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ABSTRACT

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What Are Students' Initial Ideas about 'Amount of Substance'?: "Is There a Specific Weight for a Mole?"

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What are students' initial ideas about *amount of substance*?

"Is there a specific weight for a mole?"

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Abstract

The purpose of this study is to analyze the role of students' prior knowledge in their emerging understanding of the mole. The research question this study seeks to answer is what knowledge, if any, do student have regarding the mole and what prior knowledge do they access when presented problems regarding the nature of the mole. Data collection focuses on student knowledge regarding the mole in three areas; 1) math skills and number sense, 2) the mole and 3) *amount of substance.* It was found that many students relied on observable properties of matter at a macroscopic scale in their reasoning about *amount of substance*. Reliance on observable properties of materials, like whether the substance is a solid versus liquid, or the surface features of a problem like the number quantities in chemical formulas, plays a large role in student reasoning. The implication of this research is that students may not be able to develop a conceptual understanding of the mole unless they shift their understanding from a macroscopic view of matter to a particulate model of matter.

I. Introduction

Although the mole is a central topic of high school chemistry, it is consistently one of the more difficult topics for students to learn (Ben Zvi et al, 1986; Gabel, 1984; Naiz and Lawson, 1985). Even in the best situations, students who can answer factual and algorithmic problems about the mole demonstrate little conceptual understanding (Bodner, 1991; Driver, 1994; Gabel 1987). Previous research in chemistry education has focused on barriers to solving mole problems without examining the difficulties of developing conceptual understanding. This focus results from emphasis on problem solving in the instruction and assessment of the mole currently found in chemistry classrooms. However, given the general shift in emphasis in science education from memorization of facts and algorithms to a deeper understanding of the subject matter (NSES, Project 2061) it seems necessary to consider what factors affect students' conceptual understanding of the mole.

This shift towards conceptual understanding entails a reexamination of models of learning and their implications. Conceptual change is one such theoretical model to explain how the learner achieves conceptual understanding within the constructivist framework of learning. The emphasis is on what is happening when the learner is "constructing" understanding, focusing on how "components of [an] individual's conceptual ecology interact and develop and how [their] conceptual ecology interacts with experience (Strike & Posner, 1992). Components of a learner's conceptual ecology include current scientific conceptions, misconceptions, and epistemological beliefs, for example, as well as the interaction of these components. Within the theory of conceptual change the active construction of meaning occurs through the integration of components within the learner's conceptual ecology. Moreover, the model recognizes that the learner has prior knowledge and that this knowledge is crucial to developing understanding through the active construction of meaning (Greeno, 1996; Smith, diSessa &Roschelle, 1993). The recognition that learners' prior knowledge is a fundamental aspect to achieving conceptual understanding implies that how students learn chemistry is inextricably linked to their prior experiences. As a result students learn through their own individual construction of understanding, and conceptual understanding occurs when the learners connect between concepts, experience, and strategies (Smith, diSessa, & Roschelle, 1994; Strike and Posner, 1992).

Previous research on students' understanding of the mole focused on students' problem solving ability. However the more interesting question remains unexplored: what is the knowledge that students bring to class as they try to understand the mole and what limitations develop that hinder their understanding based on this prior knowledge. The premise of this study is that students are not familiar with the topic of the mole but that they do have ideas about *amount of substance*. For example students can discuss relative amounts of volume or weight between substances, like which one weighs more or which would have a greater volume if comparing bricks to feathers. Furthermore it will be claimed that it is this knowledge of *amount of substance* that forms the basis of students developing understanding of the mole.

II. Purpose

The research question this study seeks to answer is what knowledge, if any, do students have regarding the mole and what prior knowledge do they access when presented with problems regarding the nature of the mole. The aim of this research is two-fold (1) to determine what is the nature of students' knowledge of *amount of substance* prior to instruction and (2) to evaluate how this knowledge influences student understanding of the mole. Data analysis focuses on eliciting and analyzing students' understanding of *amount of substance* as a foundation to develop conceptual understanding of the mole followed by a discussion regarding the influence of prior knowledge on students' understanding of the mole.

III. Prior Research

The mole

The mole is simply an international counting unit. The international System of Units (SI) defines the mole as

> "the amount of substance that contains as many entities as there are in exactly 0.012 kg of carbon–12 (12 g of C-12 atoms)" (Kotz & Purcell cited in Staver & Lumpe, 1995).

