Urban Seventh-grader's Translations of Chemical Equations: What Parts of the Translation Process do Students Have Trouble?

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Abstract

Use of multiple representations is a prominent scientific practice in many communities, including all science domains. Representations in science provide perceptual accessibility and a means to conceptualize and communicate abstract explanations of the phenomena we experience. For example, chemical representations such as chemical equations and ball-and-stick models are visible and tangible and therefore provide students with a more concrete perception of what happens to atoms and molecules during a chemical reaction. It is therefore important for students to develop their abilities of moving between various representations so they can accurately use the representations while organizing information and while formulating evidence-based explanations (National Research Council, 2000). However, students at all levels of chemistry have difficulty in using chemical representations, such as the inability to translate chemical representations into other forms. Our goal was to investigate urban seventh-grade students' translations of chemical equations. We found that when asked to describe a chemical equation, few students included general concepts about chemical reactions, that their descriptions were direct translations of the process and chemical symbols, and that sometimes these translations identified the symbol rather than the role of the symbol in the chemical equation. We also found that students' translations of chemical equations did correlate with their prior knowledge of chemical reactions and with their descriptions and drawings of atoms and molecules. We discuss implications to these findings in the summary and conclusion sections.

Current science reform initiatives support students' learning and use of scientific practices in order to become knowledgeable and critical participants in society (American Association for the Advancement of Science, 1990, 1993; National Research Council, 1996). One such scientific practice is the use of representations, such as graphs, data tables, diagrams, models, pictures, symbols, maps, formulae, and written or spoken verbal expressions. Science educators have shown us that students have difficulty using representations in science, particularly in chemistry (Ben-Zvi et al., 1987; Gabel, 1999; Johnstone, 1993; Kozma, 2000b; Kozma & Russell, 1997). Although much research has focused on students' use of chemical representations, few have done so with respect to urban students and with respect to students who are novices to the concepts that chemical representations depict. Also, most studies on students' conceptions of, and representations of, the particulate nature of matter are in the context of kinetic molecular theory (Harrison & Treagust, 2000, 2002; Krajcik J., 1991; Wu et al., 2001) What happens to student's use of chemical representations when we complicate the abstract science ideas even more and involve processes such as chemical change? Our study therefore investigated urban seventh-grade students' translations of chemical equations (symbolic-level representations of chemical reactions). We analyzed what these students did, and what difficulties they had, when asked to translate chemical equations into words and models. We also analyzed how students' prior knowledge of chemical reactions, as well as their knowledge of atoms and molecules, relates to their abilities in translating chemical equations before instruction on chemical reactions.

The importance of using representations

Scientific practices, whether called "inquiry" (NRC, 1996), "habits of mind" (AAAS, 1990) or any other phrase, is a way of thinking; a way of doing. And these many ways of thinking and doing include the use of representations (Latour & Woolgar, 1986). Representations have both cognitive and social uses. For example, chemical concepts help explain much of the complex phenomena that we experience in our everyday lives, yet many times the chemical concepts are abstract ideas that require some sort of visual aid to both conceptualize and to communicate the ideas. Representations have therefore become a form of language — a way that scientists can communicate ideas to others in and out of the scientific communities, as well as a way that each scientist can communicate with him/her self in order to conceptualize unobservable concepts that explain phenomena (Latour, 1990; Lemke, 1998; McGinn & Roth, 1999; Roth & McGinn, 1998).

Because we commonly use representations to explain underlying principles of various phenomenological experiences, and because representations help us communicate ideas in both science and "everyday" communities, then students should learn how to use representations to both conceptualize concepts and communicate them to others (McGinn & Roth, 1999). It is also important for students to develop their abilities of moving between various representations so they can accurately use the representations while organizing information and while formulating evidence-based explanations (National Research Council, 2000). It is therefore essential that students become adept at interpreting representations, translating between representations, and using representations to further understand science concepts that relate to their world.

Translating chemical representations

By translating representations we mean students interpret representations by obtaining appropriate information, and move among other representations of the same concept. Students move among representations by either providing other representations to convey the same information, or by identifying the similar and different information that the representations depict.

