the Gobi Dessert and they can work with it because they know it might not look exactly what it's supposed to be but for our purposes it doesn't have to look exactly like what it's supposed to be, it just has to carry the thought".

and also:

"we've done some modeling with like populations in geography and things like that, so we've drawn the continents bigger or smaller based on their population and so you end up with a really goofy map compared to the way the map of the world looks to them". "

In spite of these past experiences, the teacher did not expect 6th grade students to express meta-knowledge regarding models. Although she mentioned that in previous unit they had learned about Doppler radar used to model and predict weather patterns, she said that *"students will not come up with that on their own right away. They'd be very concrete, I think"*. She did expected students to be able to provide examples of concrete physical models that they used in class, such as the globe. In the post interview the teacher felt that students would shift their understanding of models from a concrete view, were models are replicas of real objects, toward a more abstract view, where models do not have to resemble the real objects.

<u>Teacher's thinking about how students construct and thinking about models</u>:

Before teaching the unit, the teacher was skeptical about the practicality and usefulness of the process of constructing and revising models. She was concerned that *"kids would get so hung up on trying to turn their model into something creative as opposed to really representing the way they're thinking about it"...It would be less about the science than about the 'I'm going to create a model'.*

In the post interview, the teacher said that students actually revised their models as their thinking about the phenomenon changed, but doubted that this is associated with a broader

meta-knowledge idea about scientific models: *"So I think the kids would definitely say yes my model changes as my thinking changes. Would they say that scientists do that the same way that they do? I don't know. Because I think that they see scientists as people who know instead of people that constantly question and that's the big societal um.. you know… "*
However, analyzing her classroom practice reveals that she tried to support the notion of scientists can change their models. Already in lesson 1 she mentioned that *"scientists make their models better and better over time".* She revisited this idea several times through out the unit.

Even after teaching the unit, she doubted the students' ability to explicitly refer to the meta-knowledge ideas associated with the practice: *"I just think that they aren't very good yet, it is the sixth grade thing, they are not very good at monitoring their own thinking, that meta-cognition is not something that comes naturally to them. And I don't think that developmentally we can really expect it ….And so I am not necessarily sure that they will be able to put the words to the process but if you ask them to pay attention to it they can tell you, but it is just that meta-cognition is not something that really comes to them naturally yet... More about the kids than it is about the activities".*

In spite of the challenges she thought the students enjoyed the unit: *"they really enjoy that wrestling with ideas, and defending them and show it on the transparency".*

<u>Teacher's view of the benefit of the unit:</u>
The main benefit, as perceived by the teacher is students' ability to see how their ideas change: *"Well the most challenging thing was understanding the value of the model and I am a very visual person... You would think that the modeling thing would make a good sense to me, and I have a science background and you would think that I could see the value of this, and the hardest thing for me to understand was why am I spending so much time on this because it take you a couple of tries and a couple lessons before the kids go 'ooooh I can see the difference now', and until the kids could see the difference in the models I couldn't see the difference…You have to get to the aha moment yourself before you really understand the value of it and you have to be really reflective about your teaching, because I think that if you*

are not, then I think that you can really use these units without getting there and if you don't get there than your kids aren't going to get there"

<u>Teacher's view of the value of IQWST</u>

When she started teaching IQWST units the second time she said:

"I know that I am paying a lot more attention to it now ... because I kind of get what the modeling is all about, and I think through the chemistry unit the modeling thing for me was a learning experience for me as well. I had to see the kids to get the ah ha moment before I realized the value of the modeling because I was thinking about it kind of the way the kids were when we were first doing it. How do I represent what I am thinking with the drawing and I wasn't really thinking about it as- it should be used not just to show the idea but to explain and imbed all the possibilities…. I think I am doing a much better job of that this time around".

It is obvious from these two quotes that teaching a unit that focuses on modeling was an educative experience for the teacher.

Pedagogical-content knowledge of modeling

Some comments by the teacher suggest that she had developed some pedagogical content knowledge (PCK). For example, in the teacher interview prior to the start of the unit she reflected on possible students difficulties. She mentioned the following student process skill challenges: difficulty following a sequential set of directions, difficulty moving from concrete to abstract, difficulty showing specific aspects (such as movement) in static drawings, and difficulty articulating and explaining what is represented in the drawing.

In the post-interview, the teacher pointed out that the act of evaluating models was difficult for students especially for those that did not understand the content concepts well enough, so they could not use the evaluation criteria, nor understand why a specific criterion is important. Another challenge for students mentioned by the teacher was reflecting on previous models and trying to revise them: "*I would venture to guess that some of them don't want to go back and explain how they were thinking before because it might confuse them…If I only gave them the rudimentary one and I said now that you know what you know how would you make it different. I am not sure that they are ready yet".* A better strategy for the students was to construct a new model, then put the two models on the board and compare them (‘what is missing, why is one of them better etc.).

How does the teacher support her students in modeling?

