

Using Teachers' Choice of Representations to Understand the Translation of Their Orientation Toward Science Teaching to Their Practice

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Abstract

Representations are an effective tool that chemistry teachers choose to use in their classes to help their students understand abstract concepts. According to the model of pedagogical content knowledge (PCK), a teacher's knowledge of representations is part his/her PCK, which is shaped specifically by his/her orientation towards science teaching. Yet, PCK is criticized as focusing on teachers' knowledge not how their knowledge is translated to their practice. This study used a comparative case study of two secondary chemistry teachers to explore the relationship between the teachers' choice of the representations used in their practice and their orientation toward science teaching. The study focused on the teachers' use of representation for a unit on electronic structure and the periodic table, which they both identified as abstract for students. Results of the study indicate that the teachers' choices of representations were reflective of their orientation toward science teaching. The finding support questioning a teacher about representations as a useful tool for understanding teachers' PCK as it is translated to practice.

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Introduction

Representations—models, graphs, analogies, diagrams, simulations, equations, or any method for representing knowledge—have been shown to enhance students' understanding of concepts in science (Treagust, 2007). Topics in science are “abstract,” making them difficult to learn. Science teachers, especially chemistry teachers, find their students struggle with abstract concepts in science, so many teachers use representations as a tool to help students understand the concepts. Within chemistry education, representations, especially in the form of visualizations, are often a recommended teaching tool to help students navigate the multiple perspectives (i.e. macroscopic, submicroscopic, and symbolic) through which chemistry topics are viewed and understood (De Jong & Taber, 2007; Williamson & José, 2009). With the continual development and improvement of educational technology, many different types of representations exist for science teachers' use. Research supports the usefulness of many of these different types of representations in helping students learn. Analogies, especially when they are student-generated, have been shown to improve students' learning (Spier-Dance, Mayer-Smith,

Dance, & Khan, 2005). Molecular-level computer animations of chemical processes have been shown to help students learn chemistry content (Sanger, 2009). With the variety of effective forms of representations available, teachers must make choices about the representations to use in their classrooms. The reasons for their choices have not been well-established in the research literature, especially as it relates to teachers' knowledge about science teaching and learning—their pedagogical content knowledge (PCK).

A teacher's choice of representations has the potential to help us understand how a teacher translates his/her knowledge and beliefs about teaching and learning science to practice. Research has shown that teachers' beliefs influence their instructional decisions (Keys & Bryan, 2001; Jones & Carter, 2007). Magnusson, Krajcik, and Borko (1999) postulate that teachers' knowledge of instructional strategies are strongly influenced by their PCK, specifically their orientation toward science teaching, which Magnusson et al. defined as teachers' knowledge and beliefs about teaching science. Research supports their claim (Friedrichsen, Van Driel, & Abell, 2011). Yet, PCK has been criticized because it focused on teacher knowledge not teacher practice (Kind, 2009). With the many different types of representations available to teachers, teachers choose to use specific representations as they teach. If this choice of representations is an accurate reflection of the teacher's knowledge and beliefs, examining those choices provides us with another tool to understand a teacher's PCK, specifically their orientation toward science teaching, and it provides support for the use of PCK to understand teachers' practice. To use representations as a tool for understanding teachers' orientation toward science teaching in action, we need a better understanding of the relationship between them. The purpose of this study was to understand how the representations two experienced high-school chemistry teachers used reflected their orientation toward science teaching specifically as it relates to teaching chemistry.

Background

Representations are defined as any tool that a teacher uses to help students understand an idea. Representations are many modes—verbal, visual, kinesthetic—and include “models, analogies, equations, graphs, diagrams, pictures, and simulations that can help the learner understand an idea” (Treagust, 2007, p. 379). For example, visualizations would be a specific type of representation. Visualizations are representations that allow students to create a picture of something in their minds (Williamson & José, 2009). Computer simulations would be a specific type of visualization.

Studies have focused on identifying the important components of representations that make them effective for student learning (Waldrip, Prain, & Carolan, 2010). These studies have looked at the effective implementation of representations focusing on the representations and the students' responses to the representation. For example, Nottis and McFarland (2001) found that the type of content appeared to affect whether preservice teachers generated useful, effective analogies. In another study on analogies, Spier-Dance et al. (2005) found having students generate and present their own analogies improved learning for all students in an undergraduate chemistry course. As a final example, using computer animations showing chemical processes from a molecular prospective can improve students' conceptual understanding (Sanger, 2009). The focus of these studies has not been on the teachers, but on the representations and student learning. Focusing more on teachers' use of representations, Waldrip et al. (2010) used their

research and the research literature to create a framework for “guiding teacher interactions with students” (p. 77) when using representations in their classes. While providing some instructions for teachers, this framework does not examine why teachers might choose to use representations or why they would choose to use specific types of representations. Cook (2011) examined some of the factors that influenced six different science teachers’ use of visual representations. Course content, student abilities, realism, and type of visual were found to be important factors given by the teachers for their use of visual representations. Cook focused only on visual representations that the teachers used and did not examine other types of representations, such as verbal or kinesthetic representations.

