

Teachers' Use of Computer Visualization Models in Secondary Chemistry
A Comparative Study

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Abstract

This paper compares the pedagogical decisions of four teachers when implementing visualization software to teach atomic and molecular structure from a qualitative perspective. The informants in this study were high school chemistry teachers with academic and professional backgrounds. These teachers received training on software applications and the underlying scientific concepts, expressed commitment with their classes, and taught students at the same academic level. All used the software to teach concepts related to atomic and molecular structure. The approaches ranged from superficial fact-based activities to in-depth student presentations. Indicators of the informants' beliefs and knowledge were examined to see how they influenced each teacher's decisions about using the software. Even though teachers' beliefs about learning and teaching were the primary determinants of their decisions, factors such as pedagogical content knowledge and amount of instructional materials appeared to influence teachers' choices to a lesser extent. This paper describes the strategies and the implied and stated rationales of participating teachers, and a relationship between teachers' beliefs and practices when implementing visualization models.

Introduction

Until recently, instructional tools were not available for illustrating submicroscopic particles. Instead, chemistry teachers have relied on traditional methods when presenting topics related to atomic and molecular structure. With the advent of interactive computer modeling software, teachers now have the option of using methods that are recommended by the National Research Council (NRC, 1996) Science Education Standards (NSES).

Current science education reform calls for teachers to be knowledgeable in their subject matter and learners (NSES and NRC, 1996) promote the use of scientific inquiry and learning subject matter content. The extent of a teacher's content knowledge affects the type and variety of instructional techniques used in the classroom (Ball, 1996; Cohen, 1995; Garnett & Tobin, 1989; Tobin & Fraser, 1989). In addition, science teachers' choices of instructional practices depend on their beliefs about teaching, learning, and the nature of scientific knowledge (Ball & Cohen, 1996; Wright, 1989; Garnett & Tobin, 1989; Hewson, Kerby & Cook, 1995; Lyons, Hewson, 1997; Roth & McGinn, 1998). Cultural factors also influence teachers' goals, and methods (Anyon, 1981; Lanier & Little, 1986). A combination of subject matter knowledge, and pedagogical content knowledge are likely to influence the use of new instructional tools and materials. This paper reports the findings of a study that relates individual teacher's decisions about using interactive computer modeling software to factors affecting teachers' decisions about using interactive computer modeling software. It relates individual teacher's decisions to their beliefs, knowledge, and

Description of the Software

Quantum Science Across Disciplines (QSAD) software and instructional materials were designed to address the barriers to teaching modern atomic theory at the high school level. The QSAD project, under a grant from the National Science Foundation (REC-9500000), developed computer simulations that provide interactive visual models for student

properties of atoms and molecules. In designing a suite of software applications of the project was to provide a medium that would encourage and facilitate a quantum approach to the study of biology, chemistry, and physics. One of the described QSAD software as a "computer-based manipulative" (Horwitz & Canning, 1994) meaning that the user determines its purpose. Teachers and their students use the software to meet a variety of instructional goals, but the unstructured format does not create a context for using the software. QSAD applications can function as a laboratory in which the user can conduct experiments by manipulating visual models of atoms and molecules. Although this software can be accessed over the Internet, it was used locally.

Teachers' beliefs and actions

Research has identified the influence of teachers' beliefs on their instructional practices. Several studies explored the relationship between a teacher's beliefs and the methods the teacher employs (Ball & Cohen, 1996; Cronin-Jones, & Cook, 1995; Lyons, Freitag, & Hewson, 1997; St. Onge, 1994; Tippins, & Gallard, 1994). Other research indicates that cultural factors influence teachers' beliefs about their students' abilities, their instructional goals, and the methods they use (Lyons, 1981; Lanier & Little, 1986). The beliefs and values of science teachers influence their pedagogical decisions (Garnett & Tobin, 1989; Hewson, Kerby & Freitag, & Hewson, 1997; Nevo, 1992; Notkin, 1998). Studies indicate that teachers' epistemological beliefs affect their teaching practices (Parkley & Negele, 1996) or that teachers' stated objectives are not always consistent with their instructional practices (Lyons, Freitag, & Hewson, 1997; Tippins, and Gallard (1994) contend that "the teachers' knowledge of student learning is based mainly on the teachers' own styles of teaching."

Fullan (1991) points out: "The failure of educational change may be due to the fact that any innovations and reforms were never implemented in practice (as to the fact that social, political, and economic changes were never accomplished) within the educational system" (p. 15). Cuban (1990) identifies factors that inhibited changes in teaching practices, including time, uncertainty of the consequences, and repercussions from colleagues. Miller and Olson (1994) found that teaching practices remain constant despite the introduction of a new instructional medium.

Ajzen and Fishbein (1980) contend, "beliefs are the major determinant of behavior" (p. 223), and Ajzen (1985) notes that decisions are made by weighing the advantages and disadvantages of carrying out any action. The conflict between the two alternatives leads to a "more rationalized response" (p. 19). Confidence in the appropriate behavior is also a factor in its ultimate outcome. When the person is motivated to perform the intended behavior, "changes produced by new information will often be in the planned course of action" (Ajzen, p. 1985). also points to the attitudes and actions of others as factors that affect how people behave. He adds that behavior is influenced by "beliefs about the likely consequences of success and failure, normative beliefs regarding important referents, and the probabilities of success and failure, normative beliefs regarding important referents" (p. 36). Thus, a number of factors contribute to a teacher's initial belief system, and those beliefs are reflected in subsequent actions.