Analyzing main modeling activities, as well as interviewing the teacher aimed at generating a list of instructional actions that were used to support students as they were engaged in modeling. This list will be used to develop a future rubric for assessing the effectiveness of instruction of multiple teachers, as well as revising the educative features of the curriculum. The main questions that led the analysis of lessons were: (1) How does the teacher support students in their modeling, and reflection on their practice? (2) Does the curriculum support the teacher in facilitating modeling activities? (3) What was students reaction to specific instructional features (were they engaged, confused, etc.)

Most of the teaching strategies that supported the practice reported here were recommended in the teacher materials of the curriculum. If a specific teaching strategy was initiated by the teacher, we will explicitly refer to it as such.

The main instructional strategies that the teacher used to support the use and understanding of models are listed bellow:

Asks students to discuss and revise their models: After constructing individual models, the students were grouped into groups of 4-6 students. Each student was asked to present his/her model to the group, and as a group come to a consensus on the best model for how smell travels. Then the group presents their model to the class and the group model is being discussed and questioned. The teacher often asks students if the presented model makes sense to the class, how is it similar or different from their own models, do they agree or disagree with the presented model, any questions/concerns, etc.

Asks students to explain the meaning of their drawings: The teacher “pressed for understanding” by constantly asking the students to explain their drawings. The teacher pressed individual students, small groups or the whole class. She also referred to the need in doing so, during her interview before teaching the unit:

“… you don’t know what the student means and you don’t know what that student means by the drawing and you need to ask them what they mean because they could be drawing

something like that (pointing at a model in the teacher materials) and completely thinking something like this (pointing at a model in the teacher materials)".

For example, during a group work, she asked one of the groups (pointing at their model: *"What's the other stuff? I want to know the thing, but I also want to know about the nothing here"* (refers to empty spaces in students' drawing)

***Models her own making sense of modeling**:* The teacher often describes what she is getting from a students' drawing, and asks the students if he/she agrees with her description. For example: *"My understanding of it is that in the magnified part you show the little pieces of moth balls in the air. Is that correct"?*

Or: "I see layers there: layers of air molecules and layers of the actual smell molecules. Is that the idea you are trying to get across here"? She points out the whole class unique models (correct or not)*: "This is a different model. We haven't seen the ideas of layers before…"*

She helps students to compare models by showing them how she compares two models presented in the same lesson, by two different groups: *"In the other one odor travels by itself, in this one air helps the odor".* Then she asks the students to continue and compare other aspects of these two models.

In another occasion, she presented a limited model and played the role of a student answering questions regarding this model. She provided answers that an 11 years old student would do. That helped her students to understand a) how the teacher is making sense of the models and b) how they can talk about their models, and how to use their models to explain their thinking. This technique of modeling her own use of models and thinking about models was initiated by the teacher. After analyzing classroom videos, the curriculum developers decided to include such a strategy as optional, in the revised version of the curriculum.

***Uses the models to initiate questions regarding the phenomenon**:* Usually, after a model is presented, the features of the models are discussed, and then the content ideas that the model tries to come across are discussed. This discussion of the content knowledge usually ends with a list of more related questions to be investigated. Often the teacher writes the question on the model transparency in order to come back to them later in the unit.

Visualizes the way models change with the change in their thinking*:* When students present their models, the teacher asks them to use different colors on the models, as they revise them. On her post interview she said: *"I'm trying to capture and I am trying to make very evident to them that their ideas are changing and that they are making their model change with them"*. The use of different colors was also a teacher initiative.

A specific incident of discussing a model was accompanied with many colored changes. The teacher used it to stress the MMK that models constantly change:

T: *"What did we do with the model as we questioned it as a community of scientists?... What happened to our model?"*

students answered

T: "we changed it, didn't we? We modified our model to represent out thinking, as we clarified our thinking. Do you think scientists do that?

Some students answered

T: Absolutely, all the time. It is really important that you understand that as your ideas change your models changes".

She encouraged students not only to keep track of changes on the model, but also take notes during discussions, she told the students that *"when you have to create another model, the notes will help you keep track of the class ideas"*.

Engages in reflective discussions regarding the nature of models and the purpose of using them*:* During the first lesson but after students drew their first drawing of how smell travels, the teacher led a discussion about models. Some of the prompts she used were: "I want you to think of some of the models you used before" (as students provide a variety of responses, she reminds them of using computerized models); "what is something you consider a model"? "Are there models you are using in Math class"; "Are you sure all models are smaller versions of something else?" (in response to a students' answer); "What are the shortcomings of models?"; "What do scientific models do?" Some of the prompts were suggested in the curriculum, but some of them were originated by the teacher (such as "are there models you are using in Math class?"). This discussion was a fascinating example of how a teacher captures the spirit of the discussion suggested in the curriculum materials, and makes it more relevant to the class, by linking it to their former experience in Math, and Earth Science classes.

Later lessons revisited the ideas brought up in this discussion, by leading similar (but shorter) versions of this discussion. While prompts regarding the uses of models (describe and explain) and limitations of models were repeated several times, other ideas regarding the nature of models were occasionally discussed. For example, the idea that a model should be consistent with all the observations was introduced and discussed in lesson 4.

