Teaching Chemistry using Inquiry and the Three Representations of Chemistry

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Abstract: Science education researchers advocate for a method of teaching science that makes science accessible for all students. Recent reform documents and science education researchers suggest inquiry as one method for achieving this goal (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996, 2000). The importance of inquiry in teaching science is also seen in the new Framework for K-12 Science Education. The new Framework states that science and engineering education should “focus on a limited number of disciplinary core ideas and crosscutting concepts, be designed so that students continually build on and revise their knowledge and abilities over multiple years, and support the integration of such knowledge and abilities with the practices needed to engage in scientific inquiry and engineering design” (NRC, 2012, p. 2). The Framework terminology of “science practices” can be achieved through inquiry. Unfortunately, the vision of reform-based science education advocated by science education researchers and the NRC (1996, 2000, 2012) is not being realized in classrooms due to a variety of issues that include perceived time constraints coupled with high stakes testing, unfamiliarity with how science is practiced, inadequate science content knowledge, inappropriate curriculum, or simply not knowing what inquiry is (Deboer, 2004; Krajcik, Blumenfeld, Marx, & Soloway, 2000).

In chemistry, conceptual knowledge can be viewed at three different representations: macroscopic (observable properties and processes), particulate (arrangement and motions of particles), and symbolic (chemical and mathematical notations and equations) (Gabel, 1998; Johnstone & Letton, 1993). Researchers have found that students are skilled in solving algebraic
problems in chemistry without a clear conceptual understanding of the underlying phenomena (Nurrenbern & Pickering, 1987; Sawrey, 1990; Sanger, 2005; Cracolice, Deming, & Ehlert, 2008). Lacking clear conceptual understanding of chemical phenomena is detrimental to students’ success in chemistry (Gabel, Samuel, & Hunn, 1987). Explicit instruction at the macroscopic, particulate, and symbolic levels should help students understand many fundamental concepts in chemistry since a particulate understanding of matter is needed to explain concepts on the macroscopic and symbolic levels (Gabel, 1998). Understanding chemistry at each of the levels can be difficult for students since students tend to rely on experiences at the macroscopic level to guide their understanding (Bridle & Yezierski, 2012). In terms of the three different levels of representation in chemistry, students cannot simply be given information about invisible particles and be expected to accept it and learn about it. Students must be given opportunities to explore and construct their own understandings so that “a specific representation of the atomic level fits with their understandings of the world” (Bridle & Yezierski, 2012, p. 193). Lacking conceptual knowledge in chemistry affects student performance in chemistry. Currently two approaches to improving students’ conceptual knowledge in chemistry have been explored in the literature. The two approaches that have been explored are curriculum focused on particulate-level representations of matter and inquiry-based instruction (Sanger, 2000; Ealy, 2004; Niaz, Aguilera, Maza, & Liendo, 2002; Lewis & Lewis, 2005).

Since the particulate world of chemistry is invisible and theoretical, models must be used. When models are used, the learners’ ability to comprehend the meaning of the model must be considered. In the new Framework for K-12 Science Education, the development and use of models is one of the eight key science and engineering practices (NRC, 2012). Modeling can begin in early grades and students should progress from concrete pictures to more abstract
representations (NRC, 2012). Students should be able to employ diagrams, maps, and other abstract models in order to explain their own understanding. Students’ use of models should progress as their understanding of models develops through a process of model construction and revision (NRC, 2012). There are two types of models that scientists and science learners use, mental and conceptual (NRC, 2012). Mental models are “internal, personal, idiosyncratic, incomplete, unstable, and essentially functional” (NRC, 2012, p. 56). Mental models serve as a tool for thinking and making predictions and sense of experience. In contrast, conceptual models are “explicit representations that are in some ways analogous to the phenomena they represent” (NRC, 2012, p. 56). Conceptual models serve as a tool for visualizing and understanding a phenomenon. Students’ ability levels vary when constructing, using, and evaluating models (Harrison & Treagust, 1996; Schwarz, Reiser, Davis, Kenyon, Acher, Fortus, Shwartz, Hug, & Krajcik, 2009). A learning progression for understanding models classifies student performance at levels 1-4 (Schwarz et al., 2009). At level 1, students interpret the model as an exact replica or literal illustration of reality (Schwarz et al., 2009). At level 2, students make and use models to illustrate and explain, and at level 3, students make and use models to explain and make predictions about related phenomena (Schwartz et al., 2009). At the highest level, students make and use models on their own without teacher influence and students use their models to make predictions about macroscopic behavior (Schwartz et al., 2009). The use of models requires both practice and metaknowledge (e.g. why are models important? what makes a model?) (Schwartz et al., 2009). As the learner’s ability to work with models increases and their content knowledge increases, students begin to change their models to reflect improved understanding (Schwartz et al., 2009). Having students interact with the three different levels of chemical representation
(macroscopic, particulate, and symbolic) and the development of conceptual models should increase students’ conceptual understanding of chemistry.

