LOOK ACADEMIC PUBLISHERS
OPEN ACCESS

INTERNATIONAL JOURNAL OF ENVIRONMENTAL & SCIENCE EDUCATION
2018, VOL.13 , NO.1, 69-95

Beginning Chemistry Teachers' Depictions of the Chemistry Content

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ABSTRACT

Teaching and learning chemistry involves multiple levels of representation: macroscopic (macro), submicroscopic (submicro), and symbolic. A more recent trend includes the human element, a fourth representation level that contextualizes the chemistry content through real-world applications. This three-year study follows eight beginning chemistry teachers in order to understand how the chemistry content is depicted in the classroom. Teachers need to be engaged in the analysis of key concepts in the content and common representations to recognize instruction should focus on helping students negotiate the representation levels. Support for teachers with examples will help beginning teachers better implement the tetrahedral model and empower beginning teachers to intentionally point out the connections among the different representational levels for students. This may require support to extend beyond the first three years in the classroom.

KEYWORDS
Early Career Science Teacher, Chemistry, Chemistry Tetrahedral Orientation

ARTICLE HISTORY
Received 15 December 2016
Accepted 5 February 2017

Introduction

Beginning teachers possess a limited repertoire of lesson plans and teaching modalities from which they can draw to represent the key ideas, concepts, and structure of the subject matter for students. Developing successful chemistry students involves instruction that not only provides opportunities to ask questions, collect data, and form conclusions but also involves students in real-world applications (e.g., human element) (National Research Council 2011, Mahaffy 2006, Evans, Yaron, and Leinhardt 2008, Ketelhut and Nelson 2010). However, the beginning teacher often depicts the content through a heavy reliance on instructional strategies of lecture and worksheets with few demonstrations and laboratories (Luft et al. 2011). During the first few years in the classroom, the beginning teacher is developing a repertoire of instructional strategies that

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responds to students' understandings of the content (Feiman-Nemser 2001, 2010, Van Driel, de Jong, and Verloop 2002, Justi and van Driel 2005, Mutton, Hagger, and Burn 2011)

Johnstone (1991) argued the difficulties of learning science were based on how it is taught with little consideration to what students understand. Students often have a difficult time learning science for many reasons: heavy emphasis on vocabulary within textbooks (Groves 1995, Groves 2016, Yager 1983); its abstract nature(Mayer 2011, Nakhleh 1992, Veal 2004, Zoller 1990, Treagust and Chittleborough 2001), the reliance upon mathematical equations to explain phenomenon(Laws 1996, BouJaoude and Barakat 2000), confusion caused by the student trying to negotiate different thinking levels simultaneously(Bucat and Mocerino 2009, Chandrasegaran and Treagust 2009, Johnstone 1991). Students' difficulty with the thinking levels have been extensively studied in chemistry(e.g., Kern et al. 2010, Hinton and Nakhleh 1999, Chittleborough and Treagust 2007) and are described as the macroscopic (macro) - observable properties; submicroscopic (submicro) – matter is represented by the constituent atoms, molecules, and ions; and symbolic levels – the mathematic and chemical symbols and models (Gilbert and Treagust 2009, Treagust, Chittleborough, and Mamiala 2003, Andersson 1986, Johnstone 1991). While much is known about student difficulties, few studies have specifically focused on the chemistry teachers' depiction of these representation levels within their classroom instruction(Lewthwaite and Wiebe 2010, Sande 2010, Van Driel, de Jong, and Verloop 2002). Throughout the paper, thinking levels refer to the students' understanding; representation levels depict the teachers' instructional strategies (e.g., laboratories, lecture, worksheets).

This study investigates eight beginning chemistry teachers' depiction of the chemistry content through the representation levels over a three-year period. Specifically, we aim to identify how the teacher presents and negotitates the representation levels when presenting the content to their students during the first three years in the classroom. By analyzing these eight teachers' instructional strategies, we are able to provide a more complete understanding of the ways in which teachers present the chemistry content in order to address students' difficulties learning. This understanding will be valuable to science educators in order to devise support for novice (pre-service and beginning) teachers in preservice and induction programs to develop instruction that supports students learning.

Conceptual Framework

Johnstone's(1982, 1991, 2000) levels of thought presented as a trigonal model serves as the conceptual framework for this study. Since the thinking levels were first introduced, chemistry education researchers have suggested different terminology to describe the three levels of representation(Andersson 1986, Treagust, Chittleborough, and Mamiala 2003, Bodner 1992); introduced new representation levels for depicting the chemistry content (Towns et al. 2012, Jensen 1998, Meijer, Bulte, and Pilot 2009, Kapteijn 1990); included representation levels specifically for contextualizing chemistry(Mahaffy 2006); and visualized different models to represent the levels of thought(Mahaffy 2006, Meijer, Bulte, and Pilot 2009, Talanquer 2011). There are also similarities and differences in how researchers have defined each of the representational levels.

Below we discuss the model in terms of both chemistry education and science education research in order to frame the analysis of beginning chemistry teachers' practices.

Macro representational level: What is an experience? The macro (from macroscopic) representation level is universally understood as the sensory input of observable properties (e.g., density, flammability, and color). This may also include graphical representations of the observable properties (Taber 2013). Yet, variations exist even within the definition of macro. For instance, some researchers focus solely upon macroscopic properties (Gabel 1999, Hinton and Nakhleh 1999, Treagust, Chittleborough, and Mamiala 2003), while other researchers include students' experiences with the phenomenon (Chandrasegaran, Treagust, and Mocerino 2007, Treagust, Chittleborough, and Mamiala 2003). The key difference between the two definitions is the type of experience. In the first, the experience is scientific in nature, with students measuring, observing, and categorizing based on unique macroscopic properties of the materials they are investigating (Gabel, 1999; Hinton & Nakhleh, 1999; Treagust, et al., 2003). An example could be water, which has a specific color, density, and boiling point. In the second definition, using water as an example, the students' learning experience is based on their prior experiences with water, which may include the students' personal and existing knowledge of playing or interacting with water outside of the classroom. When teaching chemistry, the instructor's intention and goals for the activity often dictates the preference for either the students' scientific or personal experiences.

The two types of experiences discussed, scientific and personal, each provide different understandings, views, and insights into the macro environment. Personal experiences provide context but may involve affective views that do not provide a conduit to understand what occurs at the subatomic representation level. Thus, ultimately, when teaching chemistry, the experience should focus on the scientific, which can be quantified and categorized for comparison amongst students and scientific findings. For the purposes of this paper, the definition for macro is based upon Gabel (1999) and Hinton and Nakhleh (1999) and defined as concrete observations of macroscopic properties that are observable, measurable, quantifiable, and reproducible.

Submicro and symbolic representation levels: What about models? The descriptions of submicro and symbolic representation levels have been consistent amongst researchers except that each includes the use of models (e.g., ball and stick, atomic drawings). The submicro representation level – sometimes referred to as the particulate world (Kern et al. 2010) – is comprised of entities not observable by the naked eye, which includes the atom and its two subcategories along with the molecular models and particulate diagrams(Chandrasegaran, Treagust, and Mocerino 2007, Kern et al. 2010, Levy Nahum et al. 2004, Treagust, Chittleborough, and Mamiala 2003). The symbolic representation level consists of a variety of symbols for chemical elements and mathematical equations including molecular structure drawings, diagrams, and computer simulations(Chandrasegaran, Treagust, and Mocerino 2007, Taber 2009). The argument for which representation level models belong involves the nature of the predictive power of the model in relation to teaching. The following will provide a rationale for the use of models in the symbolic representation level.

