Incorporating Modeling Practices into Middle School Project-Based Science

David Fortus[1], Yael Shwartz[1], Ayelet Weizman[2], Christina Schwarz[2], & Joi Merritt[3]
[1] Weizmann Institute of Science
[2] Michigan State University
[3] University of Michigan

Abstract

IQWST is an NSF-funded project developing a comprehensive and coordinated middle school inquiry-based science curriculum. Three studies, conducted in the context of pilot enactments of two 6th grade units, one in physics and the other in chemistry, investigated the ability of students to engage in different aspects of scientific modeling, their understanding of meta-modeling knowledge, the contribution of modeling to the student's learning of science content, and identifying students conceptions of models and modeling as exhibited in classroom discussions. The results corroborate previous studies that demonstrated the power of modeling in helping develop content knowledge. A minimum level of content knowledge was required for students to engage in advanced levels of modeling. The pathways in which knowledge of the practice and the content developed depended on the context and differed between students. While students were engaged in multiple aspects of the practice, their meta-modeling knowledge seemed limited. Transferring of modeling knowledge from one unit to the next was apparent. These findings are helping guide the revisions being made to the curriculum materials and informing the development of the learning progression.

Background

Science instruction focused around modeling can help learners develop deep understanding of subject matter as well as the nature of science (Lehrer & Shauble, 2000; Schwarz & White, 2005). The enactments of two 6th grade units rich in modeling activities, in physics and chemistry, were the focus of four studies described in this paper. The rationale for focusing on modeling, the various aspects of the practice, and the meta-knowledge associated with it are described in Paper 1 in this symposium (Schwarz, Fortus, Roseman, Ladewski, & Willard 2008).

Context of the study

Investigating and Questioning our World through Science and Technology (IQWST) is an NSF-funded project that brings together scientists, science educators, learning scientists, teacher educators, and specialists in technology and literacy, language, and culture to develop a comprehensive and coordinated middle school science curriculum. The standards-based design approach situates student learning in meaningful, extended investigations, in a project-based environment (Shwartz, Weizman, Fortus, & Krajcik, accepted). The materials support students in acquiring deep understandings of scientific concepts and practices such as modeling, designing investigations, explanation, and argumentation (Fortus et al., 2006). The curriculum materials are organized around driving questions that provide a context to motivate and apply the science students learn, and contain hands-on experiences, technology tools, and reading materials that extend students' first-hand experiences of phenomena and support science literacy. The teacher materials include multiple embedded educative supports that focus on content knowledge and various aspects of pedagogical content knowledge.

The first two units of the IQWST curriculum (6th grade physics and chemistry) introduce the notion of modeling as a scientific practice. While the nature of the modeling practices in both units are similar, the scientific content which underlie them is entirely different. The IQWST approach to modeling involves students creating models to explain phenomena and then reflecting on how the models account for these phenomena. Students construct class consensus models and then use this model to attempt to explain new phenomena. In the process the model is evaluated and then revised, if deemed appropriate. The models that students develop provide a window into both students' ideas about modeling and their content knowledge.

How was modeling was incorporated into both units?

Modeling is an integral component of both units. Students are involved in all aspects of modeling: constructing models, using them to illustrate, explain and predict phenomena, evaluating, and revising models. Both units scaffold the practice, and gradually increase the level of complexity of the tasks. Our assumption is that meaningful engagement in modeling requires the development of meta-modeling knowledge regarding the purpose and the nature of models. The pedagogical approach that supports the practice of modeling focuses on motivating the use of modeling practice, pushing students to reflect on their own practice of modeling through classroom discussions, providing prompts that remind students to consider key meta-knowledge or practices relating to models, and providing multiples opportunities to apply and assess their understanding. It is important to keep in mind, however, that goal of learning about modeling and models never overshadowed the goal of supporting students in building understanding of the scientific content of the units**.**

Modeling in the 6th grade physics unit: Seeing the light – Can I believe my eyes?