In general, teachers’ choices for instructional methods and strategies are influenced by a number of factors. One important factor is a teacher’s beliefs about teaching and learning (Keys & Bryan, 2001; Jones & Carter, 2007). Teachers’ instructional choices have been shown to align with their epistemological beliefs (Jones & Carter, 2007). For example, a teacher with a constructivist view of learning is more likely to choose to use some form of inquiry-based instruction. Teachers’ beliefs would be considered part of their orientation toward science teaching within the construct of pedagogical content knowledge (PCK). Magnusson, Krajcik, and Borko’s (1999) model of PCK for science teachers includes teachers’ orientation toward science teaching *which influences* their knowledge of science curriculum (specific curriculum and general science goals and objectives), knowledge of students’ science understanding (students’ difficulties and background knowledge), knowledge of assessment in science (what to assess and how), and knowledge of instructional strategies in science (general science and topic-specific). “Knowledge and beliefs about the purposes for teaching science” (p. 97) is how Magnusson et al. (1999) define a teacher’s orientation toward science teaching. They contend that teachers’ orientation toward science teaching influences or shapes their knowledge in the other domains of PCK. A teacher’s choice of representations would be part of their knowledge of instructional strategies in science. In fact, Magnusson et al., when defining a teacher’s knowledge of instructional strategies, specifically identified the knowledge of representations as an important part of this PCK domain. Friedrichsen et al. (2011) found that the research literature has begun to support the fact that a teacher’s orientation toward science teaching influenced and shaped the other domains of PCK. Understanding a teacher’s knowledge of representations should then relate to the teachers’ orientation toward science teaching. However, based on the research, Friedrichsen et al. proposed a refined definition of orientation toward science teaching. Orientation toward science teaching should be divided into three parts to include a teachers’ beliefs about (1) “the goals and purposes of science teaching,” (2) “the nature of science,” and (3) “science teaching and learning” (p. 373). This refined definition of orientation toward science teaching is utilized in this study.

To understand the connection between the use of representations in practice and a teachers’ PCK, a context in which teachers will use numerous representations is needed. A topic within the typical secondary level chemistry curriculum, in which teachers might use a variety of representations, is electron configuration and the periodic table (periodic properties/trends). This topic is taught by over 90% of high school chemistry teachers in the introductory chemistry courses in the United States (Deters, 2006; ACT, 2009). *A Framework for K-12 Science Education* (National Research Council [NRC], 2012) expects by the time students graduate from high school they will know that:

The periodic table orders elements horizontally by the number of protons in the atom's nucleus and places those with similar chemical properties in columns. The repeating patterns of this table reflect patterns of outer electron states (p. 109).

It is an important topic in high school chemistry, but it is also an abstract one (De Jong & Taber, 2007). Students cannot hold single atoms to manipulate them or explore them directly and learn electron configurations. High school students also cannot directly collect the data to explore the some of the periodic properties like atomic radius, ionization energy, or electronegativity. Since students cannot interact directly with the phenomena that they are studying, teachers have to help students understand these topics in other ways. Representations are one tool teachers can use to help students understand the periodic table and periodic properties. While there has been research on the use of different representations in science as a tool, little research has been done on the types of representations teachers use to teach a specific topic like the periodic table. These reasons make the subject of electron configurations and the periodic table an appropriate focus of this study.

Methodology

The purpose of this research was to understand how experienced teachers' choice of and use of representations corresponded with their orientation towards science teaching. Due to the nature of the study a qualitative case study methodology was used (Stake, 1995; Merriam, 1998).

Participants and Context

Two experienced secondary-level chemistry teachers, Louise and Carla (pseudonyms), were recruited to participate from a convenience sample of experienced chemistry teachers in the local area of the researcher. Louise had taught chemistry for twenty-seven years at the time of this study. She had a bachelor's degree in chemistry and recently received a master's degree in curriculum and instruction. She taught at the only public high school in her Midwestern city, and was one of three teachers in her school to teach some level of chemistry. The school had approximately 1500 students. The class observed for this study was Honors Chemistry, which was composed of mostly sophomore students. She taught another section of Honors Chemistry along with 3 sections of Introductory Chemistry.

Carla had been teaching chemistry for eleven years. She had a bachelor's degree in chemistry with a master's degree in athletic administration. She was one of three teachers who taught some level of chemistry at one of two public high schools in the city. Carla's school was in a neighboring city to Louise's school within the same state. Carla's school had approximately 1700 students. The class observed for this study was Chemistry I taught to an approximately equal mix of sophomores and juniors. Carla taught 3 sections of Chemistry I, one section of Chemistry II, a second year chemistry course, and 1 section of Biology I.

This study focused on both teachers' units on the topics of electronic structure of the atom and the periodic table. The teachers began their units on electron configurations and the periodic table at approximately the same time during the school year. Louise split the topics of electronic structure and the periodic table into two separate units, Electronic Structure and the Periodic Table, each of which ended with a 25-minute quiz as the formal assessment. The units

were her fourth and fifth unit in the school year following units called “The Nature of Chemistry,” “Matter and Energy,” and “Atomic Structure and The Mole.” She had fourteen units in the year. With daily 50-minute periods the two units together took thirteen school days including the days for the final assessments (quizzes). Louise had twenty-one written learning objectives for the two units (See Appendix, Table 1). Categorized using Bloom’s Taxonomy of Cognitive Objectives (Chipappetta, Koballa, & Collette, 1998) seven of the objectives would be categorized as Knowledge objectives, five as Comprehension, six as Application, and two as Analysis. One objective could not be classified because it was written with the verb “understand” and was too vaguely described to know what understand meant. Activities throughout the unit included students completing teacher-led worksheets, two formal lectures with fill-in-the-blank notes, two short experiments, and small group review problems along with the two 25-minute quizzes used as summative assessments for the unit.

Carla’s Periodic Table Unit was her third unit of seven in her year; it followed units titled Investigating the Scientific Method and Matter and the Atom. She had six written learning objectives for the unit (See Appendix, Table 2). Categorized using Bloom’s Taxonomy of Cognitive Objectives (Chipappetta, Koballa, & Collette, 1998), three of the objective would be categorized as Knowledge objectives, one as Comprehension, and two as Application. With daily fifty-minute class periods, the unit, including time to work on the final performance assessment, took twenty-five school days. During the unit students did guided-inquiry worksheets, three modeling activities, three short experiments, three sorting activities which corresponded to guided-inquiry worksheets, two periodic table puzzles, two 15-minute multiple-choice “Target Quizzes”, and the final performance assessment.