The constructivist learning model advocates learning strategies that provide opportunities to confront and modify their misconceptions. Students must have alternative conceptions to replace their original ideas (Posner et al., 1986). Knowledge is facilitated through the use of models, analogies, and other illustrative techniques. Using these illustrative techniques, teachers can create an environment where students are challenged and acceptable explanations are available to replace the current ones. Schwab (1983) discusses how scientists no longer view scientific knowledge as stable truths but as "principles of enquiry—conceptual structures—which could be revised" (p. 11), and calls for a similar approach to science education. Schwab (1983) discusses student questioning, and inquiry learning. "For the student to develop habits of passivity, docile learning, and dependence on teacher and to engage in active learning in which lecture and textbook are challenged" (p. 66).

Models of the teacher. Models of teaching are closely aligned with research. Kennedy (1991a) notes that people have different beliefs about the nature of teaching and that the models teachers subscribe to "represent valid and different differences of view about the nature and purpose of teaching" (p. 276). In these models, teachers must be knowledgeable about both the subject matter and the process. That differences in particular models of teaching affect "how these two are assumed to constrain and define one another" (p. 276). This study utilizes three models of teaching: additive, process, conceptual change, learning community,

The additive model is the most traditional model of teaching in which knowledge acquisition is the teacher's main goal. This knowledge comes in the form of concepts, principles, or laws that have been gathered through decades of research on a subject" (Kennedy, 1991a, p. 276). Kennedy describes the teachers' model as a gap between what students know about a subject and what they do not know (p. 277, emphasis in the original) by adding new information to students' existing knowledge.

As its name implies, the process model of teaching focuses on the processes "employed by those who contribute to the development of the academic subject" (Kennedy, 1991a, p. 277). These processes include the "methods of operating, strategies, and forms of argument" (p. 277) that are the norms of the discipline. Unlike the additive model, are to decrease the differences between students and the teacher. In this case, the focus is on the gap in procedural rather than factual knowledge.

Kennedy's (1991a) conceptual change model has the same characteristics as the model proposed earlier by Posner et al. (1986). The teacher's task in this model is to help students' conceptions are different from those of experts in the field. The classroom environment that facilitates the accommodation and assimilation of new concepts and metal constructs that correspond to the accepted views of the discipline. This is a challenge to teachers in identifying students' alternative conceptions. "The goal is to learn how students think about phenomenon" (p. 278).

Using the learning community model, teachers establish classroom norms which determine "the kind of scholarship that is valued or shunned, the kinds of issues that are considered important as opposed to routine, the kinds of issues that are being pursued, and how members of the group are expected to interact with each other" (Kennedy, 1991a, p. 279). As an alternative form of this model, teachers may combine the additive model with the learning community model. Kennedy identifies the key features of the teacher's focus. "What is relevant about academic subjects are those

strongly from student norms, and what is relevant about student norms a most strongly from subject matter norms" (pp. 279-280).

The teacher's primary goal in the transformation model is "to render relevant and meaningful to diverse learners" (Kennedy, 1991a, p. 280). this model often use metaphors and analogies that make the subject matt students. Kennedy summarizes the challenges inherent in this model of t
The transformational task itself is bi-directional. On one side, the teach academic content into something that is meaningful and relevant to divers teacher's success in this can be measured by the extent to which students people with and active interest in these academic areas. (p. 281)

Subject matter ~~beliefs~~ theories propose explanations of how scientific acquired, synthesized, and utilized. These theories include empiricism, constructivism. The empiricist view is that "all knowledge is derived f (Lawson, 1994, p. 132). Positivism is an outgrowth of empiricism and es accurate predictions about phenomena can be made based on observations data (Duschl, 1994). Nativists believe in a priori knowledge and conten knowledge is from within" (Lawson, 1994, p. 132). The constructivist mo beliefs and knowledge are products of human construction and develop fr own experiences (Dewey, 1900/1990; Piaget, 1970).

Science teachers' beliefs about the nature of science and how science influence their instructional styles and attitudes about learning scien conceptions about the nature and content of science has revealed that s of the same misconceptions as ~~Ali-Els-Khodris~~ Jaoude, 1997; Hewson, Kerby, & Cook, 1995; Novak & Gowen, 1984 et al., 1997). Benson (1989) fo even when teachers hold a contemporary view of the nature of science, t always consistent with their classroom ~~Tippins and Gallard~~ (1994) point educational experiences of teachers in which "their beliefs have been s hours spent in college classrooms internalizing objective models of sci reinforcing a view of scientific knowledge as "truth." Because the educ many science teachers were primarily through didactic instruction, tea philosophy about ~~Shante~~, 1997; Mellado, 1998; Tobin, Tippins, & Gall However, some studies have found that teachers' participation in profes may lead to reconstruction of their own scientific knowledge and belief knowledge ~~Oja~~, 1991; Tobin, Tippins, & Gallard, 1994).

Teacher knowledge ~~Research~~ has produced conflicting evidence that teache related to content knowledge. Kennedy (1991b) found that "majoring in a college does not guarantee that teachers will have the kind of subject need for teaching" (p. 14). Similarly, in their study of least and most Hidayat, ~~Redick~~ (1988) concluded that there was no correlation between knowledge and his or her effectiveness as a teacher. On the other hand, found that the depth of science teachers' content knowledge affected th instructional methods. In their study of two exemplary chemistry teach (1989) also concluded that content knowledge is the most important fact teaching.

Shulman (1986) uses the term pedagogical ~~content~~ ~~knowledge~~ ~~the~~ ~~specialized~~ knowledge of teachers that integrates knowledge of learners with subjec

describes teachers with strong pedagogical content knowledge as being an expertise to generate new explanations, representations, and clarifications. Representations teachers use to convey subject-matter concepts include analogies, illustrations, examples, explanations, and demonstrations" (Lawson (1991) also points to analogies as effective tools for concept formation from previously acquired pattern from the world of observable objects and even unobservable events" (p. 46). Cochran, DeRuiter, and King (1993) expand their conception of pedagogical content knowledge which also includes "teachers' understanding of students and of the environmental context of learning" (p. 266). The expert teachers as those who know "the kinds of difficulties that students have and how to tap into students' existing knowledge in order to make new learning possible" (p. 33).