Translating representations in chemistry involves thinking about phenomenon in three levels: symbolic, macroscopic, and molecular (Gabel, 1999; Johnstone, 1993, 1997). Also within each of these levels exists another dimension — dynamics — for change is the essence of chemistry, yet many of our chemical representations of dynamic processes are static (Harrison & Treagust, 2002). Moving among the three thinking levels and two dimensions makes the process of translating chemical equations very difficult (Johnstone, 1993, 1997). For example, each substance in a chemical equation can be looked at with a symbolic *and* dynamic perspective — that each letter (or set of letters) in a chemical formulae represents a particular molecule while the plus sign and arrows represent the process of chemical change. From a macroscopic and symbolic perspective, each group and arrangement of the atoms in a chemical formula represents a specific substance, and we understand each chemical formulae doesn't necessarily mean one molecule/compound, but so many molecules/atoms that we need analogies to help us comprehend the "amount" of the substance we see in the test tube. From a molecular perspective students are asked to translate chemical formulae into molecular models (such as ball-and-stick models) which depict concepts different from chemical formulae, such as the arrangement of atoms in relation to each other. And from a dynamic perspective, students should recognize how these models may change (i.e. vibrational, rotational and translational movements, as well as structural changes during a chemical reaction). It is apparent that students would have difficulty when dealing with the multi-layered complexity that encompasses any chemical representation. But what does this look like? What parts of the multi-layered thinking do students have trouble and what are they doing?

Our research questions and the context of this study:

Two questions encompass the focus of our study:

1. What do urban seventh graders do, and what difficulties do they have, when asked to translate chemical equations?

For well over a decade chemical educators have asked many questions concerning students' difficulties in using representations of chemical concepts. These difficulties include students' inability to connect chemical representations to the macroscale phenomenon and the inability to translate chemical representations into other forms (Ben-Zvi et al., 1987; Gabel, 1999; Harrison & Treagust, 2000; Kozma, 2000a, 2000b; Kozma & Russell, 1997; Krajcik J., 1991; Latour & Woolgar, 1979; Nussbaum, 1998; Solomonidou & Stavridou, 2000; Stavridou & Solomonidou, 1998; Wu, 2002; Wu et al., 2001). We recognize that students difficulty in navigating through chemical representations may intensify if they are novices at using the representations, if their understanding of chemical concepts are not yet coherent, and/or if students have low visual-spatial capabilities (Heitzman et al., 2004; Kozma, 2000a; Stieff et al., 2004; Wu, 2002; Wu et al., 2001). But we do not know what students translations of chemical representations look like when the students are (a) new to using representations and (b) have just begun to experience and understand chemical concepts. The urban seventh graders in this study fulfill these characteristics.

Much literature on students' translation processes involves high school or college students (Nicoll, 2003; Stavridou & Solomonidou, 1998). This study on seventh graders is advantageous because the students are novices at both the scientific content and the use of representations to explain phenomenon (Wu, 2002; Wu et al., 2001). Unlike secondary and collegiate students who have had some type of instruction on chemical reactions and the particulate nature of matter, the chemistry unit *How can I make new stuff from old stuff* (*Stuff*) (McNeill K. L. et al., 2004) is the first time middle school students are exposed to a sustained comprehensive presentation of chemical reactions. If these seventh graders have any prior experiences with chemical concepts, their understandings are most likely pieces of knowledge that are not yet cohesive (diSessa, 1993).

The students in this study are also novices in explaining physical phenomenon by molecular and symbolic representations of substances (Wu, 2002). Again, unlike secondary and collegiate students, these middle school students had only participated in one instructional unit that supports the practice of using chemical representations to explain the particulate nature of matter and physical changes of substances.

This study is also advantageous because we are looking at student learning of chemical representations in urban classrooms. These classrooms provide education to a large population of minority students — about 85% of whom are African American, and half of whom belong in lower to lower-middle income families (Blumenfeld et al., 2000). Poor urban schools are characterized by lower academic achievement, limited and outdated science resources (such as textbooks, scientific equipment, and science-related extracurricular activities), schooling practices that support passive learners, and a strong emphasis of educational achievement that is based upon behavior skills and "static conceptions of knowledge" (Barton, 2001). Middle school students in these types of school environments receive few, if any, adequate science experiences and science instruction (Atwater, 2000). If curriculum materials such as the *Stuff* unit are to support students in all learning environments, then we must take learning in urban schools into consideration. However, "…much of what we know in science education — about teaching, learning, policy and research — does not directly apply in urban settings, and in particular to poor urban settings." (Barton & Tobin, 2001, p. 844). We emphasize that the goal of this study is <u>not</u> to compare and contrast poor urban students from other more well-off students. Rather, our purpose in describing urban seventh grader's translations of chemical representations is to inform the science education community of student learning in an urban context with respect of scientific practices such as the use of representations.

