An Inquiry Approach to Atomic Structure: A Case Study of a Chemist
Implementation of Computer Visualization Software

Gerald Abegg, Boston University
Karen M. Robblee, Boston University
Peter Garik, Boston University

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Introduction

When deciding how to teach any topic, teachers draw on their knowl and the learning process, their subject matter knowledge, and beliefs a learning, and teaching. Each teacher has a unique combination of beliefs influence his or her individual approach to teaching. When teachers have they draw on their knowledge and beliefs when making decisions about moc plans.

The National Science Education Standards (NSES) call for teachers t approaches to learning rather than didactic teaching (National Research the past, resources have not been available for teaching abstract conce or similar inquiry-based approaches. Computer visualization models now for students to explore such abstract concepts, particularly those invo particles, through the types of investigations recommended by NSES.

This paper describes how one high school chemistry teacher modifie plans to include interactive computer visualization models for teaching related concepts. This teacher participated in a four week summer insti opportunities to expand his knowledge about quantum science, investigat suite of interactive software programs, and develop instructional mater his students' understanding of atomic and molecular structure from a qua perspective. The question addressed in this paper is: When a high schoo training in and access to interactive computer visualization software t molecular structure based on the quantum mechanical model: (1) what fact pedagogical decisions related to the software and (2) how does the intr knowledge and instructional tools impact his teaching? The insights gai investigation of one teacher's methods provide better understanding abo teacher's beliefs, knowledge, and actions.

QSAD Software Training

Summer institutes for secondary science teachers were held at Bost and 1998. Eight teachers from the greater Boston area attended these in attended the first institute, which focused on designing software appli high school students. A new cadre of five teachers attended the second development of curriculum materials to accompany the software. Both of institutes included background information about the design, interface, software. Institute participants received instruction on how to use the several discussions with the programmers and scientists who designed th participants demonstrated deeper understanding of quantum science conce own use of QSAD software as an inquiry medium. We were uncertain how th the summer institutes would affect their existing beliefs and practices

Review of the Literature

Many educators believe that teachers require a specialized knowled that allows them to translate subject matter knowledge into appropriate (Dewey, 1902/1990; Fenstermacher, 1986; Grossman, Wilson, & Shulman, 19 Ball, & Anderson, 1989; Shulman, 1986; Shulman, 1987). Dewey (1902/1900 study or subject thus has two aspects: one for the scientist as a scie as a teacher. These two aspect are in no sense opposed or conflicting. immediately identical" (p. 200). Shulman (1986) identified the teaching pedagogical content knowledge. He explained that pedagogical content kn knowledge of subject matter per se to the dimension of subject matter k (p. 9).

Shulman (1986; 1987) identified the characteristics of teachers wi content knowledge. Their teaching includes "the most useful forms of re matter] ideas, the most powerful analogies, illustrations, examples, ex demonstrations" (p. 9). He also noted that pedagogical content knowledg determine what aspects of a topic will be more challenging to students are likely for students of different ages. Cochran et al. (1993) modifi pedagogical content knowledge. In addition to subject-matter knowledge a knowledge, they included "teachers' knowledge of students' abilities an and developmental levels, attitudes, motivations, and prior knowledge o taught" (p. 2) as components of pedagogical content knowledge. Cochran proposed that these additional skills distinguish subject-matter teache same discipline.

A constructivist environment helps students to confront and modif misconceptions. However, students must have alternative conceptions to ideas. "It is clearly not enough to confront students with information theories-in-action. We need to know more about their conceptions, how t they change over time" (Herron, p. 44). Through appropriate models, ana representations, teachers can create an environment in which misconcept alternative conceptions are available. "By becoming aware of reasoning understand a particular science course, a teacher can both identify the demands of the subject matter and help students develop more advanced r extensively" (Karpulus, 1977, p. 172).