Another example is the prompts she used to help students think that models are used to predict: As students revisited the uses of models (describe & explain) the teacher asked: *"do models always talk about things that have already happened? what about things that might happen?"*, provided a specific example they are familiar with (Doppler radar models used to predict weather), and add "models can be used to predict" on the transparency.

Helps students develop criteria for evaluating models

After few open discussions regarding the models constructed by different groups, the teacher led a discussion aimed at having a set of criteria (the class used the term 'check-points') that they can use when they evaluate a model. These criteria were: What is it describing? How it represents the phenomena? How does it explain what you observed? Which parts of it are inaccurate? After the criteria were set, she drew a wrong model on the board and asked the students to evaluate it. The development of a set of criteria to evaluate models is an activity suggested in the curriculum. The teacher added to that the demonstration of how to use these criteria, by using them to evaluate a wrong model.

Emphasizes limitations of models

Shortcomings of models were part of every reflective discussion. Moreover, the teacher emphasized the limitations of static models in representing a dynamic phenomenon, and engaged students in finding various ways to overcome this limitation. The two common strategies were drawing arrows or little brackets around each particle to represent movement, or drawing time lines on the model to show were are the particles after 1 minute, 5 minutes, etc.

The teacher often emphasized that "all models have limitations".

In the post interview the teacher said: "*We always say that every model has some feature that isn't quite right and that is the model and not the real thing"*

Helps students synthesize the big ideas after a few modeling activities

After a few modeling activities in which students have constructed and discussed various models, the teacher took some time to help students synthesize what they have learned (in terms of content) and what features need to be included in their models. This could be considered a way to gradually develop a consensus model, for the whole class.

As a routine the teacher also emphasized the communicative aspect of models and repeatedly asked students to label any parts of their models. She also referred to some norms (probably established before this unit) for discussing each others' artifacts.

Examining this teacher's enactment of this unit provides a rich example of instruction that explicitly targets MMK as well as students' ability to participate in modeling practices. Our results suggest that this unit and teaching experience helped the teacher better appreciate the value in providing opportunities for students to construct and discuss their models in science class. While we can not say there was a change in the teacher's own understanding of models and modeling practices, as this would require a more depth evaluation of the teacher's understanding of models and modeling practices, we do report the teacher discussing and talking about some of characteristics of scientific models and modeling that we targeted in this unit.

The Students

The pre/post tests for this unit, included opportunities for students to construct models or refer to models presented to them.

An example of an open-ended item that involves modeling is:

Bill and Shauna wondered if they could smell an air freshener faster in a cold room or a warm room. They decided to do an experiment: They made the room cold (50^{o}F), plugged an air freshener in, and measured the time it takes for the smell to reach the door. The next day, they made the same room hot (85^{o}F), plugged in a new air-freshener, and again measured the time it takes for the smell to reach the door.

A. What do you think would be the results of Bill and Shauna's experiment? Circle one of the following options:

1. The smell reaches the door at the same time in both temperatures
2. The smell reaches the door faster at 85^{o}F
3. The smell reaches the door faster at 50^{o}F

B. Second, draw models that can help you explains your chose your answer in part A. (Your models should show how the odors reach the door at lower temperatures and higher temperatures)

Overall scores for the modeling items show significant improvement in students practice, as shown in Table 1:

Table 1: Pre/post tests modeling scores

	Pretest Mean (SD)	**Posttest Mean (SD)**	**Gain (SD)**	**Effect Size**
Modeling Items (Total possible points 23)	10.25 (2.90)	18.26 (3.52)	8.10 (4.02)	2.81 ($p<.001$)

In order to learn more about the practice and MMK of students, we analyzed various tasks from students' activity sheets: drawn models, written models, and answers to reflective questions about their models. The results of students' artifacts are presented along with the specific assessment item, and specific practice/MMK idea that is being assessed. Analyzing students artifacts mainly provides evidence about the students' ability to engage in a modeling practice (i.e students are actually able to construct, evaluate, compare and revise models). However, our hypothesis is that doing the practice involves some degree of understanding the MMK associated with it. Therefore we use students' reflective answers on their activity sheets, comments from classroom discussions, and students' answers from one to one interviews to make claims for understating of a specific MMK idea and of students' progress.

Our analysis of students artifacts provide evidence for a) students' ability to be engaged in a specific practices and b) indication for understanding the MMK ideas associated with the practice.

Purpose of models: Two ideas were assessed regarding this aspect of modeling: (1) "Models are used to communicate our thinking of a phenomenon", and (2) "Models are used to describe and explain phenomenon" (Understanding that models are used to predict, was also a goal of this study, but because of time constraints the teacher cut short most of the activities involving this practice. Some indications of understanding this idea, were found in students interviews, and are reported below).