2. How do urban seventh grade students' translations of chemical representations relate with their (a) prior knowledge of chemical reactions (b) knowledge of atoms and molecules?

We recognize that correlations exist among students' (in)abilities to translate representations, their chemistry language skills, and their knowledge of chemistry concepts. We also recognize that students' use of representations should develop as students' understanding of the concepts becomes more coherent (Kozma, 2000a; Lemke, 1990, 2002). But in what way do these factors relate to one another? Much literature about students' ideas of chemical representations focus on the particulate nature of matter, kinetic molecular theory and students' epistemologies of models (Harrison & Treagust, 2000; Nussbaum, 1998; Solomonidou & Stavridou, 2000). Chemical change, however, involves additional information beyond particulate nature of matter and physical states, such as the relationship(s) and interactions between substances. For example, students must apply the ideas such as molecular movement and space between molecules, in addition to the rearrangement of atoms and formation of new molecules/substances. We therefore go one step beyond students' ideas of atoms and molecules and look at chemical equations.

Before participating in the *Stuff* unit, the students in this study had participated in an 8-week instructional unit on the components of air and kinetic molecular theory. These students therefore had learned about atoms and molecules before they received instruction on chemical reactions at the molecular and symbolic levels. How might these students' ideas of atoms and molecules relate to their initial efforts to translate chemical equations? Also, how might students' prior ideas about chemical reactions relate to how they initially translate chemical equations?

Instructional Context

Seventh graders in a mid west urban school district participated in a middle school chemistry unit, *How can I make new stuff from old stuff?* (*Stuff*) (McNeill K. L. et al., 2004). This unit was designed by a learning-goals-driven model (Reiser et al., 2003) to support students engagement and learning about chemical reactions. In this unit students experienced and investigated phenomenon to help them understand content associated with chemical reactions, such as substances, properties of substances, chemical reactions at the macro- and molecular levels, and finally conservation of mass during a chemical reaction (again at the macro- and molecular levels).

As the *Stuff* unit challenges students to learn how we can make "new stuff' from "old stuff", it also guides students as they develop scientific practices, such as use of representations, in the context of chemical reactions (American Association for the Advancement of Science, 1990; McGinn & Roth, 1999; McNeill K.L. et al., 2003; National Research Council, 2000). The *Stuff* unit provides multiple opportunities for students to use various chemical representations when demonstrating chemical reactions at the symbolic and molecular levels, such as chemical equations and ball-and-stick models.

Method

Participants

Participants included 4 teachers and 102 seventh grade students in four public middle schools in a large Mid-western city (1 class per teacher, which ranged from 27-35 students per teacher). The majority of students in each school was African American and belonged in lower to lower-middle income families.

Sources of Data and Analysis Protocols

Our analysis of students' difficulties in translating representations is influenced by our recognition that correlations occur between a student's knowledge of chemistry concepts, ability to translate representations, and ability to talk about the content (Kozma, 2000a; Lemke, 2002). This study uses two types of assessment data: responses from a set of quizzes and students' pre- and post- unit tests:

<u>Quizzes:</u>

The students in this study had taken a set of three quizzes, in which each quiz was given after certain lessons of the *Stuff* unit (Table 1). The first quiz addressed students' knowledge of atoms and molecules, and their ability to communicate this knowledge by words and by drawings. This quiz was given *before* students participated in any of the lessons that concentrated on the particulate nature of matter. The questions in the first quiz included, (1) "describe how a molecule is different from an atom," and (2) "Draw a model and draw an atom."

Students' responses to items on quiz 1 were used to separate the students into two groups: Those with low knowledge of atoms and molecules, and those with medium-to-high knowledge of atoms and molecules. The items on quiz 1 were analyzed according to students' inclusion of descriptions of both atoms and molecules according to the concepts that students had learned in their previous science unit on air kinetic molecular theory. For example, students previously learn that atoms are the smallest unit of an element, atoms make up elements such as hydrogen and oxygen, and molecules are made up of atoms. We also assessed students' drawings of atoms and molecules based on the variation and similarities between the drawings as well as whether molecules are drawn as a continuous particle versus a collection of smaller particles (i.e. atoms) and whether the smaller particles matched that of the drawn atom.