The NSES emphasize the need for teachers to have the pedagogical c that allows them to "tailor learning situations to the needs of individ 1996, p. 62). These standards indicate that teachers develop pedagogica engaging in their own learning experiences. Through these experiences, t students with varying instructional strategies that utilize alternative

Ongoing professional growth activities are important opportunities improve both their content knowledge and instructional strategies. When development activities for science teachers provide opportunities to in phenomena using methods similar to those of professional scientists, th to enhance teachers' abstract reasoning skills (Oja, 1991). Pedagogical

develops when teachers reflect on their experiences in the classroom an
instructional strategies based on their self-assessments (McDiarmid, Ba
Shulman, 1986). Parke & Coble (1997) stress that "genuine, deep, and la
transformation of how teachers think about and teach science" (p. 774).
professional growth in science education requires experiences that chal
the nature of scientific knowledge.

Objectives and Methods

This paper is part of a larger study, which explored the factors a teachers' use of new, open-ended instructional materials. A subset of t institute participants served as informants in a multiple case study t contributing to teachers' decisions about implementing QSAD software in were collected from a number of sources including classroom observation informal interviews, a background questionnaire, and the Views on Scien (VOSTS) instrument (Aikenhead, Ryan, & Fleming, 1989). At the beginning week summer institute, participants created concept maps that represen of concepts related to quantum science. Interviews based on those conc measures of the participants' content knowledge and changes that occur experiences at the summer institute.

Preliminary interviews with teachers included questions related to perceptions of their teaching styles, methods used to assess student c of their students. Interviews after use of the software focused on tea and the rationale for those decisions. Brief, informal interviews with determining issues related to computer instruction and pedagogical deci rationale or motivation for instructional acts. Interview and observat determine the correspondence of teachers' stated beliefs and objectives practices.

In this paper, we report on a single case study, which investigate objectives, goals, instructional design, and pedagogical decisions. The Mike (a pseudonym) was one of five participants in the second four-wee institute. Mike had a bachelor's degree in chemistry, a Master's in com years' teaching experience. He participated regularly in professional d had presented workshops at local and national science teachers' confere which he participated in this study, Mike received a teaching award fro Society. We were particularly interested in the role of Mike's pedagogi his instructional decisions and how his new content knowledge impacted h content knowledge.

Mike's classes were observed on a daily basis from late September observation period included instruction before, during, and after the u QSAD software. Semistructured and informal interviews were conducted to goals and strategies as well as his on-going assessment of the efficacy materials. Classroom observations documented how Mike's goals translate

Physical artifacts such as tests, worksheets, and lab instructions prov related to Mike's goals and expectations for students and his emphasis concepts.

Findings

Mike's knowledge, beliefs, goals, and plans. Mike responded to hi the QSAD software with guarded interest. He appeared to be intrigued by potential as an instructional medium, and the underlying science, but h asked how he would use the software with his students. Nevertheless, of attended the 1998 summer institute, Mike emerged as a leader. He acknow knowledge and endeavored to improve his content knowledge by asking que developers. By the end of the institute, Mike conveyed seemed to be the participants in understanding explanations offered by the scientists or team and the most confidence about his content knowledge.

Mike produced the most complex concept map of the institute parti accurate relationships among the greatest number of concepts. The conce teachers included a range of 32 to 46 of the 64 potential concepts list QSAD development team. Mike's final concept map included many cross-lin concepts. In an interview based on the concept map, he offered clear an the relationships among concepts in his map. We were interested in lear knowledge growth would influence his classroom practices.

Soon after the beginning of the school year, Mike anticipated that modify instruction for the different learning styles and abilities of h some of the considerations that would determine how he used the QSAD so

> Computers are, have the ability, have the ability to give ownership t can be engaged in a task um, while I go around and mentor students. …M this project is that there's going to be some, like Abby and Ted, who sensorialy overwhelmed. They're concrete sequential – they're going to step, uh, task-result-task-result.