1. Models are used to communicate our thinking of a phenomenon

Understanding the communicative features of models is an important meta modeling knowledge. To assess the understanding of the communicative aspect of models, we examined the change in students' labeling of their models. We observed that most students added more labels of relevant features in their models over time. In cases that students' models contained 2 basic features or less (the source, and smell (continuous or particulate)) they were coded as "basic labeling". If students' models included more then these 2 features they were coded as "elaborated labeling".

Table 2 represents the results of comparing students' models drawn in the first lesson and last lesson of the unit, for the same phenomenon. Students were asked to draw a model of how smell gets from the source to their nose

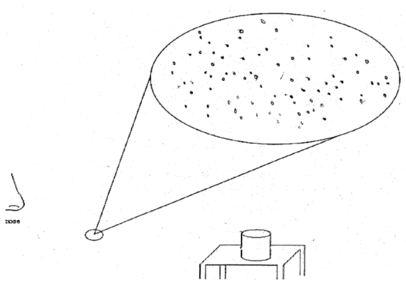
Table 2: Comparison of labeling students models

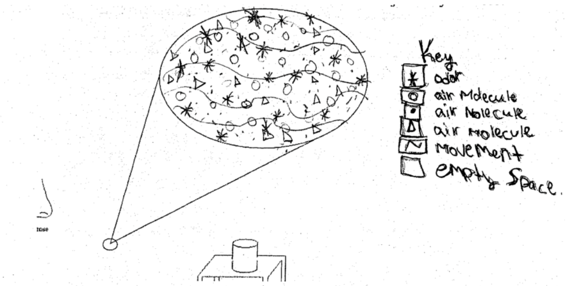
	First model	Final model
No labeling	9 (18.37%)	0
Basic labeling	40 (81.63%)	7 (14.28%)
Elaborated labeling/organized key	0	34 (69.39%)
Using scientific symbols	0	8 (16.33%)
Total	49 (100%)	49 (100%)

Although 18% of the students did not include any labeling in their first model, all students labeled their models in the last lesson. 69% of the students drew a final model with more elaborated labeling of the parts of their models, compared with their first model. Some examples of elaborated labeling included: A label of air, empty space, movement and time for smell to travel certain distance to their models. 16% of students included scientific symbols in their labeling (such as O2, N2, etc.) although not prompted by the task.

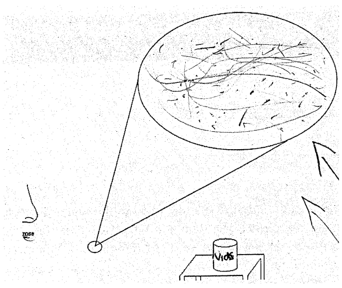
Figure 1: Students' initial and final models

First students: no labeling at the beginning, elaborated key in the final model





Second students: Basic labeling in the initial model (source is labeled as "vicks"), elaborated key in the final model.



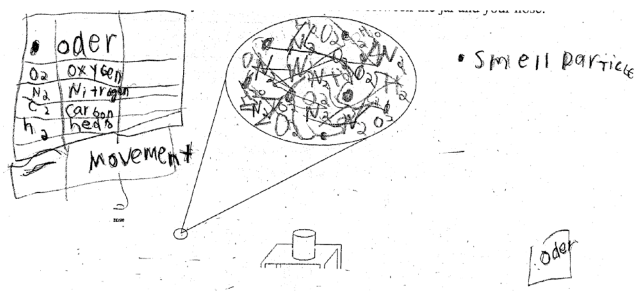


Table 3: Level of labeling of students' models in the pre/post test.

The two open-ended (OE) questions in the test involved drawing of models. Labeling was not prompted in these tasks.

Table 3

	Pre test OE2	Post test OE2	Pre test OE4	Post test OE4
No labeling	17 (38.64%)	2 (4.54%)	28 (63.64%)	18 (40.91%)
Basic labeling	26 (59.09%)	12 (27.27%)	12 (27.27%)	9 (20.45%)
Elaborated labeling/organized key	1 (2.27%)	28 (63.64%)	4 (9.09%)	16 (36.36%)
Using scientific symbols	0	2 (4.54%)	0	1 (2.27%)
Total	44 (100%)	44 (100%)	44 (100%)	44 (100%)

In both items the number of students who failed to label their models at all decreased while the number of students who elaborated their labeling increased. However since labeling was not at all prompted in the item, and considering the situation of testing, the extent of improvement is less noticeable then in the models drawn in class. Also it seems that the two open-ended items shows a slightly different pattern of improvement. This different pattern can be explained by the fact that open-ended item no. 4 included a photo of the set up. Students' models were actually some reflection of this photo. It may be that the presence of a photo changed students' perceptions of the need to label the parts in their models. This might explain why a relatively high percentage of students did not label/used basic labeling in the post test.

Other findings, from students' pre and post unit interviews, and other artifacts provide additional evidence to students' improving their understanding of the communicative value of models. In two tasks (lesson 5 and lesson 15) students are asked to compare the model drawn in this lesson to the first model drawn in lesson 1 (all models represent the same phenomenon: how can smell get from the source to their nose). The tasks asks:

- "Compare the model you constructed today to the model you constructed during lesson one.
- How has your model changed? why?
- What new ideas were included in the mode?