The second quiz addressed students' knowledge of chemical equations and their ability to translate a specific chemical equation into both words and into a molecular model. Students took this quiz *before* they participated in the unit's lessons that addressed chemical reactions at the molecular and symbolic levels. The questions in the second quiz presented the chemical equation: $2H_2O + O_2 \rightarrow 2H_2O$ and asked students to (1) "describe in words what the equation tells you," and (2) "draw a model of the process above. In your model, show what happens to the $2H_2$ and O_2." We specifically did not tell students to draw ball-and-stick models, nor *any* type of model, so that students would be open to draw what they believed would count as a model.

Table 1: Items of each Quiz

Quiz #	**Questions on Each Quiz**	**Where in *Stuff* unit**
1	(1) Describe how a molecule is different from an atom (2) Draw a model and draw an atom	Before instruction on chemical reactions
2	chemical equation: $2H_2O + O_2 \rightarrow 2H_2O$ (3) Describe in words what the equation tells you (4) Draw a model of the process above.	Before instruction on chemical reactions at molecular level
3	(1) Describe how a molecule is different from an atom (2) Draw a model and draw an atom chemical equation: $Mg + 2HCl \rightarrow MgCl_2 + H_2$ (3) Describe in words what the equation tells you (4) Draw a model of the process above.	After instruction on chemical reactions at molecular level

Analysis of the first item on this quiz — students' descriptions of chemical equations — involved a coding scheme that focused on students' ability to translate the equation and chemical symbols of the chemical reaction into scientific words and phrases (such as "goes to form," "produces," "molecules," etc.), as well as their inclusion of general concepts about chemical reactions (such as saying the equation represents a chemical reaction, or that atoms rearranged, etc.). Analysis of the second item — students' translation of the chemical equation into a model — focused on whether the information from drawings were consistent with the information provided by the chemical equation (i.e., if students drew two water molecules, if they used symbols to represent the reaction process, etc.).

The third quiz was given in order to obtain data on students' translating skills *after* instruction of chemical reactions at the symbolic and molecular levels. This third quiz therefore repeated the four questions found on quizzes one and two (Table 1). This quiz only differed by the chemical equation ($Mg + 2HCl \rightarrow MgCl_2 + H_2$) and a key which depicted what each substance represented. We provided a key on this quiz because students were more likely to have recognized water, oxygen gas and hydrogen gas (included in quiz 2) due to students' instruction of air and the kinetic molecular theory. Yet we did not expect students to have experienced chemical representations of magnesium, hydrochloric acid, and magnesium chloride.

All quiz items were scored by one trained rater. The items were checked by an independent rater, and any discrepancies between the two coders were discussed and reconciled. Due to constraints, only students in three of the four classrooms had taken the third quiz. This decreased the number of students from 102 to 80, and affected our analyses of students' difficulties in translating chemical representations *after* instruction.

<u>Pre- and Post Unit tests:</u>

Each student in this study also partook in pre- and posttests — a test given to students before and after they participate with the *Stuff* unit. A set of 8 questions (6 multiple choice and 2 open-ended) in this test included questions about chemical reactions at the macroscale, symbolic and molecular levels. The two open-ended items were scored by one rater. Twenty percent of the tests were randomly chosen and scored by an independent rater. The average inter-rater reliability was above 85% for each portion of the items.

Students' performance on the chemical reaction items of the pretest were used to form groups of low, medium and high knowledge of chemical reactions. Ranges for the low, medium and high groups were based on quartiles of students' post-test scores of the chemical reaction items. To make this range more representative of the population of urban seventh-grade students, and less biased to the students in only these 4 classes, we used post-test data from 9 teachers and 31 classes, including the students in this study (N=600). The ranges that denoted the lower and higher 25% of the students became the range for low and high groups, respectively. The middle 50% then became the range for the medium group. Grouping students' pretest scores based on these ranges resulted in two groups — low knowledge of chemical reactions (N=42) and medium knowledge of chemical reactions (N=37). (Due to high absenteeism in the schools, only those students who completed both pre- and posttests, as well as the first and second quizzes, were accounted for in our analysis (N=79)). It is not surprising that students did not fall in the high range, for students have not yet received instruction about chemical reactions.