The rationale of teaching chemistry by addressing the three levels of chemical representation is guided by learning theories grounded in work by Piaget and more recent constructivist theories including the conceptual change model. The conceptual change model holds that learning occurs when the current knowledge scheme or conceptual framework is modified due to new information or experiences that induce cognitive conflict and encourage learners to develop new knowledge schemes or conceptual frameworks that are better suited to their experiences (Driver, Asoko, Leach, Mortimer, & Scott, 1994; Staver, 1998). Reform-based teaching strategies, like inquiry, discrepant events, and predict, observe, explain (POE) demonstrations, can be used to confront students’ current conceptual framework and lead to learning through conceptual change. Addressing students’ misconceptions or alternate frameworks is also a component of the conceptual change model. In chemistry, students bring varying degrees of understanding about the behavior of matter. Students have misconceptions about atomic and molecular size, shape, and composition (Griffiths & Preston, 1992). The misconceptions include the assumption that atoms and molecules can be seen under a microscope, that the volume and weight of atoms and molecules can change based on conditions, and that the composition of molecules can vary (Griffiths & Preston, 1992). These misconceptions lead to confusion about the classification of matter and being able to distinguish between pure substances and mixtures and between elements and compounds (Stains & Talanquer, 2007). When considering physical and chemical changes, common misconceptions include the idea that boiling liquids involves the expansion of molecules and the breaking and forming of chemical bonds within the molecules (Garnett, Garnett, & Hackling, 1995; Boz, 2006; Ahtee & Varjola, 1998). The common misconceptions
noted are important because the seventh grade SC chemistry indicators address the classification of matter and physical and chemical changes, and seventh grade teachers and students will be the focus of the study. Instruction in chemistry requires constructing a correct conceptual framework within the minds of students and not simply memorizing facts and definitions. By approaching chemistry instruction through inquiry pedagogy which will include the use and construction of models and by addressing the particulate nature of matter using the three different levels of chemistry representations, students can explore and find meaning in the chemistry content that will result in the development of a scientifically accepted conceptual framework.

According to the literature, both particulate-level instruction and inquiry-based pedagogy improve students’ conceptual understanding of chemistry, but little research exists that shows the combination of the different levels of representation in chemistry and inquiry pedagogy (Gabel, 2000; Bridle & Yezierski, 2012). This study will examine how the use of inquiry pedagogy and models with specific attention to the three levels of chemistry representation affects middle level student learning. The study will also examine how teachers incorporate inquiry pedagogy and models along with the three levels of chemistry representations into their classroom teaching. One goal of the study is to analyze the growth in chemistry content knowledge for the teachers from the beginning to the end of the professional development. In order to support students in the construction of scientifically accepted conceptual frameworks, teachers must have a structured and deep conceptual knowledge base that should include the ability to translate between the macroscopic, particulate, and symbolic representations of chemistry (Gabel, 1993; Gabel, 1999; van Driel, de Jong, & Verloop, 2002). Specifically teachers should be able to make meaningful connections between observations of macroscopic phenomena and explanations of
the same phenomena at the particulate level (Gabel, 1993; Gabel, 1999; van Driel, et al., 2002). A second goal of the study is to analyze the quantity and quality of inquiry instruction and how teachers use the three different levels of representation in chemistry (macroscopic, particulate, and symbolic) during inquiry lessons. The third and final goal of the study is to investigate student growth in chemistry knowledge at the three different levels of chemistry representations and whether that growth varies with teacher instructional strategies.