Although the context of the task is content-oriented 15% and 12.5% (lesson 5, lesson 15 respectively) referred to the communicative power of their models. Some students' answers were: *"In my first model there was no key so no one knew what anything was"*. This indicates that students are reflecting on the communicative value of their models.

During students' interviews students were introduced to various models (globe, map, drawing of a food chain, models of an elbow). For some of the models students were asked: what would you change in the model? Only in the post interview, three out of six students referred to changes that would improve the communicative aspect of the model: *"add names to the map", "put arrows pointing out to what is what"* or *"make people understand the model better"*.

The data indicate that students understanding of the communicative aspect of models improved as a result of learning a modeling based unit.

2. Purpose of models: Models are used to describe, to explain (and to predict phenomenon)"

A key MMK is understanding the purpose of models. To assess students' understanding of the purpose of models, we interviewed students prior to and after the unit. Referring to a specific model (such as a model of a car, food chain or globe) students were asked: "what kind of question can you ask using this model"?

In the pre interviews 2 students could not mention any use of some of the presented models, and the other 4 students mentioned the ability to use model to describe phenomena as the only use of the models. In the post interviews all students mentioned descriptive aspects of models (including the two who did not refer to it in the pre-interview), but 3 students also included using the model to predict possible outcomes. For example, one student mentioned that a model of the car can be used to predict how many miles per gallon a real size car will be able to drive, and a second student mentioned that we could use the globe to study weather and to predict where hurricanes will hit.

Students' activity sheets throughout the unit were used as a second source of data. In the activity sheets students were asked to use the model they have drawn to describe (in writing) to a friend how the drawing explains how odor travel from one place to another. The first model students drew did not include a "zoom-in" aspect, but the second one did as described in the figure below.

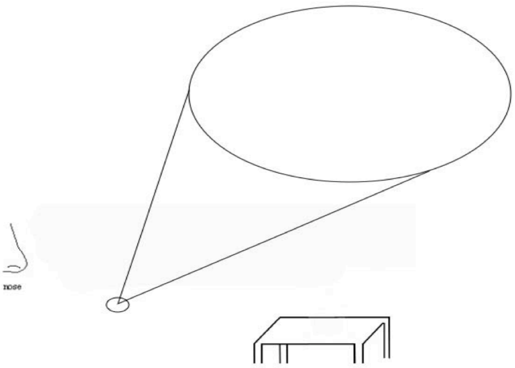


Figure 2: Scaffolding students' zoom-in modeling

While this task is more directly assessing the practice of using models to explain phenomena rather then the MMK idea that models are used to explain phenomena, our hypothesis is that if a student is able to use the model to explain phenomena, that he/she will also develop some understanding of this purpose. Using the model to explain was assessed by the following criteria:

0. No explanation
1. Ss does not connect explanation to drawing (i.e does not use drawing to explain)

2a Connects explanation to drawing but explanation includes info that is not expressed in the drawing (such as "the brain processes the data about smell", "Ms. H. opened the jar". or "whoever is closest to the mothballs detect the odor first")

2b Connects explanation to drawing but drawing includes info that is not express in the written explanation (such as drawing indicates other particles in air which is not referred to in the written explanation)

3. Explanation precisely reflects the use of drawing to explain the phenomena.

Table 4: Students use of models to explain phenomena (matching pairs)

	First model & explanation (N=27)	First zoom in model (*) & explanation (N=27)	Final zoom in model & explanation (N=27)
1 Not using the model to explain the phenomenon	2 (7.41%)	1(3.70%)	2 (7.41%)
2a Written explanation has more info	4 (14.81%)	2 (7.41%)	4 (14.81%)
2b Model has more info	2 (7.41%)	3(11.11%)	2 (7.41%)
2a & 2b Info in model and explanation do not match	1(3.70%)	1(3.70%)	0
3. Model is properly linked to written expalanation	18 (55.55%)	20 (74.07%)	19 (70.37)

(*) A zoom-in model means that a piece of air was magnified and the students had to draw what stuff looks like in the magnified area.

The results show that most students were able to connect their explanations to the drawing from the beginning of unit (55.55% in first drawn model, activity 1.1; 74.07% in first zoom in model, activity 1.2, and 70.37% in final zoom in drawn model, activity 15). Please note, that the accuracy of content of the explanation was not assessed. A student could explain a totally scientifically wrong explanation, but if the written explanation provided indication that students used the model it was coded as a proper use of models to explain phenomena. Suggestive evidence that students understood the explanatory purpose of models to explain is that some students added features to the drawing if they needed them for explaining, such as nose hair, fan, hand wafting etc. Some students tend to explain the drawing itself (my dots represents etc….) this is an indication that they are aware of the communicative aspect of the model, and that they do not realize that they are suppose to use the model to explain the phenomenon.

