What does it really mean to “honor teachers’ knowledge”? What does it mean to work with and alongside teachers to develop a rigorous and profound understanding of science? There are many ways to approach the challenge posed, and one way is through Model-Based Reasoning. Teachers, in collaboration with faculty and directors at the Sacramento Area Science Project, have been using Model-Based Reasoning to develop their understanding of science, teaching, and student learning and reasoning that enable all to develop the habits of mind that characterize science as part of the practice of inquiry. This model has generated deeper thinking about how students are not only making sense, but also how they are developing a firm grasp of a model which explains the phenomena they are observing. Open reasoning by students enables teachers to better “see” how a logic based on evidence is emerging in learners and also teachers.

Overview

Members of the Sacramento Area Science Project (SASP) and twenty-four local teachers have begun a bold experiment with the aim of improving science instruction in 6-12 classrooms. The program, funded by the National Science Foundation (NSF), is called Innovations in Science Instruction through Modeling (ISIM). It is a two-year sequence of activities that first introduces teachers to a new approach to thinking about science and science instruction, and then asks them to undertake reflective experimentation in their own classrooms as they first design and then implement curriculum units based on the approach. The program has re-integrated teachers by providing a new way to approach the science they teach and has provided strong support for classroom implementation by building grade-level/content area teams.

The model-based reasoning (MBR) approach

Our approach to science education takes two things as given. First, we believe that to be educated in science one must learn both the content and process of science. Students must learn about the major ideas in various science disciplines and how those ideas were generated and justified through inquiry. Second, we believe that science instruction should be developed around a set of principles about how people learn. The model-based reasoning approach taken in the ISIM program achieves both aims. Although different science disciplines “do science” in distinct ways, a core activity across disciplines is developing, testing, and revising models that account for a set of natural phenomena. Scientists use models to formulate questions about the natural world and attempt to make sense of their data in terms of those models. The process is iterative: models are constructed, tested, modified, or discarded, and their relationships to other models within a discipline are continually assessed.

If we accept that a key activity in science is the development and use of models, then courses that are intended to promote scientific understanding should also involve students in the processes of constructing and using models for the purpose of making sense of a wide variety of phenomena. To this aim we have developed a framework that represents a view of science as a way to make sense of the world by constructing, revising, and applying models that account for natural phenomena. We seek to highlight the commonalities across science disciplines, while simultaneously recognizing that different disciplines inquire in unique ways. This framework is described in detail in the most recent CSP Connection (Passmore, 2009).

This perspective on science as a modeling activity has been demonstrated to be a powerful way to develop deep understanding of scientific ideas and serves as a useful entry point into designing challenging learning experiences for students (Carter & Stewart, 1999; Passmore & Stewart, 2002). Other researchers have also found that centering instruction around model-based reasoning has strong benefits in terms of students’ content understanding, as well as how they view the work of science as a modeling enterprise (see for example, Schwartz & White, 2005).

Clearly, the research literature demonstrates that taking a modeling approach to science instruction shows a great deal of promise for engaging students in constructing deep understandings of both the content and process of science. Given this perspective, the main goal of the ISIM program is to understand how teachers first adopt and then promote pedagogical practices that engage students in model-based reasoning.

Professional Development Philosophy

At the Sacramento Area Science Project, we believe that professional development is about generating teacher knowledge. In their 1999 review, Cochran-Smith & Lytle posited three ways one might conceive of knowledge. In their 1999 review, Cochran-Smith & Lytle posited three ways one might conceive of knowledge. The first is what they termed “knowledge for” practice. This is the set of codified ideas that are generated as formal knowledge that is intended to inform teachers. The second is “knowledge in” practice, the set of practical skills and dispositions that a teacher develops as he or she masters the craft. And third, teachers develop a construct they call “knowledge of” practice. The authors state that, “Unlike the first two, this third conception cannot be understood in terms of a universe of knowledge that can be divided into formal knowledge, on the one hand, and practical knowledge on the other. Rather, it is assumed that the knowledge teachers need to teach well is generated when teachers treat their own classrooms and schools as sites for intentional investigation at the same time as they treat the knowledge and theory produced by others as generative material for interrogation and interpretation. (p. 250) It is this third conception of knowledge that guides our work with teachers in the ISIM program. We do not approach professional development as though teachers person- nal knowledge that guides our work with teachers in the ISIM program. We do not approach professional development as though teachers personal. Rather, it is assumed that the knowledge teachers need to teach well is generated when teachers treat their own classrooms and schools as sites for intentional investigation at the same time as they treat the knowledge and theory produced by others as generative material for interrogation and interpretation. (p. 250) It is this third conception of knowledge that guides our work with teachers in the ISIM program. We do not approach professional development as though teachers personal knowledge that guides our work with teachers in the ISIM program. We do not approach professional development as though teachers personal knowledge that guides our work with teachers in the ISIM program. We do not approach professional development as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though teachers personal knowledge as though te