Results

We first report that students did improve in translating chemical equations (19% increase, ES=.46, $p < .000$). This shows that not only are urban students able to make some translations of chemical equations, but they improved in their abilities to translate chemical equations to words and models. However, our analysis attempted to describe the difficulties students have when making these translations, so that we can tackle these difficulties during instruction. The following results focus on identifying the aspects of the translation processes that are difficult to students.

Analysis of Students' Difficulties

Our analysis of students' difficulties focused on items 3 and 4 (from quizzes 2 and 3; Table 1), which present a chemical equation and ask the students to both describe and draw a model of the equation.

<u>Analysis of "Describe in words" the chemical equation:</u>

Analysis of the pre-instruction responses to item 3, ("describe in words" what a chemical equation "tells you", N=102) showed that very few students provided descriptions in terms of general concepts about chemical reactions (such as a chemical reaction occurred, new molecules/substances, atoms rearrange). In fact, 78% of the students indicated no general chemical reaction concepts in their responses, 18% of the students provided one of the general concepts (usually stating that the equation represented a chemical reaction), and only 4% of the students provided more than one general concept of chemical reactions.

We observed this same trend, with some slight difference in percentages, on the post-instruction item (quiz 3; N=80). Upon asking the same question with a different chemical equation, the majority of students again did not include general chemical reaction concepts in their descriptions (67.5%), whereas a slightly higher percentage of students (26%) provided one general concept, and 6% included more than one general chemical reaction concept into their descriptions. A difference of means t-test showed that the average student score did significantly increase (ES=.34, $p<.05$).

Although many students did not incorporate general chemical reaction concepts into their responses, these students did try to translate the chemical and equation, specifically by translating the process symbols (such as “+” and “→”) and chemical symbols (such as “H_2”), but not without difficulty. *Before* instruction about chemical reactions at the symbolic and molecular levels, 20 of the 102 students (20%) had consistently and completely translated either the chemical symbols and/or process symbols as they are used in chemistry discourse. And, 48 of the 102 students (47%) did translate either the process symbols or chemical symbols, but came upon some difficulties. Many of these students translated the symbols by using words that identified each symbol rather than using words that described the symbol as a form of scientific notation. For example, students tend to translate “+” into “plus” instead of “interacts with” or “react”. Also, many of these students were in an in-between state, in which they were inconsistent with their translation of the symbols. A student in this state would translate one symbol into its scientific description, yet identify other symbols in the chemical equation as they are and not by their roles as scientific notations. For example, one student wrote, "two hydrogen2 plus oxygen2 makes 2water". This student translated the arrow into a process notation, “makes”, but identified the plus sign as “plus”, suggesting s/he is inconsistent with his/her translation of the entire chemical equation as a chemical reaction. Also, this student clearly recognized the names of the chemical symbols, but failed to translate the coefficients and subscripts when describing the equation, which suggests that the student did not fully understand the role of the subscripts and coefficients in the chemical equation.

Analysis of students' verbal translations of a chemical equation after instruction showed that many students still had difficulty in their consistency of translating both chemical and process symbols. However, the percentage of students who did not translate the symbols, who did not consistently translate symbols, and those who consistently translated at least one type of symbol in relation to the entire reaction, leveled to a range of 20-24 students (25% - 30%) in each group.

<u>Analysis of "Draw a model" of the chemical equation</u>

Students' tendency to use the process symbols as algorithmic notations was also apparent in student's drawings of models of the chemical equations on both pre- and post-instruction quizzes. This time the students used the "+" sign in their models, but then used an equal sign (=) instead of an arrow (→) when drawing models of the chemical reaction, which suggests students' inclination to match the plus sign with another known mathematical operator. Despite this difficulty, the percentage of students who consistently used the arrow and plus symbols in their models increased from 20% on the pre-instruction quiz to 29% from pre- to post-instruction quiz, showing that some students are improving in their ability to completely and consistently translate a chemical equation.

