Connecting Content Instruction and Scientific Modeling through Scientific Inquiry by Middle School Science Teachers

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August 9, 2016

Historically, science education has sought to accomplish two main objectives: Provide science content to students at an age-appropriate level, and equip students with skills and processes that mimic those of practicing scientists. Emphasis on these objectives has shifted as ideas in science education have changed, though value has been placed on scientific content for a longer period of time. However, recent trends are providing an opportunity for science educators to intertwine scientific content and processes through model-based inquiry (MBI). This pedagogy utilizes the idea of a "model" as a way for students to organize scientific content and practice skills because students actively develop, break, and refine mental models of scientific concepts. Studies show that students of all levels benefit from MBI, and additional studies show that teachers benefit from professional development that has an emphasis on modeling. Before reviewing studies related to student achievement and teacher improvement, a brief discussion of the history of inquiry in science education will help readers understand the fusion of scientific content and inquiry.

Science classes have been an element in the course of study throughout the history of education in the United States, though mathematics and science classes gained special prominence after the launch of *Sputnik I* by the Soviet Union in 1957. Concerned that the United States was lagging behind the Soviet Union in scientific and technological research, the federal government began to pour large amounts of money into science education. Groups of educators—with affiliations to universities, national science laboratories, and national science professional organizations—began to write standards and create curriculum for K-12 science education, developing innovative methods for teaching science. A main focus for the standards and curriculum by these groups was an emphasis on the process of science—known as scientific inquiry—and this focus became embedded as an important part of science education in the *National Science Education Standards*. These standards, established by the National Research Council (NRC) in 1996 after several years of work, were the first set of national science standards. The standards call for students to *do* science instead of passively receiving information, because learning science in an active endeavor. To deeply learn science, students must connect new knowledge with existing knowledge and "engage in problem solving, planning, decision making, and group discussions" (NRC, 1996, p. 21).

Through pre-service and in-service training, many teachers changed their instructional practices to align with the scientific inquiry in the *National Science Education Standards* (NRC, 1996). Many science classrooms incorporated "inquiry activities" whereby students would perform scientific practices to learn skills, but often these activities were divorced from specific science content. To expand the idea of scientific inquiry and reconceptualize the nature of practicing and learning science, the NRC created *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (hereafter known as "the *Framework*"). The committee responsible for writing the *Framework* concluded that science education "should focus on a limited number of disciplinary core ideas and crosscutting concepts" (NRC, 2012, p. 2). Students would build knowledge and skills during their elementary and secondary school careers, exiting with foundational scientific content and skills. The science and engineering practices (SEPs) in the *Framework* differ from scientific inquiry in the *National Science Education Standards* by specifically relating to the content students are studying; inquiry activities prior to the *Framework* did not always meet this requirement. To simplify this paper and clarify terms used by authors, the terms "SEPs" and “scientific inquiry” shall be used interchangeably from this point forward in the spirit given by the *Framework*.

To articulate the vision of science education containing disciplinary core ideas, crosscutting concepts, and SEPs into actionable standards, a consortium of organizations created the *Next Generation Science Standards*. These standards contain “ambitious targets for student learning in science that are based on the goals described in the *Framework*. These targets are framed as performance expectations that describe how students will use their knowledge as they engage in scientific and engineering practices” (NRC, 2015, p. 10). Information in the *South Carolina Academic Standards and Performance Indicators for Science 2014* originates with the *Framework*, though the South Carolina standards replace disciplinary core ideas with content at each grade level. Because the crosscutting concepts and SEPs are identical, the writers of the South Carolina standards provide similar guidance regarding the SEPs; they state that “the [SEPs] are not to be taught in isolation. There should not be a distinct ‘Inquiry’ unit at the beginning of each school year. Rather, the practices need to be employed within the content” (South Carolina Department of Education, 2014, p. 2).

The *Framework* lists eight SEPs, which are

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)

7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information. (2012, p. 42)

From the perspective of MBI, the second SEP, “developing and using models,” is the most important because students utilize the other seven SEPs to create, refine, and break models. An initial model arises from students asking questions of their world, planning and carrying out investigations, and analyzing and interpreting data from the investigations. During analysis and conclusions about the initial model, students use mathematical and computation thinking, construct explanations, engage in arguments from the data, and communicate information about the model. After completing an initial model, students conduct further physical and conceptual investigations to break and refine the model. Students continue to utilize the SEPs during this process, and synthesize relevant scientific content within the model. When the model is shown to be incapable of accurately explaining the results of an investigation, students ask further questions and follow the process to create a new initial model.