About a quarter of the students had some differences between their drawing and their explanation. The most common difference is that students may have constructed particulate drawing but wrote a macro explanation or vice versa. The interpretation of such finding is problematic since it is unclear if this represents a mixed view of matter (students shift between particulate and continuous view (Merrit, Shwartz, & Krajcik, 2007)), or lack of ability to use the model effectively to explain a phenomenon? A content understanding and meta-knowledge analysis should be compared in order to reveal the reason for this difference.

III. ***Nature of models:*** Understanding of the nature of models is also a key metacognitive modeling knowledge. that the unit focuses on. We tracked four ideas that indicate learners understanding of the nature of models: (1) A model is a simplified representation of a phenomenon in the real world (not a replica), (2) different models may represent the same phenomena, (3) models have limitations, and (4) models can be revised.

1) **A model is a simplified representation of a phenomenon in the real world**

In pre/post unit interviews, students were asked to explain why some objects (a toy car, a globe, a map, a drawing of food chain, different models of an elbow) are models or not, and why it is or it is not considered a model. In the pre unit interviews, in response to these questions all students expressed the naïve view of models as replicas of the real phenomenon (Grosslight, Unger, Jay, & Smith, 1991; Saari, 2003; Crawford & Cullin, 2005). For example: X is a model because *"it is a smaller version of something big", "smaller version of earth", "showing you all the things", "shows how something really looks like"*. Or X is not a model because: "*earth is round and the map is flat", "Not a model because it is not 3D"* (referring to a geographical map) or *"it does not look like an elbow"*. While this was still a dominant view in the post interviews as well, some students were also able to point out other aspects. For example, a student in the pre unit interview considered a drawing of a food chain as a model because *"this is a smaller version of a flower*" (pointing at one item in the food chain); in the post unit interview she had changed her reasoning to *"it shows the process"*.

2) Nature of models: Different models may represent the same phenomena

To explore students' understanding that different model may represent the same phenomena, we showed learners 3 models of an elbow (Penner, Giles, Lehrer & Schauble, 1997). We asked students whether they thought it is OK to have more then one model for the same thing. Students' responses to this question suggest that the students did see value in having multiple models prior to the unit. For examples on pre-interview some students said: "*More then one. One can be limited"; "You can compare them to see what's different about both of them"; "Each model can show something else about a topic"*.

However, some students' responses after the unit show that students were better able to articulate their ideas about why it is good to have multiple models. For example, on the pre-interview student S agreed that multiple models can represent the same phenomenon but he could not provide a clear reason for using multiple models, but in the post interview he said: *"It is good to have more then one model because some models do not show everything. You can get one thing out of a model that you couldn't get from another model"*.

Another indication that students understood the idea of multiple models was gathered from two class tasks in the students' activity sheets and reading materials. In the first task, students had to answer the following question:

- Today's models are going to be 2-dimensional (drawings) and 3-dimensional (marshmallow models) of molecules. The models are not what atoms or molecules really look like, they are just representations of the particles we can't see. Which model works best for you?

This question was used only in one of the two piloting classes.

A second task occurred later on in the unit. In the reading materials three different models of Methanol and Myrcence molecules were introduced: a model where circles represent atoms, a model where letters represent atoms, and a model where no atoms are shown (instead the model shows a general shape of the whole molecule). See figure 3.