We also recognized that before instruction, some students had difficulty recognizing that each reactant and/or product is a separate molecule/compound. These students connected all atoms of all reactants and/or products into one entirety. For example, instead of three separate molecules in the reactants (one oxygen and two hydrogen molecules) students drew all six atoms connected together into one entirety. One reason for these incidents is that students may have interpreted the plus sign as “combined” or “added” and therefore connected all of the substances together.

The analysis of students’ translation of chemical equations into models not only focuses on their use of process symbols and whether they separate molecules into their own components, but also includes if students correctly translate the coefficients and subscripts, whether they point out the rearrangement of atoms (by arrows, extra steps, text, etc.), and whether they label the substances and equation symbols. Our analysis shows that when we combine each of these variables, we find that students had improved their translations of the chemical equation into models (ES=.48, $p < .01$).

Analysis of the relationships between students’ translations and their knowledge of atoms and molecules and chemical reactions.

This analysis of the relationship between students’ translations of chemical equations and their prior knowledge of chemical reactions and their understanding of atoms and molecules pertains to students’ pretest chemical reaction scores, their responses to items 1 and 2 (questions about describing and drawing atoms and molecules, quiz 1), and their responses to items 3 and 4 (questions about describing and drawing a chemical equation, quiz 2). Therefore all of the items included in this analysis pertain to students’ responses before they learned about chemical reactions at the molecular and symbolic levels.

Students’ translations of chemical equations and their descriptions and drawings of atoms and molecules (before instruction)

Students’ were grouped into low and medium-hi knowledge of atoms and molecules based on their responses to the items about atoms and molecules. An independent samples t-test showed that students with medium-to-high knowledge about atoms and molecules performed better than those with low knowledge of atoms and molecules when translating chemical equations by all three translation components: by inclusion of general chemical reaction concepts, by direct translation of the process and chemical symbols, and by their drawings molecular models ($p<.01$ for each component). A Pearson’s correlation also shows that students’ descriptions and drawings of atoms and molecules directly relates to their translations of a chemical equation ($r = .406$; p(two-tailed) $<.01$). This suggests that those with higher knowledge of atoms and molecules may include more chemical reaction concepts while translating the chemical equation, they may be more consistent and complete with their translations of the chemical and process symbols, and they may produce more complete and consistent models of the chemical equation.

Students’ translations of chemical equations and their prior knowledge of chemical reactions

Students were grouped into low and medium knowledge of chemical reactions. An independent samples t-test showed no significant differences between the low and medium groups in their inclusion of general chemical reaction concepts while translating the chemical equation. However, the medium group did perform better than those in the low group when directly translating the chemical and process symbols of the chemical equation ($p<.05$). The medium group also performed better than the low group when asked to make (draw) a model of the chemical equation ($p<.05$). A Pearson's correlation also shows that students' translations of chemical equations does correlate with their prior knowledge of chemical reactions ($r = .383$, p(2-tailed) $<.01$). This data shows that students with higher prior knowledge of chemical reactions do not necessarily include general chemical reaction concepts in their verbal translations, but they do provide more complete and consistent direct translations of the chemical equation in the form of words and/or molecular models.

Summary and Implications

The results of our analyses resulted in three characteristics of students' difficulties in translating chemical equations. We again recognize that students improved their performance of translating chemical equations before and after instruction. However the following characteristics of students' difficulties can inform us in our teaching of chemical representations to students who are novices at both the use of representations and the content which the representations depict.

1. Few urban middle-school students in this study described chemical equations according to general chemical reaction concepts, both before and after instruction

Many chemical educators have acknowledged that students have difficulty in translating molecular or symbolic level representations into their macroscale phenomenon (Gabel, 1999; Krajcik J., & Starr, M., 2001; Nicoll, 2003). The students in this study also did not apply macroscale ideas to the chemical equation (we did not expect students to do so), yet few students even connected the general macro- and molecular-scale concepts that they learned in the *Stuff* unit, such as that the equation shows a chemical reaction, that atoms rearranged, and that new molecules (or new substances) formed. However, most students did try to directly translate the process and chemical symbols. This may suggest that when students are novices at both representation use and understanding the concepts, they will try to identify features of the chemical representation before translating the representation as a whole. Research on students' interpretation of graphs also have revealed that when instruction about graphs involves local interpretation versus global features of the graph, then students will analyze graphs based on individual features and not the relational meanings of the graph, "Even though understanding global features of a graph is valuable both for more advanced mathematics (especially in calculus) and for a full understanding of the situations represented by graphs, treatment of these features generally is overlooked in the earlier grades of the curriculum….Overemphasizing point-wise interpretations may result in a conception of a graph as a collection of isolated points rather than as an object or conceptual entity" (Leinhardt et al., 1990, p. 9,11). This same phenomenon may also apply in the context of chemistry and the interpretation and translation of chemical representations. It is therefore important for teachers to focus on translating the representation as a whole as they guide students in navigating through chemical representations.