Mike identified differences in how students learn when they have p with a concept as opposed to when the concept is unfamiliar to them. H provide a firmer foundation for new or more abstract concepts. He was a students' alternative conceptions, and referred to "classic misconcepti structure. He then explained his strategy of setting a "misconception t common misconceptions and to provide experiences that challenge student considered students' alternative conceptions to be valuable because the which new perspectives could be developed. He also mentioned the need t concepts to ensure that students had not reverted to their prior conce

He articulated a belief that "students learn best when they are en intrigued and interested and enthusiastic." To keep students interested instructional style was important "so that their interest level change they're in a pattern or a routine." Mike noted many of his students we were an important form of motivation. He endeavored to provide intrinsi to create an enthusiasm for my subject and getting them to share in tha to their innate curiosity about things around them and try to make thos deeper concepts that I'm trying to deliver in the course." He also ment of motivation for students was trying to find questions that he could r

Although Mike believed that students defined success in terms of g conception of student success was based on depth of understanding. He o definition of success:

> When students ask the right questions, are able to synthesize answers information they get from the book and go into extensions, when stude conversations with each other showing a mastery of the material that r understanding.

Mike described himself as a mentor and cheerleader for his student teaching] is where they are presented with concepts, they work on the c and I also support them, giving them the emotional and academic support his goal of helping students to make connections among chemistry topics those concepts pertain to their everyday lives. He described how he pla unit. "I start out with certain goals – what facts or information the s decide what activities will lead to those goals." He explained that labo "reinforcement of content or 'ah-ha' experiences," adding, "I like them curious.'"

Mike's classroom practices. Mike typically used a variety of instr including lecture/discussion, lab activities, demonstrations, computer s problem solving, projects, and student presentations. Most classes star previous class, either initiated by student questions or by a brief com would give an overview of the goals for the day's class. For example, at in which students were doing a lab exercise, Mike's introductory commen we were talking about something pretty profound, and some of you were g into this concept of a the Bohr atom. We have a lab to do that relates let's kind of revisit that."

Class discussions moved at a brisk pace, with students sometimes i comments. One of Mike's most common methods of engaging students in dis leave his sentences unfinished. His unspoken expectation was that stude final words or phrases to his statements. Students called out these "an dialogue with Mike. When they responded with an acceptable answer, he r phrase, and then continued with his presentation. At other times, he mo answers to be more accurate or precise. The following discussion is typ teacher-student interaction:

> Mike: Diodes are very interesting because they have a phenomenon very photoelectric effect, which is?
> Student: Light falls on surface.
> Mike: Light falls on a metal and…
> Student: releases an electron
> Mike: releases electrons, but does it happen for every…
> Student: certain wavelengths…
> Mike: certain wavelengths of light...That's a threshold energy that i

When there were disagreements among students or if the responses s misconceptions, Mike explained the topic in greater detail. At other ti specific students for answers or ideas. As a rule, every student partic another, although the more vocal students received more attention.

After attending the Quantum Science Across Disciplines (QSAD) summ Mike revised his existing instructional unit for teaching atomic struct many of the learning experiences he had used in previous years as well a activities and modifying the sequence of instruction. These changes wer content knowledge and his experiences with QSAD software. Some of the m made served to set the stage for using the software, while other change software.

Mike began the atomic structure unit as he had in previous years. such activities as: observing a conversion from mechanical to light ener pieces of wintergreen candy, viewing overhead lights through diffraction their own spectroscopes. Classroom activities generated enthusiasm and by student comments such as, "That's so cool," "Wow, look at this," an works." Students also asked numerous questions about how concepts are a contexts. When Mike was unable to answer their questions, he admitted t knowledge and encouraged students to investigate those questions on the

Mike also designated an important scientist for each of the studen prepare a presentation for the rest of the class. Student presentation the historical background for current theories on atomic structure. Dur sometimes referred to themselves as Becquerel, Millikan, etc. or interj "My guy did that." when someone referred to a particular discovery. Mik presentations with demonstrations and class discussions. For example, a presentation on Thomson, Mike used an exposed television tube to demons of a cathode ray tube. Following the presentation on Einstein, Mike dem photoelectric effect and its use in a spectrophotometer.