The first 6th grade unit focuses on investigating how light provides us information about the world. It deals with the way light (visible and non-visible) propagates, interacts with matter, and how light is detected for us to generate images of the world. The practice of modeling is introduced early in the unit and is developed in conjunction with the content. After an anchoring activity, students construct 3D physical models to show how they think we see an object. The students discuss and compare their different models in order to decide which features are most useful to accurately represent and account for patterns in light-related phenomena. In order to scaffold the construction of a drawn consensus model, the class agrees early on that specific components and relationships have to be present in the models: a light source, a light sensor (such as the eye), an object, and unblocked paths between them. They also agree on using lines and arrows to represent how light travels. The consensus model is then used to explain and predict additional phenomena such as shadows, backwards scattering versus reflection, transmission, absorption, and color perception. As the range and complexity of phenomena is increased, the model is revised to enhance its explanatory power. Finally, students use the revised model to predict and test the behavior of ultraviolet and infrared radiation to determine if they can be justifiably called non-visible light.

Modeling in the 6th grade chemistry unit: How can I smell things from a distance?

The main learning goal of the 6th grade chemistry unit is to develop a particulate view of matter. This is done by investigating the question "How can I smell things from a distance?" As in the physics unit, the students are asked to create models and use it to explain how can smell travel. The initial models reflect students' pre-existing conceptions, and are the starting point for the process of revisiting and revising them. In addition to the phenomena of smell, students are asked to draw models that explain other real world phenomena throughout the rest of the unit, such as: A) air being added to existing air in a confined container, B) air being removed from a sealed container while the remaining air expands and fills the container, C) air being compressed by decreasing the volume of the container containing it, D) a strip of pH paper changing color when held above the surface of a solution of ammonia, and E) a spot of colored dye spreading faster in hot water than in cold water. As students develop models to explain all of these phenomena, they asked to compare and revise their models to account for the observed phenomena.

The 6^{th} grade chemistry unit builds off students' experience with models and modeling in the 6^{th} grade physics unit on light (Shwartz et al., in press). In addition, the chemistry unit also introduces the idea of multiple possible models representing the same phenomenon. Dynamic computerized simulations, drawings, and many physical models (beads, ball & stick models, students acting as molecules to represent motion at different temperatures) – each emphasize different aspects of a phenomenon. The issue of simplicity and parsimony is also discussed: when is it necessary to represent the different kinds of molecules in air and when is this distracting? When do we need to represent the inner arrangement of a molecule and when is it enough to represent a molecule as a circle? The students come to the conclusion that the consensus model of matter is an abstract one that can be represented in a variety of models.

<u>Teacher Support</u>

The teacher materials of the curriculum included educative supports for guiding modeling activities. The support included teacher background knowledge about modeling and about students' common conceptions on models and modeling (Grosslight, Unger, Jay, & Smith, 1991). Figure 1 is an example of such support:

***Teacher Background Knowledge*:**
1. Scientific models are used for **explaining or predicting** phenomena in the natural world. Models and modeling are integral to scientific investigations. Scientific models include a mechanism for what causes phenomena. Scientific models allow scientists to make predictions about phenomena.
2. Scientific models have limitations. Not everything in a phenomenon can be explained with a single model. Often they are simplifications of the processes or factors underlying a particular phenomenon. For example, one could build a model of a single water molecule to represent the substances found in a cup of liquid water. Yet this model does not represent the huge numbers of water molecules in a cup of water or that all these molecules move. Therefore this model could not be used to explain what happens when water boils.
3. More than one scientific model can be developed to explain the same phenomena. Scientists judge how good a model is based on how well it helps to explain the phenomena – not by how similar it looks to the thing you are trying to explain or describe. A good model will consistently help explain or predict many relevant phenomena. For example, a good model of matter in the gas phase will consistently be used to explain all the behaviors of gas observed in the real world (e.g. what happens when air is cooled, heated, or compressed), but it will not be used to explain the behavior of solids.
4. Models need to be consistent will ALL observations of relevant phenomena. Models can change over time as new evidence become available. Models can be revised or replaced with a new model.

Figure 1: Teacher Background Knowledge – from the 6th Grade Physics Unit

Classroom discussions hold a central role in helping students develop their understanding of modeling. Teachers need to support students in thinking deeply about what they have experienced. Thoughtful dialogue is critically important if students are to make sense of the modeling activities.