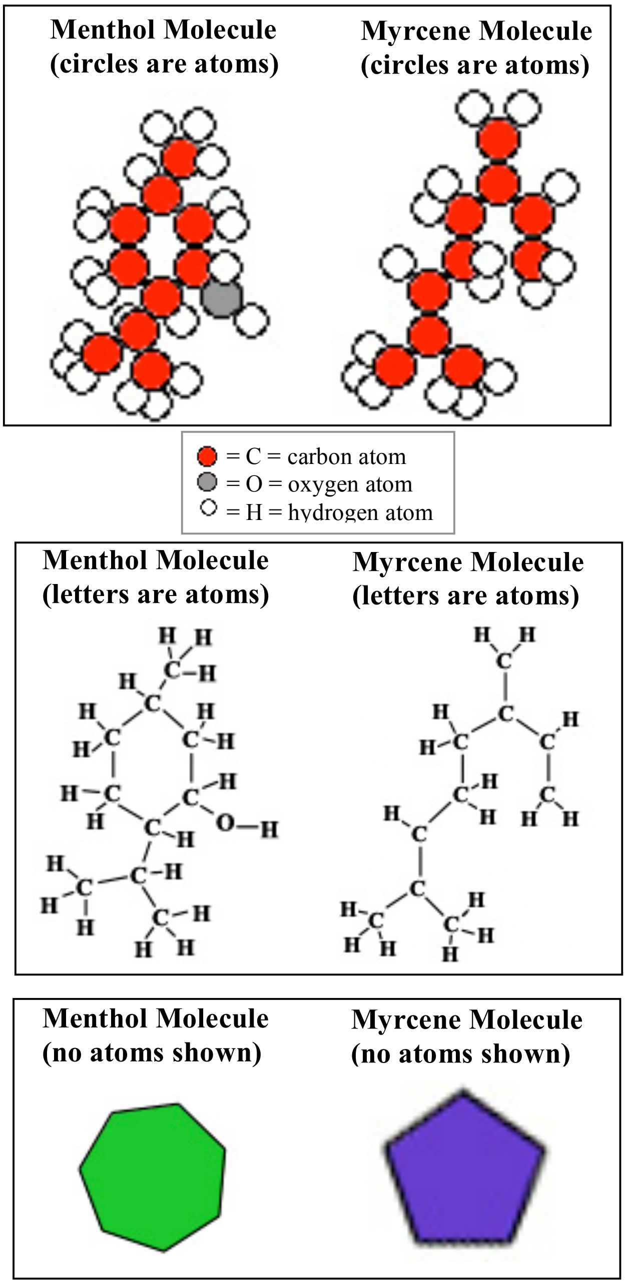


Figure 3: Multiple models of Menthol and Myrcene

Students were asked to choose one model and explain why this model is better for understanding that menthol and myrcene (M&M in results table) are different substances. This is a complicated task; however, it involves students understanding that the same molecule can be represented by multiple different representations, and that each representation highlights a different aspect.

We coded students' responses to both 2D/3D models and M&M models as:

1. Meaningless answer;
2. General descriptive answer. Examples of general descriptive answers: *"It gives you a clearer picture"; "It shows how it looks, like better"; "It is more realistic"*
3. Indicates specific reason to prefer one of the models. Example of specific reason to prefer one of the models: *"With 2D model you wouldn't know if one (atom) was further back then the others"; "This model clearly shows there is no oxygen atom in the Myrcene molecule"; "It is easier to see where each atom is located, and what kind of atom it is".*

Table 5:

	2D/3D models (lesson 5) n=19 *	M &M (Lesson 9) n=36
Meaningless answer	5.26%	8.33%
General descriptive answer	42.10%	25%
Indicates specific reason to prefer one of the models	52.63%	66.66%
Total no. of students	100%	100%

* Asked only in one class out of the two.

The results show an improvement in students' ability to make sense of multiple models. In lesson 5 53% were able to make sense of the question, and make choices between multiple models, based on specific aspect of the models. In lesson 9 about 67% of students were able to do so. Although the improvement is moderate both items indicate that students are able to meaningfully refer to specific aspects of multiple models.

3) Nature of models: **Models have limitations**

We assessed students' ability to point out limitations of models by analyzing a task from lesson 5 of the unit. In this task, the students constructed a second model of how smell travels. Students were asked: "what parts of the phenomenon is your model unable to show". Students' answers to this follow up question were coded, according to the following criteria:

1. Students' answer indicates no limitations;

2. Students' answer indicates irrelevant limitations (such as it doesn't show compression);
3. Students' answer indicates relevant limitations (doesn't show movement, speed of molecules, or how liquid ammonia evaporates).

Although a category of communication limitations was not originally designed, two out of the 47 answers referred to such limitations by saying: "I do not have a key", or "without the key you can not tell what the dots and arrows are".

Table 6: students reflecting on limitations of their models:

	No. of students
no limitations	8 (17.02%)
irrelevant limitations	9 (19.15%)
relevant limitations	28 (59.57%)
Communication limitations	2 (4.25%)
total	47 (100%)

The results indicate that a most of the students (59.6%) were able to point out limitations, and thus, probably had some understating of this MMK idea. However, 36.% of the students that made some effort to respond to the item still struggled with that task, which could indicate either that they do not understand the MMK idea of limitations, or that they do not understand the content ideas targeted in the unit. Further research is needed in order to find out what is the root cause of the students' difficulties.

4) **Models can be evaluated and revised**

During the unit, students constructed models of how smell travels three times: the first lesson, the end of learning set one, and the end of the unit. During the second and third assessment periods, students were asked to compare their current model to their first model from lesson one. Students were asked: "How is this model different from the first model you created in lesson one? and "what new ideas have you included in this model?" This task engages students in evaluating their previous models, but also think of the reason of why they had changed that model.

We coded students' responses to these questions in the following manner:

1. Students did not indicate any differences/new idea;

2a. Students refer to new knowledge expressed in models (such as particles, movement, collisions with other particles in air);

2b. Students refer to new, but wrong knowledge expressed in models;

3. Students refer to the communicative power of their models (such as "I did not have a key").

Although we were interested in students' ability to reflect on how their models have been revised, and not of content ideas, we coded for wrong ideas since this could highlight some of the complex links between content and practice.

Table 7 shows the distribution of the kind of ideas students were able to point out when comparing their first model to a newly drawn model. The table shows the total number of answers for each category and the percentage of this category of the overall answers for that question.