After learning about the history of atomic theory, students invest proposed by these theories. They used spectroscopes to examine spectra excited electrons of different elements and to analyze the "yellow" ligh apparatus, learning that a given color can be perceived in the absence o wavelength of light. They subsequently built their own spectroscopes an investigate the bright line spectra produced by sources at home or in t also determined Planck's constant experimentally using a laboratory exer Quantum Mechanics (Escalada, Rebello, & Zollman, 1999). These experience questions about the relationship between atomic structure and spectral more than one spectral line even though it has only one electron, wheth neon tube would "get used up" over a period of time, and why light from blue when seen through a window.

The sequencing of lessons included experiences that were linked to knowledge of light and the Bohr model of the atom. Through experimental discovered aspects of the planetary model that were not supported by en predicted the wavelengths of the emission spectra of hydrogen and heliu calculations and discovered that their predictions were accurate for hy

Instead of continuing with the instructional sequence from prior y QSAD software into the next stage of the atomic structure unit. He expl he would have resorted to the textbook to provide information about the model of the atoms. Mike offered his opinion of students' learning from would just be a paper and pencil exercise, with these orbitals, and it of a game." Quantum mechanics was "putting numbers with letters and tal abstraction called orbitals."

To develop the necessary conceptual foundation, he collaborated wi taught physics to create demonstrations that gave students a better unc mechanics. Mike then began the computer investigations with a different the one that had been emphasized in the summer institute. During the su focused primarily on the Diatomic Explorer, which produces graphical re and molecular orbitals of designated elements and binary molecules. Mike approach with his students, instructing them to investigate electronic Bond Explorer. In this application, the user selects the energy and sub orbital. The program generates representations of electron orbitals or Mike explained that he wanted students to understand the general proper independent of the identity of the atom. The students asked many questi but there was little evidence that they were confused or frustrated by with the abstract concepts of quantum science.

Mike had prepared a handout to guide students in their computer in handout included directions for creating visual images of the software a experiment with software parameters to find images that would give the electron structure and behavior. The instructions provided students wit as they became familiar with the user interface. The activities were al allowed students to control variables and proceed through the investiga

In describing the procedure that students should follow, Mike gave at an elephant. He explained that if they were too close, they could nc elephant looked like and might draw erroneous conclusions about its ove other hand, if they were too far away, they would not be able to detect elephant's appearance. This analogy provided a rationale for students t screen and intensity of the graphical image so that the atomic model cou amount of information.

In subsequent computer investigations, Mike's students developed a Hund's Rule and the Aufbau principle. After using the software, class d students' observations of orbital energies and the patterns of electron defined the rules based on their observations, Mike initiated class dis students observations of electrons filling patterns to Hund's Rule and addition, students made observations that allowed them to identify peri ionization energy, and electronegativity. Mike guided that discovery by

exercises that illustrated relationships between atomic number and elec
described what the students learned from the software.

> In periodic trends…especially ionization energy, QSAD was great at show shapes, and I was able to see how students responded to the software t base that they didn't have before. They had individual control of the ownership. They didn't know the goal of using the software, but they w the goal all the same. They found errors in the software, and that was the kids this is a model, and like all models, it has limitations.

Three months after using QSAD software to teach atomic structure a properties, Mike used the software again to teach covalent bonding and Mike had planned to use the QSAD software in this unit, but decided aga year time constraints. As an introduction to bonding, Mike gave the ana being diffracted by openings in a sea wall and began developing the conc destructive interference. He then made the conceptual link between the water waves and the behavior of electrons in bonding and antibonding or commented, "Oh, that's like what we did in the computer lab and it show go."