The teacher materials include support for discussion by pointing out specific places for discussions in the curriculum, by clearly defining the purpose of each discussion, and by including specific prompts. For example:

> ***Synthesizing Discussion*** *(Physics Unit, Lesson 3)*
> *Purpose: Remind Ss of the discussion about models from Lesson 2.*
> *Suggested Prompts:*
> • *What kind of model do you think would be good to describe how we see?*
> • *What should such a model include?*
> • *How can we know if this model is good?*
> • *What do we want to represent with the model?*
> • *How do you think the model will help us answer the first question on the DQB (how does light allow me to see)?*
> • *What do you want to include in the model so that it will accurately represent how you see?*

The Studies

The three studies described in this paper were conducted in the pilot enactments of the 6th grade physics and chemistry units (Fortus, 2006; Krajcik, 2006). All three studies were done at urban, rural, and suburban schools with three different teachers. For all three teachers this was either their first or second time teaching these units. None had taught both units before. Not had participated in modeling-specific professional development. The data was collected in 2006-2007. Overall the four studies used a variety of research tools: pre/post tests, students' artifacts, interviews and classroom videos.

Study 1: Using scientific models to learn about shadows

The purpose of the study was to explore the relations between the modeling practices in the physics unit and students' ability to explain a related phenomenon. More specifically we asked:

- Did students understand the scientific model of how we see?
- Did the integrated modeling & content approach taken by the unit help students understand how shadows are formed and seen?
- How was students' understanding of shadows related to their understanding of the model of how we see?

Methods

20 students (from two different classes) were interviewed at the beginning and the end of the unit; 6 of them had an additional interview after Lesson 5 (that dealt with shadows). Other data collected include student-generated artifacts, videotapes and observation-logs of lessons. In this paper we concentrate on the 6 students that were interviewed three times – 3 girls and 3 boys, 2 of them high achievers and the others middle to low achievers, based on the pre-instructional interviews. The interview protocol included questions about light and shadows, as well as about models. They were also presented with a Lego model including a person, an object (tree or flag), and a light source (flashlight- turned off), and were asked to explain how light from the light source allows the person to see the object, and whether they thought there would be a shadow or shadows in that situation. Then they were asked to make a drawn model of the situation, including the shadows, and add arrows to show how light from the light source makes the shadows and allows the person to see the shadows. A coding scheme based on the learning goals of the unit was used to analyze the interview-protocols and the students' drawn models (Weizman, & Fortus, 2007).

Findings

By the end of the unit most of the students understood the light model, but for different students this understanding developed differently as the model was developed, applied, revised and evaluated. This finding is supported by previous studies (Eaton, Anderson, & Smith, 1984) that showed how the development of new conceptions is gradual and depends on prior knowledge. Modeling supported students' understanding of the nature and vision of shadows. This result corroborates previous studies that demonstrated the power of modeling in helping develop content knowledge (Lehrer & Schauble, 2000; Schwarz & White, 2005).

There was a close relation between the understanding of the content and the practice: understanding the practice developed only after some improvements in content understanding – students that struggled with the content also had difficulties with the practice. Students who reached the highest level of understanding of modeling (such as using models to predict new phenomena) were those who had the best content knowledge. The integration of the content with the practice of modeling had joint advantages. Engaging with the practice supported students in constructing their content knowledge, but some initial content knowledge was required to engage in advanced levels of modeling.

For example, Figure 2 shows two drawings, made by the same student, that were drawn during the pre- and post- interviews. This student showed a strong initial understanding of both light and shadows. Regarding vision he held an intermediate conception: “The light shines on the tree and reflects to the person’s eyes by bouncing off, **or** the person’s eyes can see the tree where light is shining.” Regarding the nature of shadows he explained: “*a shadow is the spot where sunlight doesn’t get. Something is blocking the light from getting to this spot*.” The pre- drawing has a correct model for vision and for the direction of the shadow, but no indication how the shadow is created and seen. The post- drawing is showing high level understanding of the model, including arrows indicating how the shadow is created and seen, and showing also light that is scattered, reflected and absorbed.