Chemistry is based upon representations of the atom, and chemists often use representations to illustrate "unseen entities and processes" (Kozma et al. 2000, 106). External representations, which are visual and/or oral transmissions of information, include models, ideas, equations, analogies, diagrams, pictures, illustrations, multimedia, and simulations. These types of representations help students learn specific concepts (Bucat and Mocerino 2009, Pozzer and Roth 2003). External representations lie along a continuum from less abstract with more detail (i.e., everyday experiences) to more abstract with less detail (i.e., models) (Pozzer & Roth, 2003). This range causes difficulty when evaluating teachers' use of various representations, thus the researcher must understand the teacher's intent in using the model in order to determine whether it should be categorized as submicro or symbolic.

Talanquer (2011) described the visual language of chemistry as being made up of symbols and icons. Though symbols represent real, tangible substances (e.g., P for phosphorous), they are just symbols (Talanquer 2011, Hoffman and Laszlo 1991, Hoffmann 2007). Icons are objects designed to represent an entity (e.g., ball-and-stick representations of molecules, particulate drawings, drawings of electron shells). Hoffman and Laszlo (1991) argued that both symbols and icons are incomplete representations, unable to represent all of chemistry, but they remain useful for bridging the symbolism to meanings. To compensate for the incompleteness of symbols and icons, chemistry has combined symbolic and iconic values to produce a hybrid status between symbols and models. For example, Figure 1 represents the geometry of water (H_2O) using the Lewis structure along with lines to communicate the perspective of the molecule. The elemental symbols (H and O) and lines represent symbols, while the two-dimensional structure has an iconic value. To distinguish between symbolic and iconic values, one must look at the nature of the two representation levels. For a representation based upon signs (i.e., positive or negative), the symbolic representation level would be the best representation level. However, if the models were thought of as descriptive and explanatory, with predictive power, the iconic representation, called the submicro representation level, would be the better descriptor.

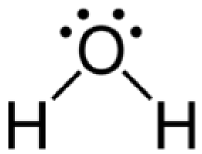

Figure 1. Symbolic and iconic representation of water (H_2O).

Researchers have also distinguished between the uses of submicro and symbolic based on reality and representation (Davidowitz & Chittleborough, 2009; Treagust, *et al.*, 2003). Treagust et al. (2003) described the submicro representation level as "real," though the particles are too small to observe, and described the symbolic representation level as representational, due to the reliance on symbols and equations. Using Figure 2, the macro level is real and visible and the submicro level is real and invisible, while the symbolic representations include the chemical diagrams that connect the submicro content, as depicted by the dashed line (Davidowitz and Chittleborough 2009). As a result, using real and representational as a determining factor, models would be found only in the symbolic level. A teacher's use of molecular representations is designated as symbolic. The researcher is then only need to determine what connections teachers make between the symbolic representation and the macro and submicro representations. As Talanquer (2011) summarized, the key to the symbolic representation level is that the models do not have any predictive power.

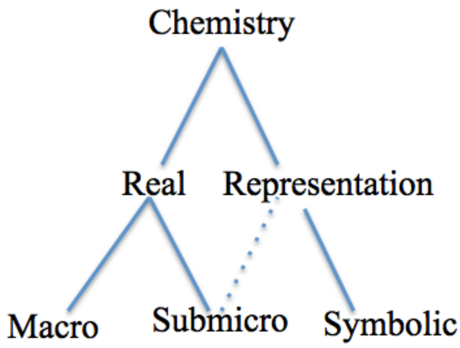

Figure 2. The relationship between the three levels of chemical representations and real and represented chemical data (modified from B. Davidowitz and G. Chittleborough, 2009, "Linking the macroscopic and the sub-microscopic levels," p. 172.)

As a result of these discussions, we drew upon Davidowitz and Chittleborough's (2009) argument of real and representational representation levels, thus determining that models were a part of the symbolic level. The submicro level was defined as providing explanations at the particulate representation level (i.e., explanations of observed behavior at the atomic level). The symbolic level was defined as symbols, elemental names, positive and negative signs, models (e.g., ball & stick, drawings), mathematical formulas, and electron configurations.

Human element representation level: What about science education? Mahaffy (2006) proposed modifications to the model in an effort to contextualize the chemistry content. With the addition of the human element, Mahaffy also suggested a modification from the trigonal model to a tetrahedral model. He proposed curricular reform that connected the content representational levels to the everyday experience, the human element. However, how does how does this new level align with science education concepts and practices.

The human element level contextualizes chemistry education through "real-life" applications, historical views, industrial processes, and environmental applications(Lewthwaite and Wiebe 2010, Shwartz, Ben-Zvi, and Hofstein 2006, Talanquer 2011). These real-life applications built upon the lives of the non-scientists (i.e., students and public) are then linked to "school chemistry." Mahaffy (2006) provided an example for non-chemistry majors studying a "breath of fresh air (p.52)," that is, how carbon dioxide and other exhaled gases interact with the atmosphere through a variety of reactions. Returning to the water example, students might explore pool water chemistry, industrial water treatment, or the environmental impacts on water and water quality. Key to the human element is helping students make connections between chemistry and their own lives in order to promote deeper conversations about the content representational levels through the human element.

The human element also places special emphasis on the development of the field of chemistry over time. Science education reform has placed a greater emphasis on the historical perspective of science for various cultures, philosophers, and scientists(*American Association for the Advancement of Science* [AAAS] 1993, 1996, National Research Council 2011) through the nature of science (NOS) (Lederman 1999). Equally important for students is understanding the practices scientists engage in order to make these discoveries which moves teaching and learning from focusing on the memorization and presentation of facts. The content needs to be presented in an authentic manner that enables students to understand how scientists conduct experiments, the types of questions asked, and how conclusions are made. Doing so addresses students' misconceptions about the chemistry content(Ben-Zvi, Eylon, and Silberstein 1986).

Mahaffy's (2006) introduction of the fourth representation level came with a reimagining of the relationship of the content representational levels (macro, submicro, and symbolic) to a tetrahedral model that adds the human element to the trigonal model. The base of the tetrahedral includes the content representational levels, and at the top of the tetrahedral model sits the human element. This suggests that the human element could be interpreted to include the students' experiences (Chandrasegaran, Treagust, and Mocerino 2007, Treagust, Chittleborough, and Mamiala 2003), which may or may not relate to the content representational levels. Key to the human element is connecting chemistry to the students' world to understand the ideas and philosophies that have shaped the discipline. We followed Mahaffy's (2006) and Chandrasegaran's, et al. (2007) definition for the human element as the contextualization of chemistry through historical events, students' experiences, real-life applications, and chemical or industrial applications.

Chemistry teachers and the tetrahedral model

Science teachers design classroom instruction to address students' prior knowledge, the wide variation in their approaches to learning, and their difficulties with the presented concept (Magnusson, Krajcik, and Borko 1999). As a result of these three variables, the teacher must have numerous representations available for use in the classroom. These representations may be based on research or derived from the "wisdom of practice" (Shulman 1986, 9). In the process of selecting a representation, the teacher must be aware of the ways students interpret and understand each representation. In chemistry, there is no one representation that is considered the most powerful approach for teaching a topic(Banks, Leach, and Moon 2005).