Data Collection

To create a rich description of each teacher’s knowledge and practice, data were collected in three forms: interviews, classroom observations, and classroom documents. First, using semi-structured interviews each teacher was interviewed individually four times over the course of the study, twice before the unit began, once at the approximate midpoint of the unit, and once after the unit ended. The interviews lasted between 40 and 90 minutes and explored the teachers’ background knowledge, their general views on teaching and learning in chemistry, and their specific lesson plans for the unit. Questions during these interviews included difficulties students had with the material, and actions the teachers took or tools they used to help students learn. While specific questions about representations were not asked during these interviews, the questions about tools and actions were open-ended enough that both teachers discussed representations they used. The final two interviews focused on the teachers’ views of how the unit was progressing and student learning. Questions were also asked about observed actions during the unit including the representations the teachers had used. All the interviews were audio-recorded and transcribed.

In addition to the interviews each teacher was observed teaching the unit. The teachers’ class periods were 50 minutes long and observations occurred each day that they taught the unit. The class periods were audio-recorded with a digital recorder (no microphones were used) and detailed field notes were taken. Field notes included reproductions of any written material the teacher wrote on a board or through a projector screen during the class period. All audio-recordings and field notes were transcribed.

Finally, documents relating to the teaching of the unit were collected from each teacher. These documents, in paper or electronic format, included worksheets, handout, lesson plans, quizzes and tests, diagrams, experiments, and other documents the teacher used during the lesson.

Data Analysis

Using a constant comparative method (Merriam, 1998), transcripts, field notes, and documents were read and coded individually first. A rich description of each teacher's orientation toward science teaching was created using Friedrichsen et al.'s (2011) definition. The description included a description of each teacher's beliefs about science teaching and learning and her beliefs about the goals and purposes for teaching science. Due to the nature of the data collection, an appropriate assessment of the teachers' Nature of Science knowledge was not conducted, so there was no description of this area made. A description of each teacher's practice was also created, then cross-comparisons between the cases were made (Stake, 1995).

Findings

Louise's Orientation toward Science Teaching

Louise's orientation toward science teaching included traditional, teacher-centered beliefs about teaching and learning science. When asked to describe herself as a teacher, she referred to herself as a "coach" and a "mentor." Her "philosophy goes [sic] down to mentor-mentee or expert-apprentice. And that's how, I'm more like their coach" (In1L)¹. When explaining what she meant by coach, Louise described teaching as "demonstrating for students" and then giving them a chance to practice. She said students "need to see some example of the thought processes as well as just see how you do science" (In1L). During the observed classes Louise regularly worked problems at the front of the class, demonstrating her thought process. Students never worked problems or explained how they got answers to questions during whole class time. Louise "demonstrated" for students in other ways too. When students worked review problems in small groups on marker boards, she took the marker boards from students to show them how she would do the problem, completing the entire problem for the students. During an experiment, Louise took some of the chemicals from students, mixed them, and then told the students how she would record the observations from the reaction. She then let the students do the next reactions. "I think they [students] benefit from seeing us do some of the work" (In3L).

Louise clearly saw herself as the center of the classroom and as responsible for the students' learning. Almost all observed class time was teacher-centered. Louise stood at the front of the classroom directing students through the solutions to homework problems or new problems she posed. She stood at the front of the class and talked a majority of the time during nearly every class period including a day when they did a short experiment. In her conversations about her teaching and her teaching practice, Louise used the term "I" most of the time. For example, "I work really hard at trying and I don't know that it helps sometimes" (In4L), Louise said about her classroom practice. Another comment she made: "How am I going to get them to

¹ The source of the teacher's quotes are cited using the formula (Data Source number participant). In = Interview, Ob=Observation, L = Louise, C= Carla. For example, In1L indicates this quote was said by Louise during her first interview.

be better at chemistry?” (In3L). Even in class once she told her students “I’m going to help you figure out what valence means”(Ob5L) These quotes demonstrate that she viewed herself as responsible for learning, as if it was something she could do for students; I is used not us or we or you. She was their coach, she was the center of the classroom, and it was her responsibility to get them to learn, not for them to help themselves.

Finally, as briefly mentioned above, Louise believed that students learn by practicing, and practicing often. The majority of the observed class time, Louise and/or the class worked or reviewed questions/problems from worksheets, homework, or samples that Louise posted through a computer projector. On eight of the thirteen days, Louise either reviewed answers to homework problems or had students doing practice problems similar to the homework problems they had been doing. Louise believed that hard work and focused effort on the problems would help students learn so she encouraged them to work. Twice she gave students a worksheet for homework she asked them for “fifteen or twenty minutes of concentrated effort”(Ob1L, Ob3L) that night on it.

Louise expressed the belief that the goals and purposes for teaching chemistry are to prepare students for their next course. “I’ve been fine tuning it (her chemistry curriculum) to try to meet the AP (Advanced Placement) curriculum requirements and keep it so that those kids could walk into chemistry in college and be prepared for those topics” (In2L). Another time she commented, “preparation for their college coursework, that’s a big part of it (curriculum) as well” (In1L). Louise repeatedly said in all four interviews and after class a few times that there was “too much content” in the course, but she had to prepare students for the next class which the objectives were written to do. Louise said the purpose of teaching electronic structure and the periodic table was so that students could understand bonding and be able to write formulas in the next unit. “The general idea is to learn electron structure so they can understand bonding” (In2L). In conversations and in her actions, the purpose for what she taught, her objectives and how much she did in each class, always appeared to be about the next step.