In order to accomplish the goals of the study, an interpretivist study will be designed that uses mixed methods, quantitative and qualitative (Glesne, 2011; Greene, Caracelli, & Graham, 1989). The interpretivist paradigm frames the research because the overarching goal of the research is to understand how inquiry pedagogy and the use of models and the three different levels of chemical representation affect student learning. The quantitative component of the study will examine teacher learning as a result of the professional development through a pre-test/post-test design. Student learning before and after teachers’ use of inquiry pedagogy and specific attention to the three different levels of chemistry representations will be measured through a pre-test/post-test design using questions from the American Association for the Advancement of Science (AAAS) testbank (AAAS Project 2061). Relationships between the teachers’ implementation of the lessons and student learning will also be explored through comparisons between the classroom observations and the students’ performance on the post-test.

The qualitative component of the study will examine the teachers’ quantity and quality of inquiry instruction and the teachers’ use of models and the three representations of chemistry within inquiry lessons. Teachers’ perceptions of student learning, chemistry content, pedagogy and their own inquiry instruction will also be examined. Teachers’ perceptions of the chemistry content and their teaching will be examined prior to the professional development and at the end
of the school year. This component will be achieved through observations, interviews, and document analysis of lesson plans. By combining both qualitative and quantitative methods under the interpretive paradigm, relationships between student learning, inquiry, models, and the three representations of chemistry can be examined.

In 2007, a similar study was conducted by Roehrig and Garrow that focused on gas laws at the high school level. Based on their study, Roehrig and Garrow concluded that “more research involving greater number of teachers and a wider range of topics is needed” (pp. 1808). My study will involve a different level of student (middle vs. high school) and different topics (matter and reactions vs. gas laws). The study will also add to the literature in another way because according to the literature both particulate-level instruction and inquiry-based pedagogy improve students’ conceptual understanding of chemistry, but little research exists that shows the combination of the different levels of representation in chemistry and inquiry pedagogy (Gabel, 2000; Bridle & Yezierski, 2012). In a 2012 study, Bridle and Yezierski addressed the gap between using both inquiry-based instructional practices and particulate-level modeling experiences. In their study, they employed a novel curriculum called Target Inquiry developed by the researchers that focused on phases of matter and chemical versus physical changes in matter. Their study focused on two high school chemistry sections in a large, suburban high school in the Midwest United States and they found that both the qualitative and quantitative results of the study provided support for the positive effect of the novel curriculum that blended inquiry instruction with particulate level modeling. Bridle and Yezierski make no inferences about the performance of the curriculum in comparison to other curricula and in other school settings, and they state that further research with different student populations and different instructors are needed to support the curriculum and other curriculum designed around similar
frameworks (Yezierski & Bridle, 2012). More studies focused on curriculum that blends inquiry instructional practices and the particulate level representations of matter are needed and warranted due to the positive results of the Yezierski and Bridle study. In my study, I investigated the following research questions.

**Research Questions**

1. In what ways are teachers addressing the three levels of chemistry teaching (macroscopic, particulate, and symbolic) during inquiry lessons?

2. Do students show growth at all three levels of chemistry (macroscopic, particulate, and symbolic) during an inquiry unit?

3. How does student growth in chemistry knowledge at the three levels vary with teacher instructional strategies?

4. How does engaging students in the construction and use of models develop students’ conceptual understanding at the macroscopic, particulate, and symbolic levels?