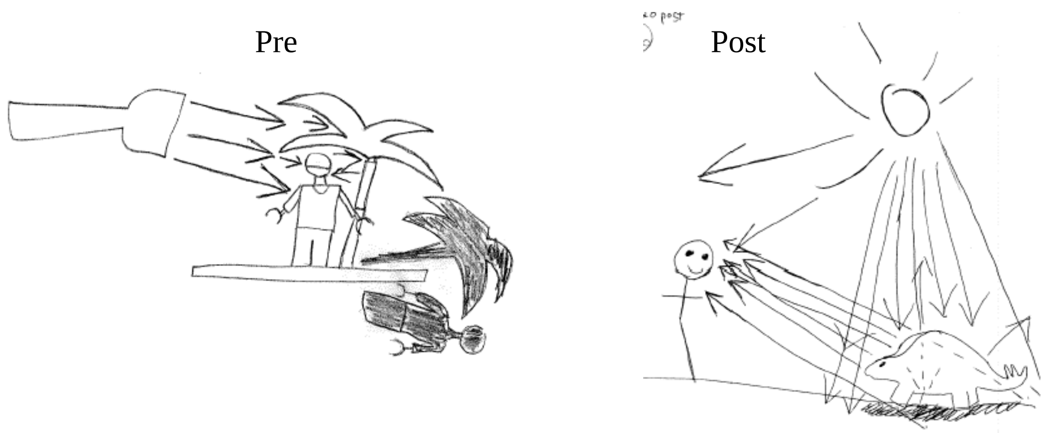

Figure 2: Pre- and Post-Instructional Drawing of How Shadows are Made and Seen

Study 2: Using modeling to develop a particle model of matter

Numerous studies have documented the difficulties middle, high school, and college students have in understanding of the particle nature of matter (Harrison & Treagust, 2002). One reason for this is that often, traditional curriculum materials present the particle model and related ideas as facts, without helping students to develop the ideas based on this model. The 6th grade IQWST chemistry unit takes the approach of building students’ ideas through the construction and revision of models. The focus of this study (Merritt, Shwartz, & Krajcik, 2007) was to understand how students’ understanding of the particle nature of matter changes over time as they experience the curriculum. Thus, we sought to answer the question: How does students’ understanding of the particle model of matter change during the curriculum?

Methods

One suburban teacher and her two 6th grade classes were the focus of the study. Data sources include pre- and posttests, students’ artifacts and video recordings of the curriculum enactment. Pre- and posttest items included items in which students created models of various phenomena.

Findings

The results revealed that the modeling approach was effective in developing understanding of the particle nature of matter. Most students moved from a continuous to a molecular view of matter. This is reflected in students' learning gains from the pre- to posttest (see Table 1) and in the increased sophistication of the models students created during instruction (see Figure 3).

Items (Max Score)	**Pretest Mean (SD)**	**Posttest Mean (SD)**	**Gain (SD)**	**Effect Size[1]**
Total (36)	16.9 (4.1)	28.2 (5.2)	11.3 (5.0)	2.8***
Multiple Choice (18)	8.8 (3.0)	14.2 (2.9)	5.4 (3.0)	1.8***
Open Ended (18)	8.4 (2.1)	14.0 (3.1)	5.5 (3.3)	2.6***
Items by category				
Modeling Items (23)	10.3 (2.9)	18.3 (3.5)	8.1 (4.0)	2.8***
Phase Change (13)	5.4 (2.0)	10.2 (2.4)	4.7 (2.7)	2.4***
Particle Nat. (18)	7.6 (2.4)	14.6 (2.9)	7.0 (3.2)	2.9***

*** p < .001

Table 1: Overall Student Learning Gains (n = 57)

Analysis of the students' models indicates that students took different paths towards developing a particle model of matter. These different pathways are indicated through the different types of models students create, the parts of the drawing that they label as well as the language used (macro versus micro) in the written portion of their models. Figure 3 is an example of one student's pathway in three different lessons.

The results also indicated the importance of the teacher ability to implement the curriculum. In sum, a curriculum that is designed to help students to explain new phenomena through the practice of modeling helps students to gain understanding of the particle nature of matter.