When studying effective chemistry teachers, chemistry education researchers look at the use of the student thinking levels(Lewthwaite and Wiebe 2010, Sande 2010). Various research studies have found that over time teachers recognize the need to modify instruction to engage students with an increased number of macro representations (Van Driel, de Jong, and Verloop 2002) and "real-life" scenarios (Lewthwaite and Wiebe 2010). However, teachers do not intentionally plan to use multiple represenations to connect the thinking levels (Sande 2010) without specific professional support to do so (Lewthwaite and Wiebe 2010, Van Driel, de Jong, and Verloop 2002). Though novice teachers engage students in macro representations through inquiry laboratories, Clermont et al. (1994) found the teachers often stopped instruction to provide submicro explanations which lowered the cognitive demand on students' understanding of the thinking levels.

Only one study has focused on the tetrahedral representations (Lewthwaite and Wiebe, 2010). They followed 74 Canadian chemistry teachers over four years to determine the impact on curriculum changes to the implemented tetrahedral instruction. Teachers were offered three professional development days per year that focused upon a specific topic for teaching eleventh or twelfth grade chemistry students. The teachers then self-reported the behaviors and classroom characteristics using a 5-point likert scale. As a result of participating in the professional development and working with the new curriculum, teachers increased the implementation of macro representations over the submicro and symbolic representations. However, the classroom representations continued to engage students in performing more calculations than manipulations or viewing visual images, demonstrations, and simulations. Overall, the teachers gradually implemented an integrated view of the tetrahedral representations.

To build on previous research studies that explore teachers' practices over a short time (Clermont et al., 1994; Van Driel, et al., 2002), this study focuses on the first three years of beginning chemistry teachers' depiction of the chemistry curriculum as they provide the conduit to connect the representation levels through the respective instructional strategies. Analyzing a large number of strategies of the chemistry content, we are able to provide a more complete understanding of the ways beginning teachers represent the chemistry curriculum in order to develop programs to support the needs of new teachers and their students.

Method and Procedures

In this mixed methods study, we adopted a triangulation design: data transformation model for data collection, methods and analysis(Creswell and Plano Clark 2007). The transformation design is a multi-phase design that begins with both qualitative (e.g., interview data) and quantitative data (e.g., types of representations) being collected during the same timeframe. The next phase involves the separate interpretation of the qualitative and quantitative to understand how beginning chemistry teachers depict the curriculum during their first three years in the classroom. Finally, the data is transformed from one data set (e.g., qualitative data) into the other type of data (e.g., quantitative data), thus allowing for the analysis and interpretation of data both qualitatively and quantitatively. Transformation, for this study, involved the identification of the specific representational levels within the interviews and classroom practices that were then represented quantitatively. An example of data transformation will be presented below in the data analysis section of this paper. The research design for this study is found in Figure 3.

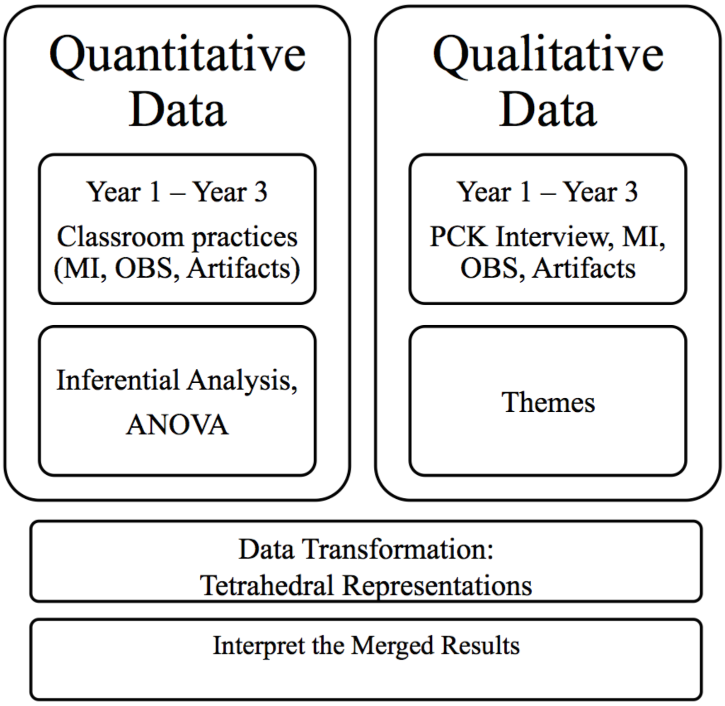

Figure 3. Beginning teachers' representation of the chemistry content data transformation model.

Participants. The study was granted approval by an IRB, institutional review board, and teachers granted consent for the collection of data for each of the three years of the study. A purposeful selection process identified participants (Merriam 1998) who met the following criteria: earned a degree or its equivalent in chemistry, held a teaching certificate in chemistry, and taught primarily chemistry concepts across each of the first three years. Eight teachers – four males and four females – met the criteria for participation. All teachers held at least a minor in chemistry along with a teaching certificate for chemistry and five teachers earned their Masters of Education (M.Ed.) by the end of the study. Each participant taught primarily tenth and/or eleventh grade chemistry at an urban school, from either the Midwest or Southwest, with more than 1,350 students during each of the three years of the study (see Table 1).

Data Sources

The study determined the participant's instructional practices and the specific chemistry concepts taught through a combination of interviews and observational data. Pertinent classroom artifacts (e.g., worksheets) from the three years of the study supplemented the working understanding of classroom practices. An additional interview conducted with the beginning teachers followed a pedagogical content knowledge (PCK) structure (Lee et al. 2007). The PCK interview and classroom practices, monthly interview, observation and artifacts are described below.

PCK interview. The first form of data was the participants' responses to the PCK interview developed by Author (2007). The PCK interview was administered prior to the start of the first year and at the end of the subsequent three years totaling four PCK interviews. The interview protocol was designed to capture teachers' PCK in two categories: (I) knowledge of student learning in science and (II) knowledge of instructional strategies. Category I captured the teachers' considerations for students' prior knowledge, variations to students' approaches to learning, and students' difficulty with the specific concept. For this study, only the Category II was explored as it captured the teachers' science-specific strategies (scientific inquiry) and representations. The categories were determined by comparing responses by experienced and beginning secondary teachers to the PCK representation levels identified by Magnusson, Krajcik, and Borko (1999). These categories remained consistent through additional interviews with secondary science teachers (Lee et al. 2007, Luft et al. 2011) which supports validity of the interview protocol (Patton 1990).

Interviewers were trained prior to the use of the semi-structured interviews with the secondary teachers. The semi-structured questions explored the teacher's considerations about a successful lesson. For the initial (Y0) interview, teachers were asked to describe any lesson or unit they considered to be successful. In succeeding annual interviews, chemistry teachers were asked to provide information about any concept in chemistry plus a specific chemistry topic identified by the researcher: year one (Y1) looked at balanced equations; and year two (Y2) and three (Y3) focused on atomic structure. When needed, the researcher would ask follow-up questions to gain understanding of provided responses. Each PCK interview lasted 15 to 30 minutes in length and the audiotape was transcribed for both qualitative and quantitative analysis. PCK interview transcripts were read line by line to identify teachers' conceptualization of the tetrahedral relationship. Further discussion of the analysis is provided in the section Data Transformation.