Mike described the differences he perceived in student learning or of the software:

> Oh, I had kids even months after using the software use it as a, an en or as an example for a new concept. The imagery was so strong in some visualization, that they and they felt comfortable about saying, "Isn' when…" And whenever I hear that I know that has made a major impact or

A number of times, Mike alluded to the fact that he expected to le using the QSAD software with his students. He anticipated improvements design based on students' experiences and his observations of those exp his reasons for using the QSAD software with his students, describing h pedagogical beliefs:

> To give them an opportunity to manipulate the concepts individually s their own issues with quantum science. Because it has become apparent of let's say twenty kids, as you're working with one particular concep four very different directions with it. And if you, in a classic lectu will, you might end up only dealing with one of those issues that that satisfies only a small fraction of the kids. Whereas the other, and th be scratching their heads, saying, "What are they talking about? I'm differently." And there's never enough time to really deal with all th have the software, the kids now are working, they're manipulating it, you can go around as a teacher and mentor them and give them some sens where they're headed and deal with their individual issues with the co as complex as quantum science, it requires that you have all your duck before you can make it to that next, before you can understand that n people their issues that goes, the reason that they can't make that l these ducks isn't in order, but you don't know which one it is until y kid. It might be they don't even have a clue what orbitals are, and yo that in line, but they don't understand the idea of, you know, electro the bottom line is you can go around and troubleshoot each person's in while everybody else is working.

Summary. Mike's comments about how students learn, the nature of as a teacher imply a consistent belief system. Data from classroom obse instructional materials Mike developed indicate that his practices are beliefs. The data also illustrate that Mike employs his pedagogical con contexts, including varying instructional methods and adapting his plan spontaneous opportunities to illustrate a concept.

Mike’s beliefs about the tentative nature of science were reflecte quantum mechanical model being the current explanation for atomic struct that, like all models, it was only a representation that provided usefu evidence. He also had the attitude that software bugs were beneficial b students to experience flaws in a model and to critique their experienc are consistent with prior understanding. He encouraged students to thin sources of information.

His stated beliefs about students’ motivation and abilities were a instructional strategies. Mike viewed students as having individual sty rates of learning. He indicated that collaboration among students helps diverse learning styles and abilities. Mike’s comments and instructiona recognized difference in learners rather than valuing one style over an belief that students benefit from inquiry learning but at a minimum, th opportunities to “manipulate” concepts.

Classroom observations provided evidence that Mike’s teaching prac with his metaphor of himself as mentor or cheerleader. However, in his organization, Mike played another role, that of architect. He designed would make predictable discoveries leading to predictable questions. Bu then gave answers or provided hints or possible resources so that stud their own questions. Mike encouraged students to investigate phenomena, explanations for their observations, and discuss their ideas with other

Rather than explaining or describing properties of atoms and molec for students to discover those properties. Although this was the first to teach about atomic structure, Mike organized his lessons as guided d spectroscopy lab, students discovered that calculations of helium elect using the Bohr equations did not agree with their observations of spect sufficient cognitive conflict for students to be willing to entertain a structure, Mike then used the QSAD software as a means of investigating mechanical model. This new model was compatible with their observed res spectroscopy lab and could be used to predict and explain behaviors of their computer investigations, students then used the quantum mechanica method for anticipating periodic properties.

Mike exhibited his pedagogical content knowledge in his interview a classroom performance. When asked about identifying students’ alternati both general and specific strategies for eliciting, recognizing, and cor statement, “Different concepts require different initial strategies,” i student learning is context-specific. He noted that students do not hav some topics. In such cases, his strategy would be to provide “a much mo which certain key concepts have to be identified, extracted out, presen straightforward and simple fashion.” Mike’s pedagogical content knowledg in his awareness of specific issues that were likely to be barriers to quantum science.

Although Mike stated that he did not fully understand the concepts his concept map and interview comments indicated a detailed knowledge o relationships among sub-concepts. His responses to interview comments i considered several approaches to teaching quantum science, and these ex we judged to be thoughtful, appropriate references to the content.