Louise demonstrated a teacher-centered orientation toward science teaching. She believed the teacher must be in control, dictating and demonstrating what and how students learn chemistry. Students needed repeated practice to learn the content, which is taught to prepare them for the next chemistry course.

Louise’s Representations

Louise used role-playing as the main type of representations during her lectures or explanations of problems. In this case, role-playing means physically behaving or “acting” like the concept being discussed. For example, if she said the electron got excited and jumped energy levels, Louise stood on a chair. She did this nearly every time she said an electron “got excited.” When she said that the atom was pulling on the electrons, she pretended like she was pulling on something. Throughout the observations, if she were talking about an “action” which an electron or atom did during any practice problem or lecture, Louise acted it out for the students. There were two specific role-playing events that Louise repeated, “quantum leaps” (the term she used in class during this action) and a nuclear shielding performance. “Quantum leaps” Louise did herself five times and had the students do three times. When talking about electrons becoming excited and jumping energy levels, Louise (or everyone) would step up on a chair and then

“jump” to an even higher energy level by stepping up on a desk. Louise then described the electrons releasing the energy and returning to their ground states, getting off the desk and chair at the same time as the verbal description. One time while the students did this quantum leap, Louise turned off lights as students climbed onto their chairs, and then turned the lights on as they returned to their “ground state” (the floor) and released the energy as light. For the nuclear shielding performance, Louise physically modeled the concept of the effect of nuclear shielding on ionization energy for students. Louise put one or two pens in her hand, saying her hand represented the nucleus and the pens represented electrons. She then asked a student to try to pull an “electron” (pen) away from her. The student could not or worked very hard to pull the “electron” from her hand. Then Louise grabbed a very large handful of pens and asked the student to try to pull one away. The student could easily pull out one from the middle of her stack. When this happened Louise pointed out that the farther from the nucleus the easier the “electron” was to remove. During one of these nuclear shielding performances, Louise mentioned how this example is actually the reverse of what it is in the atom, since the nucleus would be in the middle, not on the outside like the hand.

In addition to role-playing, Louise also used teacher-generated molecular-level drawings as representations to help her students understand the concepts. Louise had a drawing to help students see the nuclear shielding concept (See Figure 1).

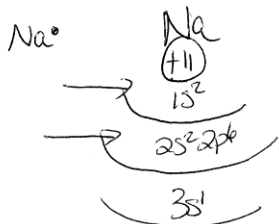


Figure 1. Louise’s drawing of nuclear shielding

When she explained nuclear shielding in practice problems, she would always draw something similar to Figure 1 as she did the problem. Louise said this was the first year she had ever used this drawing, and she was going to continue to use it because she thought it helped student visualize nuclear shielding. The other drawing Louise used was her snowman drawing (See Figure 2).



Figure 2. Louise’s “Snowman” drawing.

When she answered a question about atomic radius within a family, in a column, she would list three elements, for example lithium, sodium, and potassium. Next to the element's symbols she would draw circles to represent the atoms getting bigger down the column. The first time she drew it, she called it the "snowman effect" (Ob8L). In later practice problems, when she drew it, Louise said remember the "snowman effect" writing the word "snowman" as well at times.

Finally, Louise had verbal cues that she used to help her students remember ion formation. She repeatedly used the phrases "positive losers" and "negative gainers." When she talked about the ions metals formed, she said "Metals are positive losers" to help students remember that metal atoms lost electrons becoming positively charged. Nonmetals, then, were the "negative gainers."

Carla's Orientation toward Science Teaching

Carla's orientation toward science teaching included student-centered, reform-based beliefs about teaching and learning science. When asked to describe herself as a teacher, Carla used the terms "planner" and "facilitator."

Like I kind of plan, you would see me I like circle. I feel like an eagle. I'm like 'here I go guys ok if you need any help' and you just like constantly circling and you know answering questions. So it kind of like 'hey try this, do this, and then apply this' and so during the apply this part I feel like it is just circling and asking questions. So it is more I guess a true facilitator role than a lecture role (In1C).

Carla believed she was there to help students learn, but it was not her responsibility to do the learning; the students were responsible for their learning. Her comments reflected this belief. Carla rarely used the term I; most of her answers to questions involved the term we. She used "we" to refer to her classroom practice. "Then we'll add the charges to our periodic table, as well, and then we figure out why they're charged, who wins, and basically we talk about sports, so protons or electrons are who's winning and that's what the charge is and by how many and so we'll do that and we add that to our blue periodic table" (In2C). Her actions also demonstrated this belief. While she assigned homework to students, she did not collect it. She reasoned that it is the students' responsibility to do it, not her job to grade copied assignments. "Do your homework or don't do your homework, but you're still going to be assessed on it in a formal fashion, in a target quiz, in class where you can't run around the cafeteria and try to find the answer; it's what you know, what you don't know" (In3C). In addition, Carla often responded to student questions with questions: "Does it show a pattern?"(Ob8C) "What's the trend?" (Ob12L) "How did you know that?" (Ob20L). When she helped a student or a group of students, she asked a question and then stood there while they worked on it. She watched what they were doing, but waited while they tried it. She did not answer the question for them or do it for them; she made the students responsible for their learning.