Classroom practices. Classroom practices were studied using monthly interviews (MI) and bimonthly observations (OBS). The format for collecting the teachers' instructional practices was based upon Lawrenz, Huffman, Appeldoorn, and Sun (2002). The MI occurred once a month (September – April) during a specified two-week timeframe, for a total of twenty-four interviews for each teacher across three years. The interviews with the teachers captured the classroom practices, daily objectives, materials/technology used, and forms of assessment for one week of lessons. In cases where unforeseen circumstances interfered with the collection of a monthly interview, a make-up interview was conducted during the month of May. Each semi-structured interview was approximately 20 minutes in length. While the teacher answered open-ended questions, researchers captured teacher responses through both audio recordings and field notes.

Classroom observations (OBS) involved the researchers observing the teachers, which occurred four times per school year. The OBS protocol was based upon representation levels of *The Collaboratives for Excellence in Teacher Preparation core evaluation classroom observation protocol* (CETP-COP) for use during classroom observations, in order to document the practices of teachers (Lawrenz, Hufman, and Appeldoorn 2002). The OBS of one class hour (e.g., 45-50 minute) occurred during a two-week period that coincided with the MI collection in the months of October, December, February, and April (12 classroom observations across three years). Collection of both MI and OBS provides both teacher planning and implementation along with the sequencing of the content.

Prior to researchers visiting the classroom, teachers were contacted to determine the nature of the lesson to be observed in order to avoid shortened class hours, the administration of a test, or use of a video. During each OBS, the research assistant observed the participant's classroom and wrote down salient activities performed by both the teacher and the students during each five-minute interval for one class hour. For seven of the eight teachers, the class hour was 50 minutes in length; T6's class hour was 70 minutes in length. Each coding captured the classroom practice (e.g., discussion, laboratory). Written accounts of the observation were considered field notes and as analogous to interview transcripts (Merriam 1998). The result was four classroom observations per year for the first three years of instruction (12 maximum classroom observations across three years). The OBS provided additional documentation regarding how the teachers enacted the tetrahedral model as discussed in the PCK and MI interviews.

Classroom practices: Artifacts. Whenever possible during MI and OBS, supplementary materials associated with the lesson(s) were collected from the teachers. Classroom artifacts included worksheets, reading material, and PowerPoint presentations associated with the lessons. These artifacts served as support for the depiction of the representation levels of the tetrahedral model utilized in classroom instruction to capture the full intent of a lesson. Comparison of the classroom practices data was used when the MI, OBS, or artifacts represented the same activity. Approximately fifteen percent of the participants' instructional practices were the same instructional strategy across multiple data. When this was observed, the data were combined and treated as one or more instructional strategies for that day of instruction.

Total instructional practices. Data collected from the instructional practices were totaled by occurrence over the first three years (N = 976). Table 2 indicates the proportional average of each practice used to present the chemistry content per year for the first three years in the classroom. This total takes into account those instructional practices that overlapped. Not included in the analysis were the following lessons: (1) introducing the scientific method, metric system, dimensional analysis, or significant figures, as these do not represent topics limited to the field of chemistry; (2) not involving a chemistry concept (e.g., physics); and (3) involved in the review for or administration of a test. The total instructional practices analyzed for the study was reduced (N = 641). The data was sorted by year and by topic.

Data Analysis

Exploring how beginning chemistry teachers designed instruction for the chemistry curriculum involved analyzing the data sources for the specific instructional practices and the tetrahedral representations.

Qualitative analysis. The qualitative analysis consisted of reading the corpus of the data for the three years of PCK and MI interviews, OBS field notes, and artifacts to determine how teachers discussed and presented the representation levels. We initially coded the interview data using codes based on CET-COP for observations and monthly interviews to document the instructional strategies by the teachers (Lawrenz, Hufman, and Appeldoorn 2002). These codes focused on the type of instructional practice observed which included laboratories, lecture, worksheets, demonstrations, tests, and non-science activities (e.g., announcements). Finally, the corpus of the data was analyzed for differences of the beginning chemistry teachers across the first three years. Themes were constructed from these explorations as related to the research questions which focused on the type of instructional practices and the representational levels. Attention was given to disconfirming evidence pertaining to the codes and themes found in the data. The data were analyzed using the NVivo 9 qualitative research tool to allow for the organization of multiple codes across various documents.

Data transformation. We coded the data based on the tetrahedral representational levels using the definitions as discussed in the paper for each representation level. The responses for the PCK and classroom practices (MI, OBS, and artifacts) were transformed using the Tetrahedral Scoring Rubric (see example below). Quantification of the data involved marking tetrahedral representation levels per each representation (e.g., laboratory activity, PowerPoint) implemented. Each representational level per instructional practice was scored for presence within the data with a maximum (x = 1) and a minimum (x = 0). The following is an example from T7 Y0 PCK interview, with the scoring explanation embedded within the transcript.

IN: Just describe how you would teach the topic of balancing equations. Are there places in the concept map that you can point to where you think that fits in?

R: We could start teaching how these <u>things go together and learning how to write the equation</u> [submicro and symbolic: mentions an explanation for what goes into a balancing a chemical equation]. Then after you write it, <u>you have to balance it</u> [Symbolic only as this does not specify why balancing chemical equations is important for chemistry]. Balancing equations—we struggled with that too. But once they got it, they were very good at it. The most confusing thing for them was, first of all, <u>learning how to make the molecules</u> [Submicro as this references an explanation for how molecules are produced]…

In several occurrences T7 talks about both symbolic and submicro, but she was referring to a single activity, so the representation was scored as consisting of one symbolic representation level, one submicro representation level, and zero for both the macro and human element representation levels. Note the instructional practices artifacts were coded with the four representational representation levels as presented within the worksheet. When artifacts were not available, the analysis presented how the teacher conceptualized and implemented the repertoire.

Quantitative analysis. The transformed were analyzed using the inferential statistics associated with Statistical Package for the Social Science (SPSS). Data analysis included descriptive statistics regarding the tetrahedral representation levels by year and the tetrahedral representation levels by topic. Transformed data were totaled by the year and specific topic across all three years by the eight teachers. The higher the score per year, the more likely the practice was frequently enacted by the teachers. A paired-samples *t*-test was conducted to evaluate whether the teacher emphasized one tetrahedral representation over another based on the year. The representation levels were also analyzed comparatively with a one-way within-subjects analysis of variance (ANOVA) with the factor being the year. Follow-up analysis involved six unique paired-wise comparisons conducted among the means for macro, submicro, symbolic, and human element representational levels. Controlling for familywise error rate across the six tests at the .05 level, using the Holm's sequential Bonferroni procedure, paired samples t-tests were run to determine if there were significant differences. This follows that the first pair is significant if the *p* value is less than $\alpha = .05/6 = .0083$; the second pair will be significant if the *p* value is less than $\alpha = .05/5 = .010$; and so on. The data were then triangulated using multiple data sources, multiple methods, and collecting data over time, which contributed to the validity of the conclusions (Teddlie and Tashakkori 2009).