The term “model” has many definitions in the scientific and science education communities, and a general definition by Hestenes is that “a **model** is a **representation of structure** in a given **system** [emphasis in original]. A system is a set of related objects, which may be real or imaginary, physical or mental, simple or composite. The structure of a system is a set of relations among its objects” (2016, p. 16). Scientific models help students integrate content with their existing knowledge, and provide opportunities for students to explain their understanding through visual or verbal expressions (Khourey-Bowers & Fenk, 2009). Scientists create conceptual models to represent the physical world, but these models are subject to revision when investigations provide data that contradicts the model. By including the SEPs in the

Framework, teachers are tasked with planning activities that provide opportunities for students to act as scientists and create models that represent a situation.

When asking a member of the general public what they remember about scientific inquiry from their K-12 experience, the most probable answer will contain a reference to the scientific method (TSM). However, Windschitl, Thompson, and Braaten (2008) argue "that TSM is not scientific at all when considered from an epistemic perspective, and that it subverts young learners' understandings of both the practices and the content of the discipline" (p. 942). When teachers use TSM as their primary method of doing science, their "approach to inquiry has no explicit association with scientific concepts, principles, laws, models, etc. This disconnect of inquiry from content is not only antithetical to real science; it can place inquiry on the margins of school curriculum" (Windschitl, Thompson, & Braaten, 2008, p. 946).

As an alternate to TSM, Windschitl and Thompson (2006) argue that a different foundation for inquiry in K-12 education is necessary. Investigations should begin with students asking questions and providing tentative explanations (i.e., a model) about the natural world, and the model should include both physical and conceptual aspects. Data should be collected to test the explanatory power of the model, especially with regards to patterns or relationships. Students should construct arguments related to the patterns or relationships, which should support or refute claims from the model. MBI rectifies the issues present in TSM by providing a theory that is much closer to the core work of scientists, which satisfies the characteristics of inquiry in K-12 education and connects to the eight SEPs in the *Framework*. The focus of inquiry changes from testing a hypothesis to testing an idea, and this shift allows students to develop a conceptual understanding of the topic through the construction of a model. Students create defensible explanations of the way the world works through a series of four conversations, providing a reason for performing experiments and analyzing data. These explanations change the conversation "from an emphasis on 'what' happens in the natural world toward and emphasis on both 'how' and 'why' events happen" (Braaten & Windschitl, 2011, p. 664), allowing students to "engage in productive disciplinary discourse throughout an entire school year developing and refining 'what counts' as a good theory, model, explanation, or argument together as a community" (Braaten & Windschitl, 2011, p. 664). The process of MBI aligns with the manner in which scientists perform work, and implementing MBI is possible at any level of education which helps students develop a thorough understanding of science content and process throughout their K-12 education.

As teachers have introduced MBI into their classrooms, researchers have published case studies concerning the implementation of MBI. The studies have shown positive outcomes for students, and the outcomes include both an increased understanding of models and scientific content. For example, Schwarz et al. (2009) discussed the implementation of scientific modeling with fifth and sixth grade students, and "both groups of learners productively engaged in constructing and revising increasingly accurate models that included powerful explanatory mechanisms, and applied these models to make predictions for closely related phenomena" (p. 632). As students used models to connect content and practices, "students' reflective practice revealed that they understood models as dynamic entities that can and should be revised" (Schwarz et al., 2009, p. 650). Another study was performed by Gobert and Pallant (2004), and these researchers created a curriculum unit for middle school Earth Science in the domain of plate tectonics. The study produced results that suggest "students achieved a deeper understanding of the nature of models, as evidenced by significantly higher scores on the posttest" (Gobert & Pallant, 2004, p. 13). In addition, Gobert and Pallant (2004) believe students benefitted from a better understanding of models and used the models to connect previous information to concepts about plate tectonics. Another study, performed by Bamberger and Davis (2013), focused on two units in sixth grade science. For these units, students built models, used the models to explain phenomena, and revised the models if they provided inaccurate explanations. Bamberger and Davis found that "middle-school students who engaged in model-based science instruction developed an understanding of modelling practice and transferred some of their modelling performances across content areas" (2013, p. 234).

In the past 20 years, organizations and universities have conducted workshops and other sessions to improve the understanding of models and MBI in pre- and in-service elementary and secondary teachers. A study by Akerson et al. (2009) focused on teachers in grades K-6, and the program "prepared teachers to help students develop models, formulate explanations and evaluate data" (Akerson et al., 2009, 23). Teachers participated in a summer workshop, which "focused on science inquiry including process skills, the learning cycle, and nature of science. All topics were included under the umbrella term 'scientific modeling' as a tool used in inquiry teaching and learning in science" (Akerson et al., 2009, p. 24). After the summer intervention and workshops throughout the school year, teachers improved their ability to "grasp the concepts of scientists using scientific modeling to represent ideas. Scientific modeling proved useful in illustrating the distinction between observation and inference as teachers were asked to make observations and use their inferences to make their own models" (Akerson et al., 2009, p. 36). The increased understanding by the teachers was passed along to their students, and students built “models from investigations and interpret[ed] those models. They used the same debriefing questions with their students that we used in our workshops. Students anticipated these questions after building models and articulated their thoughts” (Akerson et al., 2009, p. 36).