Carla also believed students need to "build their knowledge" by working with other students. She said she used "a lot of what [she] would call constructivism stuff" in her class, which in practice were guided-inquiry activities (In1C). [Note: Carla never used the term guided-inquiry to describe her activities, but they were consistent with the definition of guided inquiry

(Bell, Smetana, & Binns, 2005; Trout, Lee, Moog, & Rickey, 2008).] In each observed class students spent some time working in small groups or with partners. Carla led the class occasionally, but more commonly moved through the class as students worked in their groups. Students did not complete quizzes with a partner, a group of four, or as an entire class, but quizzes were the only individual work. During whole class discussions, Carla asked different students for parts of answers to questions. As reflected in her comments that used “we,” Carla believed learning was a collaborative process.

Finally, as part of her orientation toward science teaching beliefs, Carla viewed the purpose for teaching science to be to teach students to solve problems by using their resources and applying their knowledge. Carla used a large performance-based assessment for all of her units including her Periodic Table Unit (See Appendix for the performance assessment instructions), along with an approximately 25-question multiple-choice test as the summative assessment. Carla “believed in” performance-based assessments strongly and used them since she began teaching. She gave the performance assessments as the reason why she taught or did not teach a topic. For example, question: “So you took this out, why?” Carla responded “None of this is on the periodic table puzzle assessment (the performance assessment for the unit)” (In3C). This response was similar to many Carla made. The performance assessments drove her instruction. “It doesn’t go with the [performance] assessment, so I don’t really put a lot of time into it” (In2C). Rather than memorizing or repeating knowledge, “applying knowledge” in the situations Carla created for the performance assessments was the goal she set for her students. Carla specifically said she does not have her students memorize anything, because they “still don’t learn it....I feel like it’s more important to try to teach them to learn to use their resources” (In4C).

Carla demonstrated a student-centered orientation toward science teaching. She believed students must take responsibility for themselves, building their knowledge in a social setting. The purpose of that teaching science for Carla was to teach students how to use and apply their knowledge.

Carla’s Representations

Carla used teacher-generated analogies that were not chemistry-based throughout her Periodic Table Unit as she compared chemistry concepts to items/ideas familiar to students. There were three analogies Carla repeated on multiple days during class discussions of some guided-inquiry activities. For the first analogy Carla compared electron configurations to addresses; $1s^2 2s^2 2p^3$ is like saying 502 W. Main. If you put the address in your GPS unit, it will direct you to a house. The electron configuration directs you to an element. Carla continued this analogy into a second analogy for energy-level diagrams. [Note: Energy-level diagrams is Carla’s term. Orbital diagrams is the more common term.] If electron configurations are the address, she said, then energy-level diagrams are the maps. They show you where the electrons are like a map shows you where a house is. To help students with Hund’s rule, Carla has a third analogy, which she referred to as “the bus seat rule.” She explained to students that electrons were like them getting on a bus. If there is an empty seat, you do not sit next to someone, but if all the seats have someone in them then you have to pair up. Electrons are the same way, on the “s-bus” (s-orbitals) or “p-bus” (p-orbitals) electrons will not pair up until all the seats are filled with one electron (Hund’s Rule). Carla used four more analogies during the unit, but these

analogies were not repeated as often or as well developed as the three analogies above. For example, Carla related electronegativity to strength claiming the elements said “Hey baby give me your electrons.” (Ob17L). If the element was strong like fluorine, you do not argue but give up your electrons, but if an element is a “wimpy guy” like francium, you laugh and hold onto your electrons or maybe even take his. Carla did not repeat this analogy as often as the others above. She also had short analogies similar to this one for the effects of atomic structure and electron loss or gain for ion formation.

Besides using numerous verbal analogies, Carla also used analogous physical illustrations/models. Carla started the unit with an “Alien Periodic Table.” For this activity, student got drawing of “aliens” that represent the first eighteen elements on the periodic table (See Figure 3 for three aliens and the elements they represent).

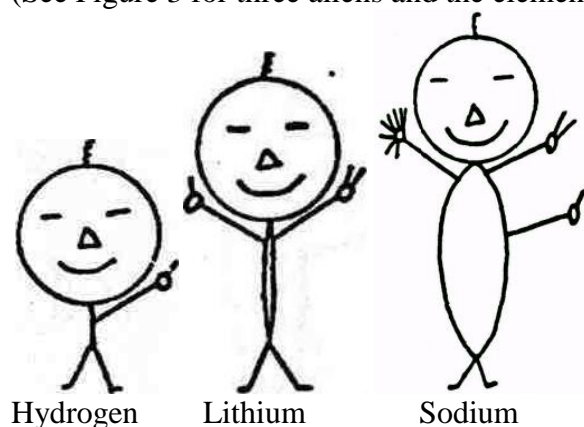


Figure 3. Aliens representing three elements in the same family

The aliens provided students with analogous models of the elements so that students could *see* some of the “characteristics” of elements and *reason* by analogy. For example, since lithium and sodium belong to the same column or family, they have the same face. Sodium has one more energy level than lithium so it has another arm. Aliens (elements) in the same family looked alike, when they went down a row they grew another arm, a new energy level, and each alien had more fingers (electrons). The aliens also got fatter down the families; atomic radius increases down a group. Carla referred to this physical representation of the elements and the patterns on the periodic table throughout the unit. She would talk about the alien/element growing another arm or adding fingers holding out her arm or hand as she talked about it. Another physical analogy that Carla used was drawing the shapes of the orbitals. She connected the energy it took to draw the shape (and she would draw them as she talked) to the energy of the orbital. Carla drew an s orbital as a circle, saying it did not take much energy to draw it. Then she would draw a p orbital, which looks like a dumbbell, saying it was a little harder to draw and took more energy. Carla used three other physical models in the unit for the concepts of frequencies and wavelength, electronegativity, and atomic radius.