Through their instructional methods, teachers convey subtle messages about science and their own beliefs about the subject (Mallard, Kennedy, & Stodol, 1994; Tobin & Fraser, 1989). Teachers who embrace contemporary philosophy as well as possessing strong subject-matter and pedagogical knowledge tend to be more creative (Borko, 1989; Grossman, Wilson, & Shulman, 1989). On the other hand, teachers with weaker pedagogical content knowledge tend to be more didactic (Borko, 1989; Grossman, Wilson, & Shulman, 1989; Shulman, 1987). According to Grossman and Shulman (1989), expert teachers "exhibited a more refined hierarchical knowledge" (p. 26). These findings indicate the significance of both domain and subject matter knowledge.

NSES (NRC, 1996) emphasize the need for teachers to have the pedagogical content knowledge that allows them to "tailor learning situations to the needs of individual students" (p. 62). These standards indicate that teachers develop pedagogical content knowledge through engaging in their own learning experiences. Pedagogical content knowledge for science teachers reflect on their experiences in the classroom and modify their instruction based on their self-assessments (Ball, & Anderson, Shulman, 1989; 1986). Ongoing professional growth activities are important opportunities for science teachers to enhance their content knowledge and instructional strategies. Reflecting on their practice is likely to help teachers enhance their pedagogical content knowledge (Cochran, DeRuiter, & King, 1993; Schön, 1983; Shulman, 1987).

Objectives and Method

This multiple case study compared the pedagogical content knowledge, and practices of high school chemistry teachers who used computer visualization software to teach concepts related to atomic and molecular structure. Participants included 16 chemistry teachers from each of four Greater Boston public high schools. The study monitored to identify how teachers used computer visualization models and materials. Data included interviews and observations focusing on teacher decisions related to software use and factors that influenced their instructional decisions. Data were analyzed for evidence of relationships between teachers' knowledge and decisions about software implementation.

Participants and Settings
Participants were secondary science teachers who attended summer institutes for secondary science teachers at Boston University in 1997 and 1998. Eight teachers from the greater Boston area attended these institutes. Three teachers attended the first institute, which fo

applications appropriate for high school students. A new cadre of five second institute, which emphasized development of curriculum materials software. Both summer institutes provided background information about and navigation of the software. Institute participants received instruction and engaged in discussions with the project's programmers and scientists.

The informants in this study included one chemistry teacher from each Boston communities. Some of the informants taught more than one level of chemistry, but this study focused only on their honors level classes. Table 1 presents demographic data for the four communities.

Table Demographic Data for the Four Communities

Town	Population	Income ^a	Per pupil spending	Education ^b
Thomsonville	55,000	\$45,600	\$7400	93% high school 60% college
Bridgeton	58,000	\$38,500	\$6400	82% high school 24% college
Cary	100,000	\$95,000	\$8300	96% high school 61% college
Easthaven	83,000	\$59,700	\$5000	92% high school 52% college

^aMedian household income

^b Level of education completed percentage of population for each

Of the four informants in this study, three participated to varying degrees in the summer institutes. The fourth informant had served as a teacher-consultant from its inception, and was, therefore, more familiar with the content and capabilities of the software. Each of the four participants was a woman between the ages of 43 and 52, with similar academic and professional backgrounds. Their backgrounds are illustrated in Table 2, which also contains information about their QASD software training. Pseudonyms have been used for all of the informants.

Table Biographical Data for Teachers

Teacher	Bachelor's Degree	Master's Degree	Teaching experience	QASD training
Nancy	Chemistry and German Literature	Natural Sciences	18 years	1997 4 weeks
Elaine	Chemistry	Chemistry	26 years	1998 2 weeks
Mike	Chemistry	Computer Science	29 years	1998 4 weeks
Matt	Chemical Engineering	School Administration	25 years	1996-1999 consultant

Data Sources and Analysis

Each of the participants answered survey questions to provide background education, teaching experience, and computer experience. Teachers completed Science Technology and Society (VOSTS) questionnaire (Aikenhead, Rya 1989) to assess their perceptions of the nature of science and the learning. Preliminary interviews with teachers included questions related to their perceptions of their teaching styles, methods used to assess student conceptions of their students. Interviews after software use focused on teachers' rationale for those decisions. Brief, informal interviews with teachers addressed issues related to computer instruction and pedagogical decisions as well as motivation for instructional acts.

Daily observations focused on teachers' instructional practices, part of which included students and decisions about how to implement QSAD software application. Interaction Analysis instrument (Flanders et al., 1974) was used to detect teacher-student interactions in each classroom. Interviews and observations were audio taped, transcribed, and coded. These data were analyzed to determine teachers' stated beliefs, objectives, and knowledge with their instructional practices.

Physical artifacts such as tests, worksheets, and lab instructions provided information related to teachers' goals and expectations for students and quantum science concepts. Activities written by the QSAD staff were offered with the software. Teachers had the option of using the materials as written or designing their own activities. Teachers' choices about these materials were noted.

The researchers' beliefs in the value of methods that promote student participation had some influence on perceptions of classroom events. Although we did not know the informants may have perceived those values. They also may have reacted differently as evaluators rather than observers of their teaching practices. The informants' role and dispositions may have influenced their behaviors during the interview questions.

That being said, we believe that the descriptions of each case and their findings from them are valid and trustworthy. This confidence comes from triangulation through the use of multiple data sources, extended periods of observation from informants, and the use of "critical subjectivity" to identify and describe researchers' "psychological and emotional states before, during, and after experience" (Reiswell, 1998, p. 196).