Results

This study was designed to determine how beginning chemistry teachers represent the content through the representation levels and how the representation levels were connected across the first three years in the classroom. Throughout this article, the teachers will be referenced with YrX-TZ in which YrX represents the year data were collected and TZ is the specific teacher. For instance, Yr1-T4 stands for the Year 1 teacher identified as number 4 and Yr3-T4 represents the same teacher during Year 3 in the classroom.

The instructional practices in light of the representation levels across the three years

Data transformation of the instructional practices provides understanding of the changing classroom instruction by the eight beginning chemistry teachers across the first three years. Table 3 and 4 presents the means and mean differences of the of frequency data regarding the macro, submicro, symbolic, and human element of the instructional practices per year as well as the statistical analyses for the comparisons. The tables show that regardless of the year the beginning chemistry teachers presented the chemistry curriculum by focusing primarily on the abstract representations – submicro and symbolic. For each year, these abstract representations were used statistically more often than both the macro and human element representational levels (Table 4). In addition, the teachers used the macro representations statistically more often than the human element. Across the three years, the teachers increased the use of macro representations with Year 1 use being significantly different in comparison to both Year 2 ($t\ (196) = 2.94$, $p = 0.004$) and Year 3 ($t\ (210) = 4.70$, $p < .001$). The instances of contextualizing chemistry content through the human element were not found to change across the three years. The question remains in how did the beginning chemistry teachers connect the representation levels.

Connecting the representational levels

While all representation levels may be present within instruction, there were few instances in which the teacher explicitly engaged students in making connections among the content representation levels. In this section, we will describe how the teachers used the instructional practices to negotiate the representation levels. We found five themes that may impact what and how the content representation levels and human element were connected.

The first year teachers' macro representations – laboratories and demonstrations – were presented at the end of the lesson or unit; subsequent years the macro representation was presented earlier and the teacher worked with the students to connect the macro to the abstract representation levels. Macro representations observed in the first and second year often were demonstrations. Most first and second year teachers were observed lecturing and engaging demonstrations within the classroom instruction that often involved all three content representation levels. When demonstrations were present within instruction, the second year teachers would implement multiple demonstrations during the class hour. For example, Yr2-T5 presented both combustion and synthesis reaction demonstrations during one class hour. The use of demonstrations decreased in the third year, as teachers shifted from presenting only demonstrations to the inclusion of laboratory experiments in Year 3. For example, when presenting conservation of matter, T3 used only a steel wool and vinegar demonstration during the first and second year. In the third year, T3 used the same demonstrations but included a laboratory experiment to explore conservation of matter. No one teacher engaged in these practices consistently, but across the second and third year, the study found more instances of multiple demonstrations or the inclusion of a laboratory activity within the same class hour.

The study assumed, when considering the teachers' practices, that published laboratory activities would present the three levels of content representations including the human element through the activity and follow-up questions. In analyzing collected classroom artifacts, researchers found that many of these laboratory experiments were designed to engage students in directed inquiry experiences. In practice, the study found that instead, the teachers often introduced these published experiments prior to a quiz or test and at the end of the unit, thus shifting the laboratory from a directed inquiry experience to a verification laboratory, regardless of the year. In doing so, the students would have spent much of a lesson or unit focusing on the abstract concepts without connecting the concept to the macro representation level. Several third year teachers suggested introducing the laboratories earlier in the teaching sequence. However, only Yr3-T1 discussed making the change "from last year and [getting] into the labs more quickly" (MI). It is not clear if the teacher was considering the macro-submicro-symbolic connections in making the change in instruction.

The first year teachers differed from the second and third year teachers in their approach to preparing students for the laboratory experiment. During pre-laboratory, the first year teacher would spend the first 5-15 minutes stating the purpose of the laboratory and introducing the directions and safety necessary for conducting the laboratory experiment. The first year teacher spent much of this time with students writing or going over the directions for the laboratory. For instance, 1Yr-T1's students were working in the textbook "copying lab directions," and, similarly, 1Yr-T5 discussed with students how to "write-up the lab." By comparison, the second and third year teachers were more likely to begin class explaining the concept and how the laboratory connected to the abstract representations (though there were a few examples of first year teachers taking this approach). For example, a second and third year teacher discuss:

The point is that each element will have a different arrangement of electrons around the atom... So we have two equations that we have been using, we have $E=hc/\lambda$...different wavelengths means different colors.... The metals, I said, were dissolved in water, so you will look for a flame with a particular color (Yr2-T6, OBS).

OK, for the lab today, you are going to utilize the double replacement reactions and the solubility chart. You want to figure out the products first. Then use the solubility chart/rules to figure out what will precipitate. Here is an example: All of these are dissolved in water, so they are all aqueous (Yr3-T8, OBS).

The third year teachers increased the use of direct inquiry laboratories in their classroom instruction. In doing so, they increased in the expectation that students manipulate information, analyze data for trends, and make conclusions by tasking the student to grapple with the connections between all three content representation levels. For example, during one observation, Yr3-T3, after conducting a laboratory activity representing double displacement, walked students through the process of knowledge construction in a discussion:

T: So which of those two do you think was the precipitate?

S: (offer responses…)

T: So here's the part where you have to think like scientists. What proof or evidence do you have that it's either one or the other? (OBS)

Teachers used models and simulations to help students understand the abstract representation levels with little consideration of the macro level. The beginning chemistry teachers implemented models, which engage students with balls and sticks or atomic drawings, and simulations, which imitate a phenomenon at the submicro representation level, regularly in the classroom instruction. Analogies, comparing new knowledge to with what they already know, were also present but not all classroom discussions were captured. These practices increased in year two but again decreased lower than originally found in year three for these teachers. These practices primarily presented the abstract representations – submicro and symbolic.

The teachers recognized the need to use models and simulations to understand the abstract nature of the content. For example, Yr2-T2 used a "rock concert" analogy to bridge the gap in student understanding about electron configurations. The instructional strategy addressed why the elements with d-orbital and f-orbital were not found on the same row of the corresponding energy level by stating students "don't understand why d and f [orbitals] lag behind. The 5d is closer than some others in the rock concert" (Yr2-T2, PCK). The teacher goes on to explain that "it takes a full day and we don't even talk about elements. Just talk about filling shells in order." In this example, the teacher begins with the analogy as just a rock concert (symbolic). However, there is a shift by the end to connect to the energy levels (submicro). However, there were instances where it was clear if the teacher helped the students make connections between the representational levels. For instance, a teacher's class objective involved the use of a worksheet and ball and stick modeling materials for students to "follow directions to make ball-and-stick models of H, F, and Ne" (Yr2-T6, MI). There may be connections between the submicro and symbolic representation levels, but it was up to the students to determine this from reading the worksheets directions.

Only T8 discussed a card-sorting activity for electron configurations focused on helping students connect the macroscopic properties of elements to the patterns within the subatomic properties of matter. The discussion focused on the *in situ* of the learning context, in which students must work to make the connections. T8 explained:

I try to break through the memorization [of the electron configurations] and get at the why the elements behave as they do. I try to focus in on the valence electrons and get into that aspect of the atom and compare it to the stable configuration of the noble gases. I want them to answer how you get there (Yr2-T8, PCK).