This definition is a designed relationship between the mass of a mole of carbon–12 atoms and the atomic mass units (amu) of an atom so that the numerical values are identical. Thus a mole of carbon weighs 12 grams and an atom of carbon is 12 amu's. Furthermore it is the standard upon which the rest of the relative masses of all the elements are determined. Within this definition of the mole is the knowledge that the mole of any substance contains the same number of entities and this number of entities is an empirically determined constant defined as Avogadro's number equaling 6.022×10^{23}. This relationship by design is a "vehicle to indirectly count atomic/molecular particles of substance by weighing macroscopic amounts" (Staver & Lumpe, 1995). The mole is the "unit of the quantity that serves to count particles" (Furio, et al, 2000). Within the SI definition of the mole as "amount of substance," the mole is both quantitative and conceptual in nature. Implicit to understanding the mole is the ability to relate the concrete to the abstract. Therefore, an expert level of understanding as described above requires the ability to relate and quantify the observed macroscopic world to a particulate world of atoms.

What we know about student thinking

Initial research on students' understanding of the mole focused on students' problem solving ability. Chandran et al (1987) found that students' prior knowledge and formal reasoning ability are related to chemistry achievement. Gabel (1984) argues that students with better proportional reasoning skills are more successful in solving mole-related chemistry problems. Lazonby (1985) found that student difficulties arise because mole problems are usually multi-step. Gabel and Sherwood (1985) found that students have difficulties with problems that involve scientific notation, two-step problems; and they also discovered that division problems are found to be more difficult than multiplication problems. The study concludes that the difficulties students exhibit with familiar problem solving contexts will make the math application even more difficult in the new subject domain of chemistry that the students are just learning. If problem solving is viewed as understanding, then these studies conclude that cognitive abilities correlate to success in chemistry. Therefore, the students who have better math and reasoning skills will be more successful in chemistry.

The underlying assumption has been that problem solving implies conceptual understanding (Nurremberg & Pickering, 1987). However, research in chemistry education has shown that most students who learn to use algorithms to solve chemistry problems lack a fundamental understanding of the concepts (Bodner, 1991; Nurremberg & Pickering, 1987). Students can solve problems using the mole but do not have conceptual understanding (Lythcott, 1990). For example, after correctly solving a task involving the reaction of potassium and water ($2K + 2H_2O \rightarrow 2KOH + H_2$) students were then asked "if given 1000 H_2O instead of the 2 as in the balanced equation, and unlimited K, how many H_2's would be produced?" Only 6 of the 13 students interviewed had a clear conceptual understanding of the amounts of substance involved in the problem to answer the interview questions correctly (Lythcott, 1990). Further, research in chemistry education indicates that even after traditional chemistry instruction, students lack conceptual understanding (Bodner, 1991: Nakhleh, 1992). As Strike and Posner (1992) recognize even though students have been taught the correct scientific concepts they still maintain misconceptions regarding fundamental ideas in science. Therefore, the realization in science education is that problem solving does not imply conceptual understanding and that even with correct instruction students develop misconceptions. This shift in emphasis to learning as conceptual understanding has prompted much of the research into student misconceptions to explain student difficulties with the mole.

Misconceptions can be described as students' misunderstanding of a concept whether from prior experience or from science instruction that affect their understanding. In chemistry, student misconceptions of the mole seem to fall into 3 main categories (Case & Fraser, 1999):

• Students define a mole as Avogadro's number (Caravellati et al, 1982: Staver & Lumpe, 1995)

• Students define mole as mass (Novick, 1976; Staver & Lumpe, 1995)

• Students extend equal volume for equal amounts of gases to solids and liquids (Astudillo & Niaz, 1996; Caravellati et al, 1982, Novick, 1976)

However in conceptual change theory students' misconceptions are considered an early level of progression in student understanding instead of an impediment to conceptual understanding. Moreover it should be acknowledged that many of these misconceptions that students have are not wrong. The students actually have many of the facts right, like a mole *is* equivalent to Avogadro's number and a mole of a substance *is* its atomic mass in grams. The concern is that these ideas do not agree with the standard normative models of chemistry, specifically the SI definition of the mole. More importantly, the argument that follows is that these misconceptions contribute to the difficulties students experience solving mole problems.