Table 7: Distribution of students' reasoning to the change of models

	Lesson 5.2.1	Lesson 5.2.2	Lesson 15
1. Not mentioning differences/new ideas	9 (19.56%)	12 (26.67%)	5 (12.50%)
2a. Mentioning new evidence, knowledge gained	27 (58.69%)	28 (62.22%)	28 (70%)
3. Mentioning changes in communicative aspects of the model	5 (10.87%)	2 (4.44%)	4 (10%)
2a.& 3 (Both content and communicative aspect were mentioned)	2 (4.35%)	0	1 (2.50%)
2b. Mentioning new bur wrong ideas	3 (6.52%)	3 (6.67%)	2 (5.00%)
Total no. of students	46 (100%)	45 (100%)	40 (100%)

Combining all students whose answers were coded as either 2 or 3, or both 2 & 3 result in 73.91% of students who were able to point out why their models changed in lesson 5.2.1, and 87.5% of the students were able to do so in lesson 15. The results show that most students were able to point out what new ideas led them to revise their models. The percentage of students that were able to do so increased over time.

In general, the results provide evidence that students are able to practice various aspects of modeling, and express understanding of MMK, as summarized below:

- Students improve the practice of modeling, and the communicability of their models
- Students understand that multiple models can be used to represent the same phenomenon.
- Students understand that different models highlight different aspects of the phenomenon.
- Students understand that models have limitations, and are able to indicate a relevant limitation in their own drawings.

- Students understand that models can be revised and are able to indicate new content ideas that are expressed in their new models.

Discussion

Engaging in the practice of modeling can help students develop a deeper understanding of the content ideas, as shown in a parallel study that focused on the content ideas of the unit (Merritt, Shwartz, Rogat & Krajcik, 2007). In the study described in this paper, we investigated the question how instruction that focused on modeling can also help students develop their understanding of the nature and use of models in science. The data provide evidence that such an approach is effective. The findings supports the recommendation of teaching by involving students in the 'doing science". Delving into specific practice such as modeling is an example of how this can be done and how effective it is (Schwartz & White, 2005, NRC, 2007).

The study provided an example of effective instruction to support students modeling and development of MMK. The results provide evidence that students were engaged in different aspects of the practice (construct, use, compare, evaluate and revise models), and were also able to demonstrate understanding of MMK ideas. It is possible to draw links between specific instructional practices and students performances: The teacher asked students to explain and label their models, and the students improved in their labeling and the way they orally communicate about their models, They also demonstrated some understanding of the importance of the communicative aspect of models in the post unit interview. The teacher visualized the way models change, and the students were able to revise models and to reflect on why they have changed their models. The teacher often emphasized limitations of models and students were able to point out limitations themselves, and reflect on the MMK idea of limitations during the post interviews.

The findings of this research, and the analysis of teacher instruction in particular had immediate implications for materials development and design: both teacher materials and student materials of the curriculum were revised; more teaching strategies and more educative features for the teachers were added. In addition, all student activity sheets were revised in order to embed reflective items in students' everyday practice of modeling. Here are some of the specific changes made to the materials as a result of this study:

- we scaffolded the use of a key earlier in the unit (lesson 4), since it appears that this was helpful for efficient communication of the students' models.
- we added questions regarding limitations earlier in the unit, and we followed-up on these questions earlier (not only in lessons 5, and 15 but also lessons 4, 10, and 13).
- we added more questions that help students make sense of other models then drawings were added (such as; 'what each gumdrop represents, when students build a gumdrop model of a molecule).

The results of this study can inform the design of future instructional materials that focus on modeling and specific content learning goals. Moreover, the study can inform professional development programs aimed at assisting teachers' to help students use scientific models and engage in the practice of modeling in order to promote the students understanding of scientific concepts and the nature of science.

The study also raises some important questions: can students perform the practice (and improve in it) without developing a profound understanding of the MMK? For example, students' improvement in labeling their models could be a result of a rote procedure that the teacher stressed over and over again. In this situation students know they have to do it, but they may not understand why it is important. Thus, our follow-up questions are:

- what is the relationship between MMK and modeling practices? (is one dependent on the other and if so which ones?)
- how do students use MMK knowledge in their practice with models?
- does effective engagement in modeling reflect improved MMK or can one engage in effectively modeling without specific MMK?

We hope to examine these questions through additional studies and analysis of students' artifacts.

Finally, we are also interested in collecting data that inform the development of learning progressions for modeling. Some potential designs for learning progression are (a) a focus on improved accuracy and completeness of students' models by revisiting the same modeling practices and same phenomenon repeatedly (which was the focus of this study); (b) a focus on improved accuracy and completeness of students' models by using the same modeling practices, but with increasingly more complex phenomena; and (c) a focus on improved accuracy and completeness of students' models by gradually incorporating more advanced practices (such as using models to make predictions vs. using models to construct explanations), or incorporating more diverse and difficult content—in other words students could use models in different ways in different subject matter over time**.** In the case of C – the question of how Modeling and MMK transfer across disciplines needs to be addressed. In IQWST modeling is the focus of two units: 6^{th} grade physics unit, which investigate light and how we see, and the 6^{th} grade chemistry unit, which was the unit under study in this paper. A future study will follow students who study both units, and assess the transferability of modeling practices and MMK. Thus, this current study will also inform our future studies by identifying important questions to address and useful methods to use when we examine teachers' instructional practices and students' understanding and use of models over time.

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