After compiling the data and writing descriptions of each of the cases, we showed them to the corresponding informant and he or she was encouraged to comment on the descriptions. Subsequent discussions with each informant provided additional insights into the cases, modification of the case study reports. After a final conference was held, we reviewed the case study reports and transcripts, and then revised the final report to reflect teachers' perspectives. This process served to verify the trustworthiness of the findings (Merriam, 1988; Yin, 1994). In one instance, the teacher (Mike) agreed with the report. In two cases, teachers (Nancy and Matt) expressed perspectives on the syntheses of the findings. Their views were incorporated in the final report. In the fourth case, the teacher (Elaine) refused to discuss the findings and their communication.

Findings

The discussion of the findings and conclusions that follow arise from teachers' beliefs and knowledge influence their decisions about using Q attempted to define teachers' beliefs in terms of their models of the self and themselves as teachers as well as the influence of the educational environment emerged from the teachers' statements, their instructional practices, V instructional products they generated. We will first describe the beliefs of a participant and how he or she used QSAD software. Then we will compare

Nancy's approach to teaching was to require students to first read their textbooks; then she added to or clarified their understanding. Nancy's interaction with students as "class discussions" rather than lecture began to initiate the flow of information. Nancy responded to those questions with transmissions of facts and procedures, asking for students' input in practical science as a body of facts and believed that those facts must be taken from more advanced courses. In Nancy's model of learning, the students internalize information. Once they had obtained this foundation of knowledge, they apply the information in problem-solving activities. Nancy's emphasis on memorization as well as her instructional methods reflected a transmissive

Nancy's model of teaching was congruent with Kennedy's (1991a) addition: the gap between what students knew and what they needed to know was her goal. Students' personal interests in science topics were secondary to her goal of essential information of the discipline. Nancy encouraged students to inquire into topics on their own time, but was unwilling to shift the instructional focus to those interests, at least if the students had taken the SAT II in chemistry.

Some aspects of Nancy's teaching aligned with the learning community model (1991a). Nancy identified goals for establishing the norms and routines of the community as being the tools and methods of more advanced students or scientists. She developed and internalized study and reasoning skills, which would help them in their pursuits. She explained that one of her goals is to train students in the skills they need for entry into the science community. As in the learning community model, Nancy made an effort to "nurture scientific values and habits of thought."

A clear picture of Nancy's beliefs about the nature of scientific knowledge emerged from this study. In some ways, Nancy's beliefs about the subject matter of teaching and learning models. Nancy expressed the expectation that the scientific knowledge people should aspire to depend on their stage in their education. Students in a first year chemistry course should aim for less knowledge and lower levels of involvement in the scientific community. Her VOSTS responses of her instructional practices suggested that Nancy perceived science as a set of skills, which could be identified, isolated, and quantified, and consequently, the currency of the subject matter.

However, Nancy disagreed with this interpretation of her beliefs about science. She expressed the following view:

Science is like an inquiry. Science is a way of going about, learning more about some knowledge, basic scientific knowledge, but I would not say that science is knowledge. More inquiry, an endeavor to learn, using the scientific method.

Despite her stated position, Nancy's pedagogical approaches focused on "basic scientific knowledge." The disparity between Nancy's statements and methods may be attributed to her hierarchical views of both participant endeavor and the kind of knowledge that is appropriate at each level. A teacher has two models of scientific knowledge - one practical and one theoretical.

The ethos of Thomsonville and its high school apparently had a strong ability to implement her models of teacher, learner, and subject matter administrative expectations that students perform well on standardized tests. This influenced Nancy's beliefs that she should teach in a manner that would emphasize the accumulation of chemistry facts. Nancy's colleagues, who also emphasize rote learning, strengthened her perception that the most efficient method for students to learn is to accumulate a body of facts. This school fit Anyon's (1981) description of a "factory school" in which "work is getting the right answer" (p. 77).

Time was an important factor in this context, and Nancy maximized her use of class time to dispense knowledge during class time. Her methods required that students read from their textbooks before she verified and consolidated that information. This meant that Nancy did not have to spend time covering information that students already understood. Nancy frequently mentioned class time, suggesting that it was a scarce commodity, and she avoided activities that did not produce sufficient learning.

In a number of ways, Nancy demonstrated her pedagogical content knowledge in terms of the milieu within which she worked. She regularly provided examples of phenomena that were being discussed in class, modifying examples and students' comments, and made frequent use of analogies to explain abstract concepts. When Nancy detected misconceptions, she pointed out the flaws in a student's reasoning, validated the logic behind these statements, and then explained what was correct. The analysis of why a student's ideas were incompatible with accepted science and suggestions of alternative interpretations of phenomena came from Nancy.

Fitting QSAD software into her established routine presented some challenges. She was unwilling to devote her own time to designing software lessons. Other researchers prepared instructional materials for students to use in two investigations. Nancy's only preparation was to review the written activities and make modifications that would provide more explicit directions.

Nancy anticipated that her students would have difficulty with the use of the software due to frequent reference to time constraints. She also expressed concern that using molecules through software investigations would require more class time than traditional methods. She planned to use the software in the school's computer lab. One lesson was designed to guide students in discovering periodic trends. For the other lesson, students would conduct a two-part investigation of the relationship between bond length and bond strength in diatomic molecules.

Nancy's first deviation from her plan for the ionization energy activity was to have students use the textbook to partially complete the worksheet for homework. The sections of the data table indicating the number of electrons in each shell they would be investigating. In lab, the students were supposed to produce the first 18 elements and record the energy of the highest occupied orbital. They were to graph this data, discovering trends in ionization energy from their comparison.

However, on the day before the scheduled computer lab activity, a student had a homework problem involving ionization energy. Nancy expanded on her answer and explained the relationship between the number of valence electrons and the energy of an electron. She also explained the "special stability" conferred on atoms with filled orbitals and sketched the ionization energy graph on the board. Nancy then taught the material that students were to have investigated using the software. Nancy demonstrated these concepts using the QSAD software while students worked on their worksheet, confirming what she had already told them in class.