In addition to the verbal and physical analogies, Carla used role-playing to demonstrate the rules that dictate orbital filling in an atom (Hund’s rule, Pauli’s exclusion Principle, and Aufbau’s Principle). Carla set up some stools to represent orbitals; ten stools at the front of the room with two short stools in the front row (the 1s orbital), two taller stools in the second row

(the 2s orbital), and six taller stools grouped in pairs in the third row (the 2p orbitals). Students then acted as electrons. Carla picked a student, had him choose a stool to sit in, and then she told him if it was ok to sit there. If it was not okay, the student had to keep trying stools until he located the right one (a short stool that represented the 1s orbital). Then another student was asked to find a stool, and the process repeated itself. Once the stools were full, Carla made the students spin on the stools, but they could not spin the same way as the person to whom they were sitting by. She then asked students what the rules for sitting in the stools had been, and they connected these to the rules for filling electrons in energy-level diagrams (e.g. they had to sit in the shortest/closest stools first, which represented the electrons filling in the lowest energy levels first).

Finally, similar to Louise, Carla had some verbal and visual cues to help students remember concepts. She had one mnemonic to help students remember the energy order of the orbitals: “smart people don’t forget.” As a verbal reminder that the d and f orbitals are in a lower numbered energy level than the row number they are in, Carla would say if you are getting a D in chemistry you’re a little behind (one row behind or smaller in number) and if you are getting an F you’re really behind (2 rows behind). Several times when students were working, Carla mentioned if you are getting a D/F are you caught up? It was simply a verbal reminder to help students. Carla also had a few visual reminders. On the periodic table, she drew a strong arm on fluorine and “wimpy guy” next to francium to remind them of the electronegativity trend and what electronegativity referred to, strength. Carla also pretended to row a boat across the large periodic table at the front of the room when students got the terms column or group and rows mixed up. If the students talked about two elements in the same row but used the term group, Carla started making rowing motions in front of a large periodic table she had at the front of the room.

Discussion

When discussing their knowledge of students’ difficulties with the topics in these periodic table units, both Louise and Carla said the topic was abstract for students and students had a hard time seeing it or relating to it. During interviews both indicated that they used their representations to help students understand this “abstract” topic. Louise and Carla’s general reasoning for using representation is consistent with the research on representations. As mentioned previously, representations are useful techniques for helping students understand abstract concepts (Treagust, 2007; De Jong & Taber, 2007; Williamson & José, 2009). Table 1 provides a summarized comparison of Louise and Carla and their use of representations.

Table 1
Summary Comparison of Louise and Carla

Louise	Carla
<ul style="list-style-type: none"> • “Coach”/ “Mentor” • Was responsible for showing students how to think about chemistry • Used numerous practice problems • Taught to prepare students for next 	<ul style="list-style-type: none"> • “Facilitator”/ “Planner” • Was responsible for providing students opportunities to build their knowledge • Used guided inquiry and group work

course	<ul style="list-style-type: none"> • Taught to help students learn to apply their knowledge
Louise's Representations	Carla's Representations
<ul style="list-style-type: none"> • Role-Playing • Molecular-level drawings • Verbal Cues 	<ul style="list-style-type: none"> • Verbal analogies • Analogous Physical models • Role-playing • Verbal-cues • Visual Reminders
Representations were	Representations were
<ul style="list-style-type: none"> • Direct demonstrations of content • Teacher-generated • Not assessed formally in terms of students understanding of them • Used mainly to <i>understand explanations of content</i>, i.e. why atoms are smaller across a period • Representations did not require student participation 	<ul style="list-style-type: none"> • Connections to other concepts mostly • Teacher-generated, but student-focused • Not assessed formally in terms of students understanding of them • Used mainly to <i>remember or understand definitions of content</i>, i.e. what is an electron configuration • Some representations required student participation/use

Louise and Carla's orientations towards science teaching differ, which is reflected in the representations they chose for the concept of electronic structure. Louise believed she had to demonstrate for the students how to think about science and solve the problems so the representations she chose allowed her to demonstrate concepts to the students. She acted like the electrons and the atoms: she jumped up, she pushed, and she pulled. She even drew representations of the atoms themselves to demonstrate the concepts—the atoms with their energy levels as shields, for example—as ways for Louise to “show” students. Louise did not use analogies or metaphors, which require a comparison to something distinctly different. During her role-playing, Louise was just being atoms and/or electrons, doing what they do, so she could show the students their behavior.

Another aspect of Louise's orientation toward science teaching is her belief that the purpose of teaching chemistry was to prepare her students for their next chemistry course. Her learning objectives for this unit (See Table 1 in the Appendix) were written based on what she thought students needed to know for college or Advanced Placement chemistry, which included higher-order learning objectives for describing, comparing, and/or analyzing the periodic trends. Louise used her representations to help with the higher-order learning objectives she had. The concepts Louise's representations focused were explanations or reasons for the periodic patterns. Louise used the pens in her hand to help students understand why ionization energy might decrease with increasing size and thus increasing nuclear shielding, and the quantum leaps were meant to understand why there were only certain colors in an element's spectrum—there were distinct steps to take to get on the desk instead of a ramp or slide. Louise's representations did not help students understand the definition of ionization energy or an electron configuration.

Contrastingly, Carla had a more student-centered, social-learning orientation towards science teaching, believing that students had to be responsible to build their own knowledge. Carla's representations, mostly verbal and physical analogies, related the chemistry concepts to other ideas familiar to the students. Her representations did not demonstrate concepts, but rather provided students with connections to help them build their knowledge. While the representations would have been more student-centered if the students had generated them (Spier-Dance et al., 2005), Carla made the effort to relate to topics familiar to students or involve her students in the representations she generated.