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By midyear, the written representation of our model reflected our enhanced understanding and focus. This iteration of our model reflected both a deeper understanding of ocean currents and an increasingly sophisticated method for representing the model. As our model became clearer, our representation became clearer as well and so we were ready to design the instructional sequence.

In the spring, we taught a series of lessons to engage our students in developing and reasoning with the model explaining Earth’s deep ocean currents. Our goal was to provide the students with the appropriate data and lab experiences in the proper sequence, so that they could construct a model similar to our own. We were able to observe each other teach several of the lessons we had collaboratively designed. Through the lessons, students developed a nuanced and complex understanding of the nature of density currents, particularly related to temperature and salinity differences. However, as we carefully examined what happened in our classrooms, it became clear that our model lacked an explicit description of the phenomena it explained in Earth’s oceans. The lessons only weakly linked the density currents the students experienced in the labs to real world oceanographic data. By this point, we understood the fundamental relationship between density currents in fluids and Earth’s deep ocean circulation. However, that understanding did not translate completely into the lessons we had designed for our students. It was difficult to turn our model into an appropriate sequence of experiences for students; yet we were determined to find a solution.

As we reflected upon our experiences during the summer of 2008, many of our ideas took root and blossomed. Our focus shifted, from envisioning our model as one about deep ocean currents, to thinking of it more broadly as a model of density currents related to the phenomenon of deep ocean currents or layer formation. We realized that the entire Earth science curriculum could be grounded in our model of density currents. While acknowledging other models could unify Earth science, we were excited that we could apply our model throughout the curriculum, that convection in Earth’s mantle (driving plate tectonics), convection in the atmosphere (driving wind and weather), the formation of solar systems and stars, and deep ocean currents could all be explained through our model of density currents in fluids. Additionally, we thought that if our students developed a model of density currents near the start of the school year, the model could be specifically tied to real world data during each major unit in Earth science. For our oceanography unit, we could now effectively introduce real month-by-month global temperature and salinity data for the students to consider. Students could analyze the data in light of their existing understanding of density currents, and develop a much richer model directly connected to Earth’s oceans.

The final version of our model of deep ocean currents is shown in Figure 1. The left side of the diagram is the general model of density currents, while the text on the right highlights the most important features related specifically to deep ocean currents. Overall, the process of developing our model and observing our lessons unfold in the classroom was very rewarding for both teachers and students. We noticed that during our lessons, the students were engaged in the subject matter at a deeper conceptual level than we had ever experienced in the past. It also seemed to be much easier for students to grasp new science concepts related to density currents once they had gone through the process of developing their own models. For example, when we moved into the weather unit, students often invoked their density current models appropriately to explain meteorological phenomena. It was a joy to see our work in model-based reasoning positively impacting our students. It was also a pleasure to work together in a study group with intelligent, dedicated and curious colleagues.

Through this professional collaborative experience our model evolved over time, but we have evolved as teachers at least as much.

OUR FINAL MODEL OF DEEP OCEAN CIRCULATION (thermohaline circulation).

In Earth’s oceans:

- Temperature Differences
- Phase Changes
- Saliency Differences
- Density Differences

Critical Elements of our Model (to bound the model):
- The primary driving force is the seasonal ice formation at the poles, creating pulses of salinity.
- The critical temperature factor is the seasons.
- The critical phase change factor is the slow freezing of ocean water.
- The critical salinity factor is that in the oceans salinity differences affect density much more than water temperature differences.
- The critical density factor is that density differences in a fluid lead to currents or layer formation.
- The natural phenomena explained by this model are the deep ocean currents (thermohaline circulation).