Nancy's students completed the second computer lab activity as planned. During this activity, they used the software to create specified diatomic molecules formed by the electron clouds around nonpolar, polar, and ionic molecules. Students adjusted the internuclear distance between pairs of atoms to determine the energy and the corresponding bond length. They experienced a few navigation problems. Nancy relied on one of the researchers to help students. Nancy expressed her surprise at students' ability to use the software and comprehend the graphical images.

Elaine. Elaine and her colleagues at Bridgeton High School had redesigned their program two years prior to this study with the goal of providing a student-centered learning environment based on a variety of learning station activities. At the beginning of each instructional unit, students received a "contract sheet" containing a list of activities and a column for teachers to verify completion. Teachers lectured during class while most class periods were "work days" in which students completed their assignments. This educational environment reflected the working-class community and the nature of the class job is often characterized by work that is routine and mechanical. The fragmented part of a larger process with which workers are not usually

Elaine's assessment of students' abilities in her honors chemistry class was that "particularly gifted," a few students were "very sharp," and some students were in the honors section." She explained that her students were "motivated to get the material." Consistent with her teaching style, Elaine's exchanges with students suggested a belief that what was taught in previous classes was retained as it was taught and that students shared the concepts she had explained to them. When asked about students' preconceptions, Elaine's response indicated that they were not a consideration in her teaching.

On several occasions, students' questions indicated confusion about Elaine's responses focused on the immediate answer to questions rather than the questions. She did not probe for common misconceptions, but relied on her questions to provide clues for flaws in their understanding. If students did not ask questions in response to her questions, Elaine assumed that the learning process was complete.

Learning was product-driven in Elaine's class. She frequently explained that the purpose of learning particular content was to prepare for a test or quiz or to complete homework. Students' classwork grades were based on the number of completed assignments on the contract sheet. All work products had the same worth, and completion of assignments was emphasized more than the learning that may have occurred in the process. Elaine expressed interest in the subject matter, and Elaine acknowledged that some students were motivated by receiving credit for completing tasks or knowing how to answer questions.

Elaine's strongest belief was that students had to be actively engaged. She described herself as a facilitator, and described her role in that

I mean lecturing, to have them listen and to obey my every word. But to help themselves. I mean, their learning is up to them. I'm here to help them, if necessary. They have to do it on their own to really learn it.

Elaine facilitated students' learning primarily by providing the source which students could access chemistry facts and skills and by monitoring efforts. She equated student activity and completion of assignments with primarily on formal assessments to determine what students had learned.

Elaine's model of teaching was similar to Kennedy's (1991a) additive modification. Her goal was for students to decrease the gap between the accumulated facts of the discipline, and she supplied the resource to provide that information. As a teacher, Elaine was one of several potential sources to students' existing knowledge. However, students had the primary responsibility as well as obtaining the knowledge of the discipline.

Elaine's content knowledge was adequate for the demands of her department students. She was able to deliver the baseline information that students needed for their learning station activities. However, at times Elaine appeared confused about questions about their homework. Her delayed responses appeared to be that she had read the questions in advance. Once she looked at these questions in their context, she read an entire question, Elaine had the content knowledge needed to provide

Using Shulman's (1986, 1987) model, Elaine's pedagogical content knowledge about teaching about atomic structure, Elaine did not use any more familiar resources (e.g., metaphor or analogy) to assist students in their conceptualization of the concepts. Examples and real-world applications that Elaine did mention were identical to those that students learned about through audiovisual materials at the learning station. Elaine was unaware of subtle clues that signaled possible misconceptions, and her responses varied within the framework established by the Bridgeton instructional program.

Elaine's responses to the VOSTS questionnaire suggested that she viewed knowledge as being transmitted from a number of sources—teacher, textbook, video, or computer. Elaine's expectation that students would obtain information from a variety of sources was further evidence of a belief in a transmission model of knowledge. The following comment exemplifies Elaine's point of view: "Hopefully there will be the different things, that they'll at least be exposed to the major concepts. On the computer they'll get it in the video or whatever."

Elaine's use of QSAD materials conformed to her models of teacher, learner, and matter. She and her colleagues made frequent use of computer software and drills or drill and practice exercises, and the work-products resulting from them consisted of brief answers that verified students' use of the software. Elaine was asked for assistance in designing activities for the QSAD software, specifying what students should have to guide their use of these computer applications. However, she was not interested in using the software as a medium for investigating chemistry. She specified an activity that would prompt students to create images of the ground state energies of the electrons and shapes of the electron cloud

Elaine thought that students would ask more questions about atomic structure software and would be curious about how the graphical images related to studying. She planned to rely on students to ask questions about what the software, stating, "if they care enough, they will ask." In practice, she only to software navigation and whether they were required to complete

Mike. Mike used his prior experiences with chemistry students and knew individual students in his current class to assess what prior knowledge and learning experiences. He then designed activities that would make use of students' experiences, and interests. Through demonstrations and laboratory exercises, Mike designed experiences designed to challenge students' weak or naïve conceptions. He provided opportunities for students to bring their personal perspectives into the classroom. He experience the social and technological aspects of the discipline through student presentations, projects, and use of computers and scientific inquiry. His instruction began with the textbook or with Mike's introduction to a topic through demonstrations, lab activities, or student presentations were starting the learning process. From there, students developed their understanding of concepts through various paths. These instructional strategies reflected a constructivist model.

Mike's model of the teacher resembled Kennedy's (1991a) transformational model, which contained some aspects of the conceptual change model. Evidence of the model was at the organizational level. Mike's emphasis on the social and emotional aspects were revealed in his leadership role in the development and implementation of curricula at his school and his inclusion of student presentations on topics.

The conceptual change model was more apparent at the level of classroom practice. Mike's objective was for students to investigate concepts and learn by inquiry. He elicited students' current understanding and beliefs about concepts before instruction that might challenge their preconceptions. Once students had some degree of understanding of their previous ideas, Mike guided their learning experiences to encourage them to develop more acceptable explanations for phenomena.