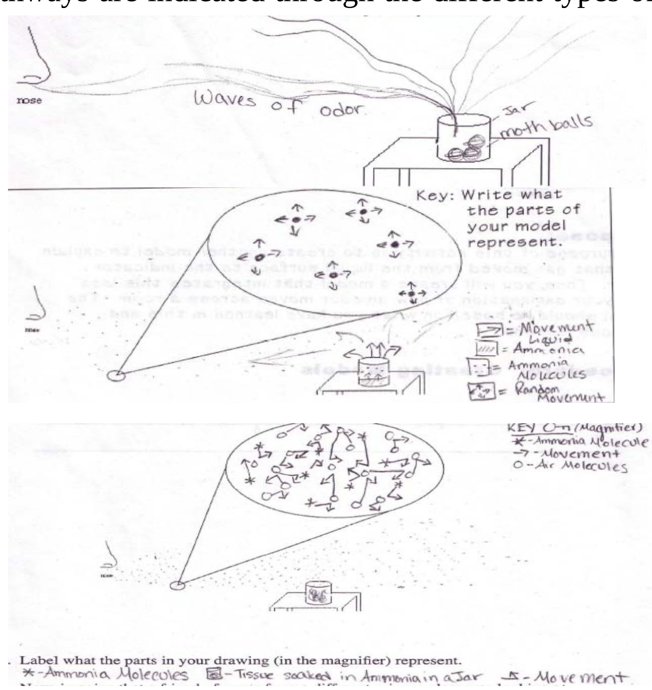

Figure 2: Changes in a students' models of the same phenomena

[1] Effect size: Calculated by dividing the difference between pre and posttest mean scores by the pretest standard deviation

Study 3: Developing the Practice of Scientific Modeling through Classroom Discussions

Discussions are an important component of inquiry learning that can foster learning of scientific practices. Many studies have shown how students' scientific knowledge is constructed and communicated through cultural and social interactions (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Students need considerable support in developing and discussing scientific practices (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Richmond & Striley, 1996). Both IQWST units provide supports for discussions, by indicating the types of discussions in each lesson, and suggesting relevant prompts for each classroom discussion (Fortus et al., 2006). The types of discussions in the curriculum include: brainstorming, connecting, synthesizing, summarizing and pressing for understanding. The questions investigated in this study were (Weizman, Shwartz, & Fortus, submitted):

- What are the characteristics of classroom discussions around models and modeling?
- What changes in students' engagement in modeling practices are reflected through discussions?
- What changes in students' meta-modeling knowledge are reflected through discussions?
- What is the contribution of classroom discussions to the observed changes?
- What are students' perceptions of the contribution of discussions to their learning?

Methods

Sixteen lessons from the two units that included discussions on modeling were videotaped (including some discussions on other topics for comparison). Since some lessons lasted more than one class period, the data include about 30 class periods in each school. In addition, after the units were completed, stimulated recall interviews were held with four students about their impressions of the discussions involving modeling. Each student was shown three segments of discussions that s/he participated in and asked about their understanding and attitudes at the time the discussion took place. They were then asked about the effectiveness of discussions in comparison to other instructional methods.

Findings

Analyzing classroom discussions reveals the following changes in students' engagement in modeling:

1. Students were able to engage in more advanced modeling practices in later lessons of the same units. For example, about mid-unit (both for physics and chemistry) students were able to use their model to explain a phenomenon they already observed. In the latter lessons they were able also to use their models to predict the outcome of an experiment before conducting it.
2. Students become experienced in modeling and can apply the same practices to new content and new situations. For example, students construct models in the chemistry unit based on their knowledge and experience from the physics unit. The students could identify the components that need to be in the "smell" model (i.e. a source, a detector (nose) and a way to describe the traveling of the smell) more easily, based on their experience with the components needed for the light model.
3. As students gain more experience generating explanations and learn to base their explanations on evidence, their modeling practices that are related to explanations develop too. These practices include using models to explain phenomena, evaluating and revising models, as expressed in classroom discussions. For example, in one of the first lessons of the light unit students' evaluation of models during a classroom discussion

concentrates on external features of the models, while in one of the later lessons in the smell unit the evaluation deals with the nature of the model and students are able to persuade their peers using arguments based on models.

Students acknowledged the role of discussions in the lessons and indicated that whole-class discussions helped them learn about models. The contribution of the discussions appeared to be related to the influence of the group on individual learners, and the way knowledge is constructed in a community.

Conclusions and Discussion

Each of the studies presented above highlight a different perspective that helps assess the effectiveness of incorporating modeling into middle school science curriculum. Our main conclusions from them are:

Relation between content and practice

Studies 1 and 2 provide evidence for the effectiveness of the modeling approach in supporting the understanding of scientific content knowledge. For both units there were significant learning gains, as demonstrated in pre/post tests. It appears that the relation between content and modeling practice are complex. While Study 1 found that some initial content knowledge is needed to be able to use a model, Study 2 found that students were able to use their models, and communicate effectively even if they had a complete continuous view of matter and no perception of particles at all. It might be that different contexts provide different pathways in which the practice and content understanding develop. This conclusion may have a major effect on the development of learning progression on modeling. This complex relation between modeling practice and content knowledge also has implications for assessment – what do items involving aspects of modeling assess – content understanding, modeling abilities, or both? Can the content-practice entanglement be unraveled?