A study by Lotter, Yow, and Peters (2013) discussed the effects of a professional development program around inquiry instruction on the practices of middle school teachers and coaches. The program supported a community of practice around inquiry because teachers “engaged in practice-teaching during which they negotiated the skills of inquiry teaching with the help of coach-led reflection sessions. This mutual engagement in inquiry teaching and reflection helped the teachers build a shared repertoire around inquiry” (Lotter, Yow, & Peters, 2013, p. 2). Teachers and coaches participated in a summer institute and four follow-up sessions, and analysis of data “showed that the teachers and coaches gained a better understanding of inquiry-based teaching practices through participating in the PD program” (Lotter et al., 2013, p. 14). Students benefitted from their teacher’s participation in the program because teachers brought the inquiry strategies from the program into their classroom (Lotter et al., 2013).

As the conception of what students should know and be able to do after completing science courses in K-12 education has evolved, the understanding of inquiry by the science education community has also changed. The initial statements in the *National Science Education Standards* provided guidance to educators, and the science and engineering practices provided by the *Framework* deepened the understanding of the science education community. Researchers have several avenues for future work about MBI, and one area could be to provide explicit connections between the work students perform in class and the work of practicing scientists. Another area could be the relationship between MBI and project-based learning; both pedagogies contain similar features but have different foci. Bamberger and Davis (2013) suggest research that focuses on the use of models to facilitate transfer of learning, and Gobert and Pallant (2004) recommend work that characterizes how students make connections between general knowledge and specific science content. As the vision of science education continues to change from didactic learning to co-constructing information with students, models and MBI will provide opportunities for students to experience science in a meaningful way and grow into the next generation of scientists.

References

Akerson, V. L., Townsend, J. S., Donnelly, L. A., Hanson, D. L., Tira, P., White, O. (2009). Scientific modeling for inquiring teachers network (SMIT'N): The influence of elementary teachers' views of nature of science, inquiry, and modeling. *Journal of Science Teacher Education, 20*, 21-40. doi: 10.1007/s10972-008-9116-5

Bamberger, Y. M., & Davis, E. A. (2013). Middle-school science students' scientific modelling performances across content areas within a learning progression. *International Journal of Science Education, 35*(2), 213-238. doi: 10.1080/09500693.2011.624133

Braaten, M. & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education, 95*, 639-669. doi: 10.1002/sce.20449

Gobert, J. D., & Pallant, A. (2004). Fostering students' epistemologies of models via authentic model-based tasks. *Journal of Science Education and Technology, 13*(1), 7-22. Retrieved from http://concord.org/sites/default/files/pdf/student-epistemologies-models-jset-2004.pdf

Hestenes, D. (2016). Conceptual Modeling in physics, mathematics and cognitive science. *SemiotiX*. Retrieved from http://semioticon.com/semiotix/2015/11/conceptual-modeling-in-physics-mathematics-and-cognitive-science/

Khourey-Bowers, C. & Fenk, C. (2009). Influence of constructivist professional development on chemistry content knowledge and scientific model development.

Journal of Science Teacher Education, 20, 437-457. doi: 10.1007/s10972-009-9140-0

Lotter, C., Yow, J. A., & Peters, T. T. (2013). Building a community of practice around inquiry instruction through a professional development program. *International Journal of Science and Mathematics Education, 12*, 1-23. doi: 10.1007/s10763-012-9391-7

National Research Council. (1996). *National Science Education Standards.* Washington, DC: The National Academies Press, 1996. doi:10.17226/4962

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press. doi:10.17226/13165.

National Research Council. (2015). *Guide to implementing the Next Generation Science Standards*. Washington, DC: National Academies Press. doi:10.17226/18802

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Schwartz, Y., … Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(4), 632-654. doi: 10.1002/tea.20311

South Carolina Department of Education. (2014). *South Carolina academic standards and performance indicators for science 2014*. Columbia, SC: South Carolina Department of Education. Retrieved from http://ed.sc.gov/scdoe/assets/file/agency/ccr/Standards-Learning/documents/South_Carolina_Academic_Standards_and_Performance_Indicators_for_Science_2014.pdf

Windschitl, M. & Thompson, J. (2006). Transcending simple forms of school science investigation: The impact of preservice instruction on teachers' understandings of Model-Based Inquiry. *American Educational Research Journal, 43*(4), 783-835.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-Based Inquiry as a new paradigm of preference for school science investigations. *Science Education, 92*, 941-967. doi: 10.1002/sce.20259