Mike's constructivist model of the learner mirrored his model of the teacher, which focused on the individual talents and abilities of his students and explained how each person's strengths in building his or her own knowledge. He pointed out the importance of learning and encouraged students to assist each other. Mike coordinated activities that students had opportunities to discover aspects of chemistry concepts through their own construction in class. Mike's students constructed their individual knowledge through their own construction influenced others in creating a conceptual community.

Mike's classroom practices contained an abundance of "the most powerful form of knowledge representation," which Shulman (1986, 1987) identifies as indicators of expert knowledge. Mike planned instructional units so that new understanding was built on students' prior knowledge and modified his plans based on his on-going understanding. He anticipated many of the alternative conceptions that students held and asked questions and comments, and he addressed their misconceptions by introducing them to new experiences and providing concrete analogies for abstract phenomena. He used examples with experiences that allowed them to construct their own understanding. The examples, demonstrations, metaphors, and analogies that Mike used came from students' personal experiences and interests.

Mike's beliefs included convictions about how scientific knowledge is learned. He expressed the view that "science is a process by which knowledge is built and that knowledge building process has bumps in the road and chugging along." This belief was evidenced in Mike's instructional design through a series of experiences that caused them to question their previous knowledge and rebuild their knowledge. However, Mike's instructional practices and his nature of science were incompatible with some of his VOSTS responses. For example, an answer identifying science as a body of knowledge stood in contrast to his instructional practices, which promoted inquiry and encouraged students to question science.

Mike was aware of different learning styles and a range of abilities. His overall expectation was that his honors students could meet the demands of college. He also made several references to the standards set by the community and parental expectations that Cary students would excel on standardized tests. Mike appeared to be influenced by the culture of Cary High School, which encouraged students to take a questioning attitude. An example of an "executive elite school," the expectation at Cary High School would develop their "analytical intellectual powers" (p. 83).

Mike had a detailed plan for using QSAD software. The lessons included investigations in which students experimentally determined Planck's constant. The results allowed students to discover aspects of the planetary model that were not supported by empirical evidence. They predicted the wavelengths of the emission spectrum of hydrogen through their own calculations and discovered that their predictions were correct for hydrogen but not for helium. Students subsequently built their own spectroscopes to investigate the bright line spectra produced by sources at home or in the laboratory.

Mike incorporated QSAD software into the next stage of this instructional design: an investigation of the electronic structure of atoms. For this purpose, students used a computer application in which the user selects the energy and sublevel of a single electron. The program generates representations of electron orbitals or densities of electron probability. Mike followed guidelines and suggestions from a handout that he had prepared for the students. He provided them with some technical guidance as they became familiar with the user interface. The investigations were also open-ended in that they allowed students to control variables in their investigations by different routes. Mike's rationale for using this program was to provide students with opportunities to understand the general properties of atoms independent of particular atoms.

Mike also used QSAD software applications to guide students in the discovery of the structure and periodic trends in atomic size, ionization energy, and electronegativity. He was enthusiastic about the students' interaction and learning outcomes with the software.

In periodic trends...especially ionization energy, QSAD was great at showing trends and shapes, and I was able to see how students responded to the software that they didn't have before. They had individual control of the software. They didn't know the goal of using the software, but they were working towards the same goal. They found errors in the software, and that was good because it shows that the model is not perfect, and like all models it has limitations.

Matt described himself as a constructivist, and many of his classroom practices reflected that approach to learning. He varied his instructional styles

focus of the group, employing both cooperative and competitive strategic activities, Matt encouraged students' cooperation with team members. In discussions, he prompted students to listen critically to their classmates' points with which they disagreed. Matt offered critiques and suggestions and the manner in which they explained them. Matt also varied the locus of focus. On some occasions, students determined the direction and focus of their discussions. At other times Matt provided students with detailed explanations of concepts.

Students learned by multiple methods and used various combinations of sources. The initial source of information was the textbook, but the sequence through which knowledge and understanding grew varied from one day to the next. Students learned from Matt through small group and whole class discussions, laboratory activities, computer investigations, and demonstrations. Students reflected and created shared meanings with their classmates through the use of learning maps. Many of Matt's instructional techniques led to identification of concepts. Often motivated students to re-explore their ideas.

Matt's model of teaching fit Kennedy's (1991a) conceptual change model and some aspects of the learning community model. As in the conceptual change model, Matt was to identify students' preexisting notions about chemistry and transform them into "concepts that are like the concepts formed by experts in the field" (p. 10). Assessment methods such as concept maps, learning logs, and student portfolios focused on students' thoughts and reasoning processes rather than production of correct answers.

His model of the teacher was similar to the learning community model, emphasizing developing habits and establishing norms of behavior. Matt's expectations for homework, lab reports, small group work, and class discussions were well established when classroom observations began. He expected his students to approach him as scientists, identifying their interests in a topic, designing inquiries, and engaging in discussions with him and their peers. The class operated effectively because students had internalized these classroom norms. For example, Matt did not assign homework. Nevertheless, students frequently asked questions about their homework. It all appeared to have read the same sections and attempted the same questions. Like Kennedy's (1991a) learning community teacher, Matt's classroom "recreated a practice... that enabled students to engage in a process of collective sense-making."

Matt's teaching was spontaneous and flexible in response to what was happening in his classes, but at times, there was an apparent incongruity between Matt's teaching and his instructional practices. While Matt espoused constructivist learning, he frequently utilized strategies that supported that model of learning, but not always. In some cases, what began as class discussions became detailed lectures. Matt asked and answered his own questions.