Many studies in chemistry education have linked barriers to problem solving to student misconceptions. Novick (1976) argues that if students view the mole as a property of the molecule they do not perceive the mole as a counting unit. Students frequently cannot define the mole in terms of carbon–12 and instead define the mole as Avogadro's number and/or define the mole as mass. What results is that students confuse quantity with constant mass and not a constant number of entities (Novick, 1976). Staver & Lumpe (1995) conclude that students understand the mole as a numerical identity that blocks their ability to problem–solve. Students are using the mole algorithmically rather than understanding the mole as an entity of the number of particles of any substance so the number 6.02 x 1023 has no relationship to the mass or particle number of a substance. The general conclusion reached by the misconception research is that students' understanding of the mole as a number limits their ability to problem solve successfully.

The focus of this previous research in chemistry education has been how misconceptions affect student problem solving but not how these misconceptions developed. In contrast to studying misconceptions in terms of students' problem–solving ability, the purpose of this study is to explore students' prior knowledge of *amount of substance* that affects their conceptual understanding of the mole. Since students have not had instruction on the mole the idea of *amount of substance* is used in this study instead.

Amount of substance is referred to in the standard definition of the mole and it has colloquial use for example, how much, how big, more. The colloquial use of the concept *amount of substance* can refer to weight, size, volume, and amounts; topics that students all have experience thinking about. Moreover the SI definition of the mole implicitly links these same topics, specifically weight, size, and amount so it seems appropriate to associate students' knowledge of *amount of substance* as an initial foundation to their emerging understanding of the mole.

IV. Methods

Research Design Overview

The purpose of this study design is to collect and analyze student ideas about *amount of substance* as a basis for conceptual understanding of the mole. The aim is to use methods of qualitative research to develop theoretical categories that can then be tested more generally as described in Grounded Theory (Charmaz, 1983; Strauss & Corbin, 1994). Grounded theory follows the cycle of collecting and analyzing data simultaneously. The data analysis occurs in two phases. The initial phase seeks to discover what emerges from the data. The second phase of analysis proceeds with "focused coding." The codes are defined in the process of developing theoretical categories that can ground a developing theoretical framework (Charmaz, 1983). This study focuses on the initial discovery phase and the categories of students understanding that emerge.

The study design began with the generation of questions that were then posed to students. The aim of the data collection was to gather a range of student responses to multiple questions prior to instruction on the mole. Student responses were collected and analyzed to determine patterns of knowledge and reasoning regarding the mole and *amount of substance*. The data analysis occurred in two stages. The first stage of data analysis sought to discover what emerged from the student responses. The second stage focused on coding the student responses to develop categories to describe student prior knowledge.

The study

Student responses were collected from two chemistry classes in an urban high school in the San Francisco Bay Area. Students ranged in age from 15 to 18 and were enrolled in a standard chemistry course that was taught in one semester with double block periods. 35 students participated in the trials and 5 were interviewed. The students were chosen by convenience, i.e. classrooms involved with Living by Chemistry, a high school chemistry curriculum project, and prior to instruction on the mole. Students were given a pre-test at the beginning of the instructional unit on the mole. The pre-test consisted of 20 assessment items that were administered by the teacher as a quiz. Student responses were collected and sorted into emerging categories of understanding regarding *amount of substance.*

In addition, interviews were conducted with 5 students from different ability ranges based on their grades and classroom participation as assessed by the teacher. The interviews were conducted using a "think-aloud" protocol that focused on what students were thinking about as they answered the assessment questions in a semi-structured interview format. Thus, each subject was asked the same set of questions, but different follow-up prompts were used based on the student responses. In this study the interviews served only to confirm and correlate student reasoning found in the written student responses and are not a large component of the analysis that follows.

Assessment design

Previous studies have tested students' math skills and knowledge of the mole as a result of instruction without assessing what prior knowledge students employ when initially presented with chemistry problems that ultimately test their knowledge of the mole. These studies occurred after student were instructed in the mole and thus the students were able to answer and think about different types of questions than students in this study who have not had instruction in the mole. Therefore the assessment items in this study were designed to measure students' math skills, what they know and do not know about the mole, and how they think about *amount of substance.* For example students were asked questions regarding the magnitude of the mole, what they thought a mole is, and then probed about their understanding of the mole, mass, and the relationship between macroscopic ideas of mass and the molecular/atomic level. Some assessment questions were designed to mimic typical mass-mole questions in chemistry, while others were designed to probe for more conceptual understanding of *amount of substance* with various levels of chemistry understanding. In addition, more questions were used then actually discussed and analyzed in this paper. Samples of the questions are shown in Table 1 and grouped according to math skills, knowledge of the mole, and understanding of *amount of substance.*