Across the three years lectures shifted to cover fewer concepts; more engagement with submicro explanations and less focus on memorization and skill development for solving chemical and mathematical equations. The focus on teacher-led lectures emphasized the abstract representation levels, wherein students received knowledge directly, with some knowledge construction incorporated into the lectures. Overtime, the second and third year teachers' lectures focused on fewer concepts and providing more macro representations to support the abstract. Conversely, the use of discussions, which is a purposeful interaction between teacher and student, was not a commonly implemented strategy, although it increased for teachers in their second and third year. Both lectures and discussions were used concurrently with other instructional practices (e.g., demonstrations, videos) across the three years.

Regardless of the year, a typical class lecture introduced the content and, when appropriate, examples of how to solve related chemical equations and mathematical problems. For example,

A student asks why they can't write 2H2 as H4. Teacher explains and moves to another example. Next example is aluminum and oxygen forming aluminum oxide. Teacher tells students to balance the equation, gives them time to work alone (Yr1-T8, OBS).

Students are completing the first problem and going through the answer on the SMART board. Students are given another problem to answer: draw Bethyl, 2-4-dimethyl hexane (Yr2-T1, OBS).

Teacher asks students what will happen to P [pressure] inside a 0.25L can of deodorant that starts at 25^{o}C and 1.2atm if temp is raised to 100^{o}C? Teacher asks, which of the given information in this problem is unnecessary to solve the problem? Student responds that they don't need to know volume (Yr3-T2, OBS).

The first year teacher spent the class hour lecturing on a complex concept that focused more on the symbolic representations rather than connecting it to the macro or submicro representation levels. The lecture involved multiple ideas and providing worksheets to practice skills of solving mathematical and chemical equations. In this example, Yr1-T2's objective for the day stated, "to have students make a connection between equilibrium constant and dissociation constant, and how strong acids completely dissociate [while] weak ones don't" (MI). The class hour included a "lecture on pH and pOH and dissociation constants; KA & KB, strong and weak acids and bases." During the lesson, "students work from textbook, as a group" (Yr1-T2, MI). During a week of instruction, the first year teacher typically presented a new concept(s) daily. However, the teachers questioned whether they were moving too slowly or quickly and covering the topic in depth enough for the students. The impact on student learning included concerns about whether the students would "shut down in class" (Yr1-T7, MI) when given too much information, or needed to be challenged (Yr1-T4, MI) with multiple topics to maintain engagement. These concerns cause us to think that the teachers are not making purposeful instructional decisions to help students connect the content representation levels.

Conversely, there were instances among first year teachers of instruction on a single concept carrying over multiple days working to make connections between the submicro and symbolic representation levels. For example, Yr1-T8's objective for one class hour was the "introduction to electron configuration (section 4.2)" (MI), using a lecture and a simulation on electron configurations, which the teacher continued to expand on for an additional two days.

The second and third year teachers' lectures presented fewer concepts, in order to engage in purposeful learning connecting the content representation levels. While the class hour may include multiple supporting representations, they were all focused on a single topic. For example, Yr3-T4 (OBS) represented conservation of mass using a steel wool and vinegar demonstration along with a laboratory experiment involving an effervescent antacid and water, then the teacher returned to the demonstration at the end of the class hour. The teachers emphasized the purposeful learning of the content, which moved students from memorizing material and toward engaging with the content on the multiple content levels. The teachers stated that, over time, they had a better understanding of the material as well as what to emphasize to support student learning. For instance, two teachers discussed organization and understanding student challenges:

I feel more organized. It's definitely easier going through it the second time. Having gone through it once before, I have some things prepared. I have some idea what it's about and some understanding about the timing. I can change things or look at things from last year and make a decision on whether to change or keep. I kind of know what to expect. (Yr2-T6, MI)

I really felt that I was able to teach the material in a more concise manner in the third year and focus on the portions that students find difficult (Yr3-T8, MI)

The third year teacher is making changes due to student difficulty but we cannot determine if it is related to students connecting the content representation levels. The teachers continued to question what is the foundational knowledge of chemistry all students needed to know. As an illustration, Yr3-T3 discussed the curriculum of a lesson:

I keep trying to change my curriculum….But how do I get things accomplished efficiently? Even like today, nothing took that long, but I didn't want to pack any more in today. I am looking for the happy medium….I am concerned [about] leaving some stuff behind. I keep incorporating all these new things, and I wonder what happened to the stuff I used to do. How do you figure out what is important? (MI)

Based on the data, foundational knowledge does not include purposeful connections of the content representations for these teachers.

Nature of how the teacher presented the chemistry concept may impact the representation levels. We analyzed how the teachers presented chemistry based on the common topics across the three years. When analyzing the curriculum topics across a year, we found six major topics, with atomic structure and chemical bonding, tied among the topics, being discussed twice as much as gas laws (4^{th}). Table 5 presents the mean frequency of the each representation level of the tetrahedral representations within topics. The assumption is that all concepts will present all three content representation levels; however, with analysis this did not hold. Instead, frequently one content representation level was only briefly discussed or not mentioned at all. For example, Yr1-T4 presented gas pressure by engaging students with a crushing cans demonstration. When observed conducting the can demonstration, the 35-minute lecture included 1) discussing steam inside the can; 2) defining pressure; 3) presenting Boyle's law by including an example problem; 4) mathematically theorizing Charles's law; and 5) presenting Avogadro's law, which connects the observable to the submicro explanation as part of the formula. Although the submicro explanation connection was implied, the teacher did not discuss the behavior of the water molecules beyond the observable properties: temperature, pressure, and volume of the can demonstration.

Reactions, gas laws, and thermodynamics practices emphasized the macro and symbolic representation levels across all three years. For example, gas laws were discussed using pressure, temperature, and volume (measureable properties) along with the representative mathematical equations (symbolic). For example, Yr1-T4 stated, "I had a bag of cans. I put some water and heated the can and then I put the can in ice…. We talked about pressure and the gas laws" (PCK). In another example, this from the third year, Yr3-T2 engaged students in discussing the gas laws with questions about the pop can demonstration, asking "Why no inc[rease] in pressure?" Students correctly identified that there was a hole in the top. "Right – so what happens if inc[rease] T and the can is sealed?" (OBS). The teachers increased student engagement in the submicro explanations in relation to the macro and symbolic during the second and third year. The following example demonstrates the introduction of the submicro within the discussion of kinetic molecular theory:

Temperature is going to be key. We're basing the whole theory on the motion of molecules; we have to know the temperature so we can know kinetic energy…. You must be able to convert between these units (Yr2-T5, OBS).

Atoms, stoichiometry, and bonding instruction, conversely, emphasized the abstract representation levels across the three years. For example, the first year lessons on atomic structure presented the location of the particles within an atom with little focus on the energy and light production. Atom macro instruction increased in year two and stayed consistent in year three. For example, Yr2-T5 (PCK) described several laboratory experiments that were used to help students understand electron levels. Further discussion of the changing strategies for atomic structure instruction will be discussed in the next section. Stoichiometry and bonding macro instruction decreased in year two and increased in year three. Only instruction on atomic structure and reactions were found to engage students in the human element.