Students' prior experiences were important to Matt in terms of the alternative conceptions they may have generated. Matt's model of the teacher had the characteristics of the conceptual change model, particularly in his awareness of alternative conceptions and his ability to correct students' erroneous ideas. Matt diligently probed for flaws in students' ideas. When detected, he solicited other students' ideas, identified the nature of the errors, provided examples of similar erroneous ideas, and guided students in constructing alternative explanations for their experiences.

Matt's teaching was spontaneous and flexible in response to students questions. He exhibited an impressive knowledge of chemistry but at times providing definitive answers to students' questions. His frequent use of a variety of instructional methods, and ability to adapt instructional indicators of Matt's strong pedagogical content knowledge.

In his VOSTS responses, Matt indicated a belief that scientific knowledge is a series of logical steps. This view was supported by Matt's periodic reference to a "rigorous spiral." He conscientiously revisited previous concepts, adding to students' understanding. Matt's interview comments and classroom practices were consistent with his VOSTS responses that scientific theories are discovered through discussions, lab exercises, and computer activities were geared toward scientifically accepted explanations of chemical phenomena. Matt commented that models are valuable in being able to "predict reality," suggesting a logic of science. However, Matt rejected this interpretation of his use of the term "model" as meaning the "real model" of the atom, not a "reality of nature."

The culture of the school and community appeared to coincide with Matt's goal to be able to verbalize their knowledge. In Matt's descriptions of his students' kinds of conversations that occurred in their homes and schools, he believed that parents' children's knowledge from these conversations. Matt's efforts to encourage students to use language were well supported by the milieu. His classes were almost entirely consistent with a (1981) description of an "affluent professional school" in which "students are encouraged to express and apply ideas and concepts. Work involves individual thought, expansion and illustration of ideas, and choice of appropriate method and materials."

Before introducing the QSAD software, Matt provided a context for students to learn about atomic structure. Students first read about atomic structure in their textbooks and then performed flame tests to determine the wavelengths of light emitted when various elements were heated and conducted similar experiments using emission tubes. After these labs, Matt began a discussion of different atomic models.

Students used the QSAD software for several investigations related to atomic bonding. Before students' initial use of the software, Matt gave the following directions:

Investigate something from the s area that actually has valence electrons and something from the p end, something from the d end, and something from the f end. I want you to learn how to use the software to view all the different things, move in and out, flip between different slices, learning where the nodes are and what have you, but compare the two. That's what you'll do your report on.

Students followed these directions, learning how to navigate within the software and interpret the visual images as they investigated their choice of atoms. Matt answered students' questions, but primarily observing their use of the software. Half of the class worked in small groups at computers while the remainder worked at their desks, discussing their plans for an investigation or working on their reports.

Matt explained his rationale for this approach. He believed that his students' reading and interpreting information from the graphical interface, such as electron orbitals, occupancy, and differences in density views from different angles. He explained, "If they've got a particular task and they play around with it, they start to zero in on what's relevant." Matt realized that students

interface, and he had a simple strategy for those occasions. "They asked students had investigated their atoms using the software, they prepared included information about the visual displays. Through Matt's encouragement asked questions and challenged the assertions of their peers, leading to properties of atoms and molecules.

Conclusions

A number of factors influenced teachers' decisions about using QSAD combined models of learner and teacher were the primary factors that determined software was used in the classroom. Factors that appeared to support their use included sufficient time for students to investigate phenomena, teacher knowledge, and the amount of training using QSAD software. Table 3 presents conclusions about the factors that affected teachers' use of the software from greatest to least use of the software as medium for inquiry learning.

Despite some variation in how the teachers used the software, their use reflected their models of learning and teaching. The transmission/additive model used the software primarily to add to students' knowledge or confirm what they had learned from other sources. The constructivist/conceptual change model teachers use the software in the laboratory, encouraging students to discover and test ideas about atoms.

Table 3. Factors Affecting Software Use

Informant	Model of Learner	Model of Teacher	Class time (min/wk)	Classroom interaction	Pedagogical content knowledge	QSAD software training
Matt	C	CC/LC	315	Highly varied	High	High
Mike	C	Tf/CC	270	Highly varied	High	Moderate-high
Nancy	T	A/LC	250	Little variation	Moderate-high	Low-moderate
Elaine	T	A	220	Little variation	Low	Moderate

Key:

C = Construction Model A = Additive Model LC = Learning Community Model
 T = Transmission Model CC = Conceptual Change Model Tf = Transformation Model

Comparisons of the two cases in which teachers used the software for information reveal both differences and similarities. The factors that were common were the teachers' models of learner and teacher. Both teachers reflected transmission models of learning and additive models of teaching. In the combined transmission/additive model, the flow of information occurred in both contexts. The belief that the goal of teaching is adding to students' knowledge was supported by the milieu in both schools. As Park & Erickson & Yungent's (1996) study of the factors that inhibit science education reform, in both classes, "students were not treated as inputs for topics of interest or

teaching. Rather they were treated as interruptions to the other science to be taught" (p. 147).

On the other hand, Nancy had much higher expectations than Elaine with students' academic abilities and goals. Nancy considered her students to high standards for their learning outcomes. Elaine believed that most of honors caliber," expecting only that students would be able to complete reproduce facts and perform routine calculations on assessments. Elaine and hints for students during formative assessments. In contrast, Nancy perform well on standardized tests by committing facts to memory.

The two teachers who used the software as a medium for inquiry learning: characteristics in common. Conceptual change was an important theme for and they varied their instructional methods and sequences of learning a nature of the concepts they were teaching and their knowledge of student culture of the school allowed teachers the autonomy to use different methods high expectations for student achievement. All of these characteristics two cases.

All of the informants were influenced by the ethos of their schools. taught in schools where teachers were able to design and carry out their and Nancy worked in schools where their colleagues subscribed to transmission learning and where fact-based tests were used to provide evidence of student and Elaine's schools imposed shared models of teaching, learning, and assessment Nancy's case, her stated preference for inquiry approaches to learning perceptions of school and community expectations.