As part of her orientation toward science teaching, Carla believed the purpose for teaching science was to help the students learn to apply their knowledge to a new situation. Carla's learning objectives (See Table 2 in the Appendix) were lower-order and her representations helped students understand definitions of concepts—gain the knowledge to apply. Since her goals for teaching chemistry did not include students having a conceptual understanding of the phenomena, Carla's representations did not focus on the explanations for the concepts being studied. Carla had a representation to help students understand what an electron configuration is, her address analogy, but she did not have any representation to help them understand, for example, nuclear shielding to explain why fluorine is highly electronegative, the strong guy, and francium weakly electronegative, the wimpy guy. The students did not need this knowledge to “apply their knowledge” of periodic trends on the performance assessment. Carla's representations helped students understand the definition of the concepts; the bus seat rule helped students remember a rule or definition for orbital filling, two electrons do not pair when there are empty equivalent orbitals, but it does not provide an understanding of the explanation for the rule, which would be because they are both negatively charged and therefore repel.

One similarity between Louise and Carla was their use of verbal cues. Louise and Carla both used the verbal cues as reminders of terminology or facts. “Positive Loser” for Louise reminded students that ions are positive when they lose electrons, while “smart people don't forget” reminded Carla's students of the order of the orbitals. This overlap of representation use demonstrates a similarity in their teaching practices despite different orientation towards science teaching. For both Louise and Carla, a significant portion of their learning objectives classify as knowledge-based. The verbal cues were meant by both teachers to help students with these knowledge-based objectives, but their purposes for the knowledge-based objectives overall differed. Louise felt she needed to give students the knowledge they needed for the next course, while for Carla the students needed the knowledge to apply it. In defining orientation toward science teaching, Magnusson et al. (1999) argued “it is not the use of a particular strategy but the purpose of employing it that distinguishes a teacher's orientation toward science teaching” (p. 97). For verbal cues, the ultimate purpose of the learning, belief about the purposes for teaching chemistry, differed for Carla and Louise.

Louise and Carla are teachers with different orientations toward science teaching and the representations they used to teach the same content reflect these differences. The findings from this study support Magnusson et al.'s (1999) supposition that a teachers' orientation toward science influenced their knowledge of instructional strategies. In addition it appears to go beyond just knowledge, but is translated to teaching practice as Louise and Carla's cases

demonstrates. If these teachers are effectively translating their knowledge to practice, then their instructional choices, in practice, should be reflective of their orientation toward science teaching. Yet, important to understanding the differences how Louise and Carla's representations aligned with their orientation towards science teaching was the use of Friedrichsen et al.'s (2011) refined definition of orientation toward science teaching. The types of representations they chose (i.e. analogies vs. demonstrations) corresponded with their beliefs about science teaching and learning, while the focus of their representations and their use of verbal cues reflected of their beliefs about the goals and purposes for teaching science. Without the distinction of beliefs about the purposes of science teaching, the fact that both Carla and Louise used verbal cues might have created a point of confusion between their representation use and their orientation toward science teaching, since their beliefs about teaching and learning vary significantly. However, using Friedrichsen et al.'s definition of orientation provided an opportunity to consider the purposes of the representations in light of both Louise and Carla's purposes for teaching science, which provides a better context for the similarities. The findings of this study suggest the use Friedrichsen et al.'s refined definition of orientation toward science teaching might be useful in future research studies which attempt to understand the differences in teachers' PCK.

It should be noted that neither Louise nor Carla used representations in a manner suggested by research as being the most effective for student learning. The representations used by Louise and Carla were teacher-generated and never formally assessed. In neither class were students given the chance to come up with their own drawing, analogy, or another form of a representation for the concepts they were learning. While teacher-generated or pre-generated representations are effective in helping students learn (Treagust, 2007; Sanger, 2009; Williamson & José, 2009), giving students the opportunity to develop their own has been shown to be even more effective (Spier-Dance et al., 2005; Waldrip et al. 2010). Similarly, both teachers' representations were never part of a formal or informal assessment to determine if students understood the representations being used or how they connected with the content or other representations (Treagust, 2007). Thus both teachers have little data to support whether or not their representations helped students understand the concepts or if students used the representations to understand the concepts. Without a discussion or assessment of the representation and how it relates to the concept, students might develop misconceptions about the concepts (Waldrip et al. 2010). For example, Louise's pens-in-the-hand demonstration may have created the idea that inner electrons are the easiest to remove from an atom because those were the easiest pens to remove, when in fact it is the outer electrons that are the easiest to remove from an atom. Without formal or informal assessment of their representations it is hard for the teachers to gauge the success of their representations, though both thought their representations were useful and effective for students.

Conclusions

While small qualitative research studies cannot allow for generalizable claims to be made, they can provide support for theories and good information for future research. PCK has been criticized because it can be used to focus on teachers' knowledge not their practice; it is important to investigate how the knowledge is translated to practice (Abell, 2008). It might be said teachers have knowledge of instructional strategies or beliefs about teaching and learning, PCK, but do not translate that knowledge to their classroom practice. Louise and Carla's case

studies provide some support for the use of PCK as a way to understand teachers' practice. For both teachers, their choice of representations they actually used in practice aligned with their orientation toward science teaching; their PCK, their knowledge, was being translated to their teaching practice. The results of the study suggest that uncovering the representations a teacher uses to teach specific content might be an effective means of understanding a teacher's orientation toward science teaching as it translates to their practice. Understanding a teacher's practice typically requires observations, but observations of a teacher's classroom practice requires access to their classrooms and a significant time by the researchers. Interviewing teachers, however, can be more easily accomplished. Interview questions about tools or representations that teachers use to help students understand specific topic could be part of an interview. As described in the methodology section, neither Louise nor Carla were asked direct questions about representations they used to help students understand, yet both discussed the representations they were observed during the interviews. Neither Carla nor Louise required questions about the specific representations to begin discussing them and their descriptions of the representations matched their practice. This suggests that representations might provide a specific action for researchers to understand how a teachers' orientation toward science teaching, using Friedrichsen et al.'s (2011) definition, is reflected in their teaching practice. Delving into a teacher's use of representations provides a way to understand PCK's translation to practice without the time it takes to observe their practice.