2. Urban middle-school students in this study may apply algorithmic processes when asked to translate chemical equations.

Students in this study were able to make more direct translations of chemical equations by using words that related to equation and chemical symbols — yet many times these translations were included both copying the process and chemical symbols verbatim, and/or translating the representation into what it is, or what it mathematically represents, instead of what the symbol represents as a form of scientific notation. For example, "→" was "arrow" instead of "produces" and "+" was "plus" instead of phrases such as "reacts with". Students' tendency to treat the process symbols like mathematical symbols was apparent in both students' verbal descriptions and in their production of models of the chemical equation. Many students also used the equal sign ("=") rather than an arrow to represent the process. This is consistent with literature that discusses students' tendencies to interpret chemical representations by algorithmic functions (Krajcik J. S. et al., 2003; Nicoll, 2003). However, these algorithmic-processing applications usually refer to the chemical formulae and stoichiometry, whereas these students also attribute the process symbols as mathematical operators.

It is not surprising that students apply mathematics to chemical equations, for a student will use the tools he/she already has to answer questions, and these students are bringing prior ideas and prior interpretation practices into the context of translating chemical representations — a practice that is new to them (Driver et al., 1985). The findings suggest that students who are new at using representations and new to concepts such as chemical change may not understand the explicit discrepancies of the function of symbols that are used in more than one discourse community (i.e. roles of symbols in mathematical equations versus in chemical equations). This indicates that if we are going to instruct students in middle-school about the particulate nature of matter, we should be aware of the students' tendency to apply mathematics in the context of chemical equations, and make this comparison to the students so they might better understand the roles of commonly used symbols in different domains of scientific discourse.

3. In this study, urban middle-school students' use of chemical representations such as chemical equations relates considerably with their prior knowledge of chemical reactions and knowledge of atoms and molecules.

Chemical educators have previously recognized that intercorrelations exist between students' use of chemical representations, their knowledge of the represented concepts, and the ability to communicate these ideas (Kozma, 2000a). Our study agrees with this recognition. The correlations are significant, which suggests the importance applying all three of these components during instruction to help students become competent in using chemical representations.

Conclusion

The difficulty of using chemical representations is commonly discussed and well documented, and includes students epistemologies and use of the representations (Gabel, 1999; Johnstone, 1993, 1997). This study both adds to and compliments the literature of chemical representations by describing the difficulties that novices may have as they *begin* to use representations and as they *begin* to experience and learn about chemical concepts (such as chemical change) in a formal instructional setting. Our analysis shows that students do learn to translate chemical equations by describing them in words and producing models of the equation. This study also identifies three characteristics that relate to students' difficulties in translating chemical equations: that few students indicate general chemical reaction concepts when translating chemical equations into words, that students translations may follow algorithmic and mathematical processes, and that students' knowledge of both atoms/molecules and of prior chemical reaction concepts, as well as students' ways of talking about these concepts, relate to their translations of chemical equations.

This work informs chemistry teachers and curriculum designers of ways to support students who are novices in both the use of representations and the chemical concepts that students are learning. Based on our analysis, we emphasize the importance in stressing general chemical reaction concepts to students when navigating through various chemical reaction representations, in explicitly distinguishing process symbols of chemical equations from the same symbols in mathematical equations, and in being aware of the strong relationship between students' knowledge of chemical concepts, their use of representations around the concepts, and students' ability to communicate these ideas by words and by other representations. However, the research of urban seventh graders' use of chemical concepts does not stop here. Future research will explore how students' understandings of chemical reactions, atoms and molecules and students' use of representations to communicate these ideas might develop through the *Stuff* instructional unit, and how the relationships between these characteristics change over time.

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