The beginning teachers also described a changing view of the ways in which the curriculum was arranged. After the first year, the teachers questioned the material presented and the order in which it was presented by colleagues and the textbook. In one example, Yr3-T6 stated, "In years past, I followed the sequence from other teachers and found there's not a whole lot of logic to the sequence"

(MI). Not all teachers made changes to the sequence, but a few did. For example, Yr3-T1 and his colleague modified the ACS's (2006) *Chemistry in the Curriculum* (ChemCom) by starting "with chemical reactions first and work[ing] backwards from there" (MI). The changing view may be a result of the teacher grappling with how to make the content understandable in light of the multi-representation levels. Yr1-T4 described this best:

Chemistry is a little hard because it's not sequential. It's parallel. You have to know multiple things to be able to draw good conclusions. But you can't learn things in parallel, or students don't learn in parallel. They have to be taught one thing and another thing and then taught another thing (MI).

Contextualizing chemistry instruction with the human element increased over the three years. Third year teachers, when compared to practices implemented in the first year, differed in the use of the human element. The data presented in Table 3 and Table 4 shows that the teachers increased their use of the human element across the three years. Examples from classroom instruction for the human element include (1) nature of science (NOS), (2) real world and industrial applications, and (3) socio-scientific issues (SSI). Influencing the instances of the human element within the representation was the nature of the objective.

The teachers across the first three years implemented the human element primarily for teaching atomic structure. Within these representations, the teacher connected the learning to real world and industrial applications and NOS elements. One prevalent representation for atomic structure was the flame test laboratory experiment that demonstrated the human element – real world and industrial applications. For example, Yr1-T2 and Yr3-T2 flame test worksheets stated, "What compound would be useful in making a red firecracker?" (Artifact). In another example, Yr2-T6 provided the sequence of events for Unit 7: Light and Electrons: "Day 4 – Flame Tests Lab, Day 5 – Fireworks! Video and worksheet, and Day 6 – Finish Fireworks worksheet and Flame Tests lab report due! (MI)"

NOS elements were emphasized when presenting the history of the atom. All teachers conceptualized and implemented the NOS element - *scientific knowledge is open to revision in light of new evidence* (National Research Council 2011). Primarily the teachers used lecture or a video (i.e., History of the Atom, Rutherford's gold foil experiment) to highlight this human element. The emphasis on the historical aspect of NOS may be a result of the goals for the unit. Yr2-T3 explains that the textbook "talks about the history and the experiments leading up to the current model of the atom. I state it to the students that it'll be more historical" (PCK). In addition to teaching a historical context for the atom, two teachers –T5 and T7 – also use the NOS element: *scientific knowledge is based on empirical evidence* (NRC, 2011). For example, T7 in the second and third years provided students with a series of scientific data from which to draw the structure of the atom. With each series of data, the History of the Atom worksheet asked students, "4. How does this evidence now create a new picture of the atom? 5. Using the new evidence create a new picture of the atom. How is it different? How is the same?" (Artifact). Additionally, Yr2-T5 discussed the use of a mystery box activity:

I give them a box with something in it and they have to come up with theories of what's in there, draw a picture of it, just to show that we have to use other observations or data besides sight, which kind of freaks us out (PCK).

Yr2-T5 continued use of the mystery box during the third year as well.

Real world and industrial applications contextualized various laboratory and research projects. Examples included a silver tarnish, potato chip calorimetry, dyes and chemical bonding, and soap efficiency (bonding) laboratories. Student research projects were used to explore real world and industrial applications such as: (1) reports on inventions in chemistry, (2) an element project in which students are asked to discuss the use of the element, and (3) American Chemical Society's (ACS) *Molecule of the Week* (2015). Many representations from the ACS's (2006) ChemCom also brought in elements of SSI. ChemCom lessons captured within the beginning chemistry teachers' practices comprised of water chemistry including water contamination and consumption, petroleum and ethanol, and the synthesis of aspirin. This curriculum provided the teacher with specific examples of ways to present the content, which teachers find useful. As Yr3-T1 stated, "I wish I had more specific examples of stuff I could use. For example, using a barrel of oil to show the chemistry behind the refining process. It is more relevant for the students" (PCK).

Conclusions

The purpose of this study was to report how beginning chemistry teachers depict the chemistry content through the content and human element representation levels. We found differences between the strategies implemented by teachers during their first year in the classroom and strategies used by those same teachers in their second and third years teaching. The study is based on a small number of beginning chemistry teachers from two areas in the United States who participated in the three-year study, which does not allow us to generalize these conclusions. However, our findings lead us to several compelling implications for science education and recommendations for future research.

In this study, the eight beginning teachers presented instruction primarily using lecture across the three years in the classroom. They characterized teaching as telling students about the content and working mathematical and chemical equations. As in Luft et al.(2011), the teachers had a limited repertoire in year one but over time were modifying and adding other instructional practices to represent key concepts in the curriculum. Even with a heavy emphasis on the abstract representational levels, across the three years, the teachers increased the use of laboratory activities and demonstrations that involved the macro and human element representation levels to engage students in learning. However, rather than an inquiry-oriented instruction, the lesson order mirrored Friedrichsen's et al.(2009) preservice secondary biology teachers who used the "Inform-Verify-Practice" (p. 376) as the instructional format. As science educators, we must challenge novice teachers to move beyond traditional modes of teaching to reflect those practices that support student exploration of the content.

The teachers were found to connect the content representation levels during classroom instruction with more regularity over time. However, under closer inspection, within certain instructional strategies and topics, teachers consistently depicted only one or two content representation levels, regardless of the year in the study. There were shifts in what the teachers presented, but the implemented instruction did not consistently depict all three content representational levels, and, though this study observed slight increases, there were still few instances of presenting the human element. Teachers who used the ACS (2006, 2015) curriculum were found to engage students in the human element more often than the rest of the teacher participants, suggesting that the chemistry curriculum available to teachers may play a large role in how teachers present instruction. In addition, Luft et al. (2011) found that beginning teachers often turned to their colleague(s) for instructional strategies to teach the content. These colleagues may also influence how the curriculum is interpreted and implemented in the classroom (Luft and Patterson 2002, Luft et al. 2011), including an influence on beginning teachers' understanding of the macro-micro thinking (Van Driel et al., 2002). Specifically, this study suggests science educators should provide explicit instruction on the chemistry representation levels during preservice and induction programs.

Based on our conceptual framework, Johnstone's (1981, 1992, 2000) levels of thought, we argued for the model (tetrahedral) and the specific definitions for each component that would be appropriate for the chemistry teacher. Talanquer (2011) has cautioned against the application and interpretation that the models represent and encompass without clearing identifying what and how each would be used for analysis. The content representational levels (macro, submicro, symbolic) served as the basis of the classroom instruction focusing on key concepts in chemistry. The study expected that teachers would follow a tetrahedral model, which held in the analysis but there fewer instances of the human element.

Support programs need to address the beginning chemistry teachers' representations to consistently engage students in connecting the content levels. Science educators should engage the teachers in exploring the difference between teacher and student understandings as found in van Driel, de Jong, and Verloop's (2002) study. In addition, teachers need to be engaged in the analysis of key concepts through vignettes(Boz and Boz 2008, Friedrichsen et al. 2009) in order to examine how to design instruction to help students negotiate the representation levels. Support programs may empower beginning teachers to intentionally point out the connections among the different representational levels for students. This may require support to extend beyond the first three years in the classroom.