Current research has yet to identify good or desired PCK for effective science teachers, another criticism of PCK (Abell 2008; Kind 2009). This study did not collect student achievement data, so it is difficult to identify if either teacher was more effective. However, orientation toward science teaching, and PCK, does not reflect effective use of teaching strategies or beliefs, but rather what a teacher knows or believes (Kind 2009). Carla used more reformed-based teaching strategies like guided inquiry, but as mentioned above neither teacher used representations as the research suggests they should and both teachers had a large majority of learning objectives in the lower portions of Bloom's Taxonomy. If one of the teachers' students had performed significantly better than the other, then judgments could be made about the importance of the differences between the two teachers despite some of these similarities. Future studies should include student data to begin to contribute to the discussion on effective PCK for science teachers.

Uncovering the representations a teacher uses when teaching, especially an abstract topic like electronic structure and the periodic table, can give researchers, educators, and maybe even the teacher, insight into the teacher's orientation toward science teaching. Understanding a teachers' orientation toward science teaching is helpful for designing effective professional development and learning experiences for teachers. Starting learning experiences from a teacher's beliefs or orientation towards science teaching creates a learning situation in which the teacher is more likely to learn and develop professionally (Hammerness, et al., 2005; Jones & Carter, 2007). Using representations as a reflection of a teacher's orientation toward science teaching, their PCK, in practice can allow for the creation of professional development targeted for teachers, providing a chance for teachers to evolve and improve their practice.

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Appendix

Table 1

Louise's Unit Objectives.

Objectives for Electronic Structure Unit		Bloom's Taxonomy Category
1.	Use the modern model of the atom to explain bonding	Application
2.	Describe the wave in terms of speed, frequency, amplitude, and wavelength	Comprehension
3.	Identify the major areas of the electromagnetic spectrum	Knowledge
4.	Explain what is meant by a quantum of energy	Comprehension
5.	Understand that four quantum numbers describe the energy of each electron in an atom	*Cannot be classified
6.	Use 4 quantum numbers to describe the energy of an electron	Application
7.	Describe atomic orbitals in terms of shape, size, and energy	Comprehension
8.	<i>Write ground state electron configurations for both atoms and ions</i>	Knowledge
9.	<i>Write shorthand configurations for both atoms and ions</i>	Knowledge
10.	<i>Relate electron configuration to ions when atoms bond</i>	Knowledge
11.	<i>Write Lewis dot notation for atoms and ions</i>	Knowledge
12.	Predict the formulas for ionic compounds using the electron configurations	Application
Objectives for the Periodic Table Unit		
13.	State and apply the periodic law	Application
14.	Contrast Mendeleev and Moseley's periodic tables.	Analysis
15.	Define atomic radius, ionization energy, electron affinity, and electronegativity	Knowledge
16.	<i>Interpret and predict properties of elements based on atomic radius, ionization energy, electron affinity, and electronegativity trends.</i>	Application
17.	<i>Contrast group trends and periodic trends</i>	Analysis
18.	<i>Write Lewis Dot structures for elements, ions, and compounds</i>	Knowledge
19.	Compare alkali and alkaline-earth metals reactivity- lab	Comprehension
20.	<i>Predict bonding ratios from an element's valence.</i>	Application
21.	<i>Explain cation and anion formation predicting compound formulas.</i>	Comprehension

Note. Objectives in italics were identified by Louise in interviews as being the most important objectives.

Table 2
Carla's Goals for her Periodic Table Unit.

Objectives of The Periodic Table Unit		Bloom's Taxonomy Category
Overall Goal	Why the Periodic Table looks the way that it does, explain and apply	Application
Target 1	I can write out the electron configuration for a given element and identify a given element based on its electron configuration	Knowledge
Target 2	I can draw an energy level diagram to show the energy of the electrons within an atom	Comprehension
Target 3	I can calculate the wavelength and frequency of an electron as it relates to the electromagnetic spectrum and Bohr's model	Application
Target 4	I can identify the elements that have specific families on the Periodic Table	Knowledge
Target 5	I can find an element's oxidation number based on it's location on the periodic table relative to the Noble Gases	Application
Target 6	I can identify the general trends of the atomic radius, reactivity, and electronegativity of elements both across and down on the Periodic Table	Knowledge

Note. Carla's terminology is used. Targets were given to students, but not the overall goal.

Carla's Periodic Table Performance Assessment

Background Information and Purpose

In this assessment, you will use your knowledge of the periodic properties, the periodic trends review project, any of your own notes, people at your table, and the provided list of clues to:

- Create a periodic table using 30 cards that represent elements from a different universe
- Predict the oxidation number and electron configuration for each element card
- Build an Energy level diagram for this universe
- Compare and contrast some of the elements in this new universe with some elements in our universe

This universe has different characteristics than our own, but the same trends. For example, there could be different sublevel shapes, different numbers of sublevels, different number of electrons that are allowed in each orbital and different numbers of electrons that are allowed in each energy level. These differences will give rise to a different looking periodic table, but the basic concepts you have learned will still apply to this universe. For example, the concept that an element will gain or lose electrons to have a filled Energy level and thus will be stable, still pertains to the new universe.

Each element is represented by a code letter. Clues for many elements are listed below, or can be found in the cards themselves.