Although the two more affluent towns, Cary and Easthaven, were the sites: QSAD software was used for inquiry learning, socioeconomic factors did strong correlation to the teachers' use of QSAD materials. Easthaven and neighboring towns with similar socioeconomic compositions, but Matt and teaching and learning were dramatically different as were their approaches. The two teachers' perceptions of community expectations were different parents' expectations that instruction would emphasize preparation for Matt believed that parents were more interested in their children's ability intelligent discussions about what they had learned. These different beliefs teachers' disparate choices about how to use the software.

The role of science teachers' views of the nature of scientific knowledge because classroom observations, teachers' comments, and VOSTS responses contradictory data about teachers' perceptions related to the nature of scientific knowledge. In comparing the informants' views of science to the scientific community, their interview responses were more aligned with than were their classroom practices. The VOSTS instrument was not a good the teachers' stated beliefs or their pedagogical decisions.

Time was not an initial focus of this study. Nevertheless, it emerged some of the participants. The data show similar trends in the amount of degree to which teachers used the QSAD software as a tool for inquiry. the greatest amount of class time per week, made greatest use of the software while Elaine, the teacher with the least amount of time, made very little

However, Nancy and Mike had a relatively minor difference in the length but a major difference in their decisions about how to employ the software.

The belief systems of the informants appeared to have the greatest influence on pedagogical strategies and decisions about implementing QSAD materials. In teachers' content knowledge and pedagogical content knowledge also influenced decisions about software use. Of the four informants in this study, Nancy exhibited strong content knowledge in their classroom practices. With few exceptions, each of these teachers was able to answer students' questions. Elaine's content knowledge was adequate for transmitting knowledge, but her students and presentation of information appeared to be more automatic than the specific nuances of students' questions. Of the three teachers with strong content knowledge, Mike and Matt were more proficient in the concepts related to the software and were more experienced with the QSAD software. Their deeper content knowledge appeared to facilitate their use of the software in an inquiry mode. Content knowledge was a determining factor in their decisions to use the software in this manner.

The teachers who advocated constructivist approaches to learning relied on their content knowledge to a greater extent than the transmission model teachers. These teachers used their content knowledge, not only as a source to be shared but also as a referent to guide their modification of the learning environment with the new instructional tool. These teachers viewed one of their roles as promoting cognitive disequilibrium. They subsequently used their knowledge of the subject matter to guide students toward scientifically acceptable explanations. From the constructivist teachers' perspectives, the subject matter was more interesting than which questions to ask than in providing definitive answers for student questions. These teachers were more likely to encourage a wider range of student questions. These teachers were more likely to view science as a way of understanding and explaining natural phenomena than as a source of knowledge. They expressed the belief that all knowledge is tentative and comes from shared meanings.

Nancy, Mike, and Matt all modified their original plans for using QSAD. Modifications were made so that the software would conform more closely to their teaching methods. On the other hand, Mike and Matt made changes in their lessons and assessments of what and how students were learning from the software. As a result of using the software to teach in a different way, Mike and Matt learned more about QSAD software and their students' learning. Their pedagogical content knowledge was a source for making adjustments to the curriculum, while the new knowledge gained from teaching with the software improved their existing pedagogical content knowledge. In the absence of new strategies for teaching, Nancy and Elaine did not exhibit changes in their pedagogical content knowledge.

When asked what they do when students don't understand or master material allotted, all of the teachers responded that they encouraged their students to seek help. None of the teachers suggested trying a different pedagogical approach. All of the teachers relied on more of the same type of instruction or providing one-on-one instruction. All of the teachers believe that the methods they use are effective and that if the quantity of instruction is increased.

Implications

This study identifies several factors that must be considered when at educational reforms. Change is not a process that comes easily in class As others have found (Cronin-Jones, 1991; Nespor, 1987; Munby, 1982), influence their pedagogical decisions and should be considered when att classroom practices. For reform efforts to be successful, attempts at c account teachers' belief systems and the prevailing ethos of the school

The use of computer visualization models to investigate microscopic i more feasible with increasing computers availability in schools. Using students can now investigate topics that traditionally were taught usin methods. The results from this study suggest that to understand why tea new instructional approaches, we must identify how teachers' beliefs ab subject matter, and milieu influence their decisions. This information investigate approaches for encouraging teachers to learn about and expe approaches that foster construction of knowledge. These issues are of c teacher educators, curriculum developers, and school administrators. Th success or failure of professional development initiatives and educatio

All four cases in this study revealed that the teachers acted as ager Reform efforts must address this aspect of the educational process. The culture and teachers' models of learning and teaching may provide an ap policy changes that will be enacted at the classroom level. If teachers community value the development of critical thinking and student inquir they may be more inclined to use constructivist methods. On the other h method by which teachers and students are held accountable, teachers ma use transmission methods. The results of this small sample of teachers possibility that longer class periods would increase the amount of inqu

At the level of the individual teacher, reformers who endorse inquiry in those teachers who employ constructivist models of learning and the of teaching. Based on this study, these teachers incorporate a variety and create learning environments that are more student-centered. Such p aligned with the goals of inquiry learning as ~~NRC 1996~~ by ~~NES~~ using tha the constructivist teachers support the goals of current science educat

The findings from this study suggest a close correlation between a t learner and his or her model of teaching. A broader study would provide this hypothesis and develop a generalized theory of a relationship betw teaching and learning, providing insight about how these models develop methods of reconciling differences between teachers' beliefs and curren

The learning outcomes for students using inquiry-based interactive c be investigated as well as the role of supporting materials in facilita learning. This study also suggests the need for an investigation into p between teachers' actual classroom practices and their stated beliefs a or how science should be taught. Other areas of potential research incl between teachers' models of the learner or teacher and the variety of i use as well as the influence of teachers' beliefs and knowledge on the systemic reform.

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