Mike’s classroom practices contained an abundance of “the most pow representation,” which Shulman (1986) identifies as indicators of pedag Mike planned instructional units so that students would form a knowledg prior experiences. He then provided students with experiences that allo their own understanding of the abstract concepts related to quantum sci anticipated many of the alternative conceptions that students revealed comments, and he addressed their misconceptions by introducing disequil providing concrete analogies for abstract phenomena. The examples, demo and analogies that Mike used contained links to students’ personal expe

Mike’s teaching reflected pedagogical content knowledge in tailorin explanations to students’ comments and identifying students’ misconcept reflected an awareness of potential difficulties that students were lik variations in students’ learning styles and abilities. Prior to teachin Mike readily identified analogies, models, and instructional sequence t students’ understanding of quantum science. In class, he used some of t others in response to students’ specific questions and comments. For e analogy of a staircase when explaining quanta of energy, saying that a down in increments of stair steps but could not move up in fractions o student’s response indicated that he mistakenly thought that the energ two principal energy levels was the same, Mike explained that while ana explaining ideas, they can never give a completely accurate representat student’s comments suggested that she was confused by the two-dimension by the software. Mike gave the analogy of a loaf of marbled bread and a of the bread to the entire loaf. He then asked students to visualize sl such as an orange or a pair of balloons.

When reflecting on students’ comprehension, Mike identified clues that students understood the material. However, he noted that students concepts, implying that their comments and actions might be misleading. be interpreted as vigilance in continuing to probe for signs of student

Mike explained how he would motivate another teacher to participat use the QSAD materials:

> It’s a question of time if I could get them to sit down and play with about it and then use some of the, um, some of the exercises that dif developed to use it I think it becomes self-evident that it’s useful trouble I see is the barrier for the use of this software is getting just get a sense of comfort with it because so many teachers are uncom

> limb and sometimes and it might be the very nature of the subject mate very classically math people. They'd like to have an ordered and struc that, and the comfort comes from knowing it's ordered and structured t it's going and what's happening. And you take some software like this, whole new world. It's very unsettling, they don't have all the answers necessarily what's happening next and they lose that comfort level. So not the average, but for a lot of science teachers I think who fit tha not going to happen until they've had a chance to sit down and achieve it.

In his use of QSAD software, Mike created an instructional plan th scaffolding for students' construction of knowledge. Mike designed a to which QSAD software played an important role. He created a context for inquiry skills in conjunction with learning the chemistry concepts inhe activities that preceded software investigations set the stage for stud atomic structure. As students used the software, Mike noted their diffi and suggestions. He also encouraged students to collaborate with each o students were generating their own theories about periodicity, which wa of their investigations. He then adjusted his instructional plans by el start a dialogue about periodic properties of elements.

During the units on atomic structure and periodic properties, Mike examples of real-world applications of the quantum science concepts, bu used in class were different from the ones he had mentioned during early planned to mention why gemstones have specific colors, the quantum effe and the chemistry behind the colors of pH indicators, but his in-class these phenomena. Instead, classroom demonstrations included the design ray tubes and the emission spectra of different types of light bulbs.

After using QSAD software, Mike reflected on his students' engagem programs and evaluated the methods he used to guide their learning. He a those methods met his goals and identified which aspects of the instruc modification. Through this process of reflection and revision, Mike bot pedagogical knowledge.

Conclusions

Using computer visualization models, high school teachers can creat learning environments in which students successfully construct and empl the quantum mechanical atom. Factors that appear to have contributed to project include the teacher's willingness to learn along with students, over the learning environment and his strong pedagogical content knowled with the necessary insight to plan, monitor, and assess student underst students engaged in parallel learning experiences.

Generalizations cannot be made on the basis of a single case study teachers' use of new instructional tools for teaching atomic structure t perspective provides a compelling picture of the evolutionary process i content knowledge growth. This study suggests that when incorporating n materials, teachers' decisions about how, when, and in what form to use

function of their pedagogical content knowledge. In turn, through reflec
implementation of new materials, teachers learn how to improve their pe
thereby improving on their existing pedagogical content knowledge.

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