Learning this model is greatly facilitated if participants have already developed and tested a model of how temperature differences can create density currents in a fluid, and how adding more matter to the same volume (i.e. salt to water) affects density (and why). Once understanding of this basic model has been achieved, one can reason that seasonal temperature differences (and the corresponding cyclical freezing and thawing of polar ice) are a critical factor in the deep ocean circulation pattern. As sea ice forms near a pole from freezing ocean water, the water beneath the ice becomes highly saline (salt is excluded from the crystal matrix as liquid water solidifies into ice). Each winter, at alternating poles, these pulses of cold saline (i.e. dense) water act as one of the “pumps” for the global deep ocean circulation system.
MBR Instruction vs. Traditional Science Teaching

When instruction is intentionally organized to promote MBR, students work in small groups to deliberate over ideas and come to consensus about the model. The content we formerly covered, by using vocabulary exercises or question sets, often bubbled naturally to the surface in the course of trying to deeply understand what makes a wave and why it behaves the way it does in the various media. Students found themselves seeking facts and terminology as they needed them instead of having them introduced in a disconnected fashion. We also noticed that students were more likely to remember material and draw on their knowledge of that material in future lessons. In addition to knowing facts, it seemed the students more often understood underlying mechanisms. Overall, we feel that this approach gave students a much more cohesive scientific understanding compared to the frequently fragmented information they acquired through other methods. We still made use of some traditional vocabulary and practice with algorithms, but this practice was shorter and placed differently in the sequencing of the unit.

Students Think and Act Like Scientists

Other recent developments in the ISIM program for us as teachers was struggling to develop our precise statement of ideas. We worked hard at conceptualizing our model of waves and realized that our students would benefit from a similar, carefully scaffolded struggle to develop understanding. Thus our work, and that of the students, was more in line with the ways in which scientists grapple with patterns, develop, apply, revise, or extend a model, and create explanations. In the end, the ideas that made up the model gave us reasons to do activities or lessons because these had a specific purpose in a larger well-articulated scheme.

Much of science occurs in an informal environment where ideas are shared among peers. Such communications require use of consistent reasoning, precise language, clarifying and articulating ideas, and then testing understanding. In the ISIM lessons, we saw our students performing many of these scientific skills and we intentionally built in frequent opportunities for them to exchange and challenge their unfolding ideas in peer groups. Scientists apply their knowledge in new contexts, combine ideas in new and unique ways, apply ideas to accounts for new phenomena and seek to understand causes and mechanisms. During our wave unit, students engaged in these types of activities. Their application of knowledge to novel situations was supported by our instruction, and supplying students with the tools to analyze, reason, and deduce. Many times we have heard the lament that students aren’t thinking, however, in MBR classrooms more of them are and they are questioning the material at a deeper level, making more frequent inferences, and coming to conclusions without us directing them to the answers.

Overall, working with the ISIM team on MBR lessons has emphasized that a scientific body of knowledge is created by detailed observations of scientists working together over a long period of time. If it is possible to recreate this experience for students, we can give them many gifts and abilities including a true-to-life understanding of what it means to think scientifically, draw conclusions from data, work with other people productively, think critically, and develop a cohesive knowledge-base about how the world works.

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They had rarely been asked to think or act this way in their first six years of schooling, so we realized it would take some training and practice to develop strong scientific 

argumentation skills. Going into our second summer institute, we were certainly we needed a tool – some way for students to organize their thinking to let them know what goes into a good scientific explanation. We did our research, and read several articles on scientific reasoning with inspiration (see particularly McNall & Krajcik, 2007), so when the three of us sat down with program organizer Cindy Passmore, our ideas began to gel. According to the National Science Education Standards (NSES), “scientific explanations in- 
corporate existing scientific knowledge and new evidence from observations, experiments, or models into internally consistent, logically supported claims that are not total-ly incorrect. Students are questioning both the teacher and each other, as they discuss new topics. They are beginning to see the science they learn in the 6th grade as a cohesive group of phenomena that can all be understood through fundamental science principles. As instructors, we still have a lot to learn to draw out all the knowledge our students are capable of, but rather than being discouraged or disappointed, we were excited and motivated to continue to help students make con- 
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