Practical involvement in modeling develops before meta-modeling knowledge

Studies 2 and 3 show that students were highly engaged in "doing" modeling: constructing, evaluating, discussing, and revising. However, we have much less evidence for the development of the meta-modeling knowledge (MMK) associated with the practice. For example: With appropriate teacher guidance students were able to evaluate a model, using several evaluation questions they agreed upon: Does the model include all four components? Does the model show movement of particles? Does the model explain how smell travels? However, we do not have solid evidence that students grasped the notion that all models are evaluated by some general criteria such as how consistent they are with evidence.

Since both units were designed to primarily support content understanding, it may be they provide less support for the development of MMK than for the practice itself. Also, the enacting teachers themselves put more emphasis on content knowledge then on discussing MMK issues. In order to validate this emerging conclusion, a version of the curriculum with enhanced MMK support has been produced. This version is being currently piloted.

Research need to focus on relatively limited aspects of modeling

In both units under study, the students were engaged in a broad range of aspects of modeling: construct, use to explain and predict, evaluate, and revise. The three studies described here focused on the overall impact of the units, and not on specific aspects of modeling. We need to focus and learn more on each aspect. For example, considering the process of "constructing models", the following question may be investigated – what exactly happens when a student constructs a model for the very first time, what kind of knowledge comes to play? What are the differences between constructing an individual model and a group model? What kind of knowledge do students use when they construct models in different contexts? Developing a learning progression on modeling requires taking a closer look at each aspect.

More teacher support needed for modeling

The studies described here followed three teachers as they enacted the units. All teachers put a stronger emphasis on the science content then on modeling meta-knowledge. One of the teachers in particular was focused more on the scientific correctness and accuracy of the students' models rather than using the students' models as thinking tools. More support for teachers, both in PD and embedded in the curriculum, is needed to promote the learning goal of understanding the role of models in science.

Implications

The findings of these three studies have informed the unit developers about the strengths and weaknesses of the modeling approach. The designers have revised the units and enhanced the embedded support provided in the teacher guides. This support includes more teacher background regarding the meta-knowledge underlying the practice and more information about students' common conceptions. In addition, specific class discussions for discussing modeling were designed in order to help the teacher orchestrate the type and time of discussions when they are most helpful. The units with 'enhanced' modeling features are being currently piloted.

References

Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5-12.

Eaton, J. F., Anderson, C. W., & Smith, E. L. (1984). Students' misconceptions interfere with science learning: Case studies of fifth-grade students. *The Elementary School Journal, 84*(4), 365-379.

Fortus, D. (2006). Seeing the light: Can we believe our eyes? Michigan State University.

Fortus, D., Hug, B., Krajcik, J. S., Kuhn, L., McNeill, K. L., Reiser, B. J., et al. (2006). *Sequencing and supporting complex scientific inquiry practices in instructional materials for middle school students*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, San Francisco, CA.

Grosslight, L., Unger, C., Jay, E., & Smith, C. L. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*(9), 799-822.

Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *The Journal of the Learning Sciences, 8*(3 & 4), 451-493.

Krajcik, J. (2006). How can I smell things from a distance? University of Michigan.

Lehrer, R., & Schauble, L. (2000). Modeling in mathematics and science. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 5, pp. 101-159). Mahwah, NJ: Erlbaum Associates.

Richmond, G., & Striley, J. (1996). Making meaning in classrooms: Social processes in small-group discourse and scientific knowledge building. *Journal of Research in Science Teaching, 33*(8), 839-858.

Schwarz, C. V., & White, B. Y. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction, 23*(2), 165-205.

Shwartz, Y., Weizman, A., Fortus, D., & Krajcik, J. (accepted). The IQWST experience: Coherence as a design principle. *The Elementary School Journal*.

Weizman, A., Shwartz, Y., & Fortus, D. (submitted). *Developing the Practice of Scientific Modeling through Classroom Discussions.* Paper presented at the National Association for Research in Science Teaching, Baltimore, MD.