Our findings caused us to rethink the definition of the human element to include the historical, the personal experiences, and chemical or industrial applications. Data analysis shows that the teachers often contextualized the chemistry content using the historical and chemical or industrial application. The use of chemical or industrial applications was primarily aligned with ACS (2006, 2015) curriculum and materials. ACS's (2006) ChemCom also presented SSI related to the chemistry content. The teachers also incorporated the historical as it relates to the NOS element *scientific knowledge is open to revision in light of new evidence* (NRC, 2011) though primarily for atomic structure. In addition, a few teachers incorporated the NOS element *scientific knowledge is based on empirical evidence* (NRC, 2011). There were no apparent examples of the personal experiences framing instruction within this data set. Based on how these teachers depicted chemistry, we suggest modifying the description of the human element representation level to include the history of science, nature of science, socioscientific issues, and chemical or industrial applications.

The current research literature on the representation levels has focused primarily on novice chemistry teachers. Further research should explore how experienced chemistry teachers represent and negotiate the representational levels using qualitative and mixed research methods that builds on Lewthwaite and Wiebe (2010) quantitative research study. Johnstone (1991) introduced the representation levels in light of all disciplines of science by referencing the three levels for physics – macro, the invisible forces, and the symbolic with math and formulas – and biology – macro, the micro (cells), and the biochemical (DNA) (p. 78). In addition, recent science reform documents support a tetrahedral model; explicitly within the documents of Manitoba, Canada (Manitoba Education Citizenship and Youth, 2006; 2007) and implicitly within in the documents of the United States(NGSS Lead States 2013). There should be similar studies exploring secondary teachers in physics, biology, and the earth and space sciences represent and negotiate the representation levels including how these disciplines represent the human element.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

The authors of this study would like to recognize the following research assistants and faculty who helped with various parts of this study: Gillian Roehrig, Anne Kern, Jennifer Neakrase, Jonah, Firestone, Sissy Wong, Irasema Ortega, Charles Weeks and Holly Crawford. This study was made possible by National Science Foundation grants 0550847, 0918697, 0732600, and 0632368. The findings, conclusions, and opinions herein represent the views of the authors and do not necessarily represent the view of personnel affiliated with the National Science Foundation.

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Table 1. Background Demographics of Study Participants

Teacher	Sex	Degree(s)	School Location/Region
T1	M	BS Chemical Engineering, Minor Chemistry, M.Ed.	Urban/Midwest
T2	M	BS Chemistry	Urban/Midwest
T3	F	BS Chemistry & Chemical Engineering, M.Ed.	Urban/Midwest
T4	F	BS Chemistry; MBA & M.Ed.	Suburban/Southwest
T5	F	BS Chemistry	Urban/Midwest
T6	M	BS Chemical Engineering, Minor Chemistry; MEd	Urban/Midwest
T7	F	BA Nutritional Science, Minor Chemistry; M.Ed.	Urban/Southwest
T8	M	BS Chemistry, Minor History; M.Ed.	Suburban/Midwest

Table 2. Proportional Averages of Representations by Beginning Teachers During the First Three Years

Representation(s)	Y1 (*N* = 211)	Y2 (*N* = 199)	Y3 (*N* = 231)
Lecture			
Information	30.0	25.1	28.1
Examples	9.0	6.5	9.5
Discussion	2.0	4.0	3.9
Laboratory			
Open/guided inquiry	1.0	1.5	0.9
Directed inquiry	8.0	7.6	11.9
Verification laboratory	9.0	9.5	8.9
Demonstrations	8.0	12.1	10.4
Models/Simulations	8.5	11.6	7.4
Worksheet	12.0	9.5	7.8
Textbook	5.0	4.0	5.2
Video	5.0	6.5	3.9
Research Projects	3.0	2.0	2.1

Table 3. Mean Frequency of the Macro, Submicro, Symbolic, and Human Element Per Year

	Yr1 (*N* = 211)	Yr2 (*N* = 197)	Yr3 (*N* = 231)	*F*	*α*
Macroscopic	0.49 (0.49)	0.61 (0.49)	0.70 (0.46)	11.23	< 0.001*
Submicroscopic	0.83 (0.37)	0.82 (0.39)	0.84 (0.37)	0.77	0.46
Symbolic	0.87 (0.33)	0.82 (0.39)	0.87 (0.33)	1.99	0.14
Human Element	0.11 (0.32)	0.12 (0.32)	0.15 (0.35)	0.47	0.63

Table 4. *Mean difference and paired sample t-test for the representational levels per year.*

	Year 1		Year 2		Year 3	
	MD	t	MD	t	MD	t
Macro-Submicro	0.34	7.86*	0.21	4.50*	0.14	3.36*
Submicro-Symbolic	0.04	1.30	0.00	0.00	0.03	1.24
Symbolic-Human Element	0.76	22.42*	0.70	18.5*	0.72	21.56*
Macro-Symbolic	0.38	8.17*	0.21	4.21*	0.17	4.24*
Submicro-Human element	0.72	21.34*	0.70	19.21*	0.69	21.38*
Macro-Human Element	0.37	10.40*	0.49	13.02*	0.55	16.12*

* Significant at $p < .001$

Table 5. Mean Frequency of the Macro, Submicro, Symbolic and Human Element Representations by Topics* During the First Three Years

Topics	Macro Mean (SD)			Submicro Mean (SD)			Symbolic Mean (SD)			Human Element Mean (SD)		
	Yr1	Yr2	Yr3	Yr1	Yr2	Yr3	Yr1	Yr2	Yr3	Yr1	Yr2	Yr3
Atom	0.45 (0.49)	0.53 (0.26)	0.58 (0.28)	0.93 (0.32)	0.98 (0.40)	0.88 (0.34)	0.91 (0.41)	0.87 (0.47)	0.86 (0.38)	0.23 (0.37)	0.24 (0.33)	0.23 (0.24)
Stoichiometry	0.41 (0.49)	0.34 (0.47)	0.50 (0.50)	0.75 (0.43)	0.89 (0.32)	0.75 (0.43)	0.89 (0.32)	0.94 (0.23)	1.00 (0.00)	0.02 (0.15)	0.03 (0.17)	0.00 (0.00)
Reactions	0.60 (0.49)	0.93 (0.26)	0.91 (0.28)	0.88 (0.32)	0.80 (0.40)	0.87 (0.34)	0.78 (0.41)	0.67 (0.47)	0.81 (0.38)	0.17 (0.37)	0.13 (0.33)	0.06 (0.23)
Bonding	0.21 (0.41)	0.19 (0.39)	0.42 (0.49)	0.88 (0.32)	0.89 (0.32)	1.00 (0.00)	0.95 (0.21)	0.96 (0.19)	0.95 (0.22)	0.07 (0.26)	0.00 (0.00)	0.21 (0.41)
Gas Laws	0.90 (0.30)	0.91 (0.29)	0.96 (0.20)	0.35 (0.30)	0.50 (0.48)	0.57 (0.50)	0.75 (0.43)	0.64 (0.48)	0.82 (0.38)	0.00 (0.00)	0.05 (0.21)	0.09 (0.28)
Thermodynamics	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	0.58 (0.49)	0.60 (0.49)	0.94 (0.24)	1.00 (0.00)	0.80 (0.40)	1.00 (0.00)	0.08 (0.28)	0.07 (0.25)	0.25 (0.43)

*The topics presented have 10 or more representations per year. Concepts not included: nuclear chemistry, organic chemistry, and foundational topics (e.g., density).