Table 1: Assessment item questions

Math Skills
Which is larger 7.04 x 10^{34} or 1.48 x 10^{35}? Explain your reasoning. How many hours are in a week? Show your work. How many eggs are in 1/4 of a dozen? Explain. How many eggs are in 0.22 of a dozen? Show your work. If there are 16 ounces in a pint, how many pints are in 22 ounces? Show your work.
Prior knowledge of "mole"
Which do you think has more marbles, a dozen or 1 mole? Which do you think is more 1,000 marbles or 1 mole of marbles? How many objects are in a mole? Explain your reasoning.
amount of substance
Which weighs more one mole of iron (Fe) or 1 mole of water (H_2O)? Explain your reasoning. The molecular formula for vinegar is $C_2H_4O_2$ and the chemical formula for sugar is $C_6H_{12}O_6$. a) Do you think that the 5 mole vinegar solution has the same mass as the 5 mole sugar solution? Explain your reasoning. (Assume both solutions have the same number of water molecules.) b) If you had exactly 1.0g of vinegar solution and 1.0g pure sugar solution, would you have the same number of atoms in each sample? Why or why not? c) If you had exactly 1.0g of pure vinegar and 1.0g of pure sugar would you have the same number of molecules in each sample? Why or why not? Which weighs more? 5 grams of $CaCl_2$ OR 10 grams of NaCl? Explain. Which weighs more? 10 grams of $CaCl_2$ OR 10 grams of NaCl? Explain. Which weighs more? 10 moles of $CaCl_2$ OR 10 moles of NaOH? Explain.

V. Results

Data collection focused on student knowledge regarding the mole in three areas; 1) math skills and number sense, 2) the mole, and 3) *amount of substance*. Initial data analysis consisted of coding patterns of student understanding that emerged from the student responses. First it should be noted that there were a number of "don't know" and blanks in the student responses.

In addition, the data substantiated that the students have no knowledge of the mole as taught in chemistry. Once this was recognized the student responses were then analyzed for patterns of understanding. Following the qualitative tradition, the categories were allowed to emerge from the data. In this way student understanding of mole and *amount of substance* could be discovered in their responses (Charmaz, 1983). Upon further review of the student responses only two of the assessment items within the larger set of items were chosen for further data analysis. These two questions were chosen because they seemed to elicit interesting responses containing students' ideas about the *amount of substance.*

The next phase was an examination of the student responses to the chosen questions. It was found that many students relied on observable properties of matter at a macroscopic scale in their reasoning. This pattern in the data then informed the second phase of focused coding to generalizable categories for further analysis.

Math Skills

Student understanding seems to follow the general trend found in previous research cited earlier that students are not familiar with scientific notation and that division problems are more difficult than multiplication.

Prior knowledge of "the mole"

Overall analysis of student knowledge of the mole is that they have none. None of the student responses indicate any standard understanding of the mole even to the level recognized in the misconception literature. Many of the students (54%) either answered "don't know" or left the questions blank. The remaining students guessed. Most of their guesses are numerical values and there seemed to be no pattern to the numbers that they assigned to the value of the mole or the description of the mole as a quantity. Furthermore, none of the students provided an answer that a chemist would even recognize as related to the mole. Samples of students' responses as "guesses" are shown in table 3. Overall the majority of the students, 19 out of the 35, did not know what a mole is and the remaining 16 students who guessed showed no indication that they had any experience using a mole as a measurement unit in chemistry. This is important to substantiate because the purpose of this study is to learn of students' prior knowledge not the understanding and misconceptions that develop with instruction as studied previously.

Table 2: student responses to the question "How many objects are in a mole?"

Category of student responses	Frequency (out of 35)	Percentage
Blank	8	23%
"don't know"	11	31%
Numerical guesses	10	29%
Descriptive guesses	6	17%

Table 3. sample of student responses to the question "How many objects are in a mole?"

Guesses as a numerical quantity
"1,000"
"8 because that's how many where on the T.V. show."
"not very many, moles are stuff"
"Something along the lines of 2.38 x 10^{23} or 2.73 x 10^{28}"
"I think there are 20 moles"
"A lot"
"none or just one"

Descriptive Guesses
"A mole is a formula so it has to be an equation"
"One object but many of the same thing"
"It depends on the size of the mole."
"Probably the same amount as the thing or mole is another word of saying it" "I don't know what a mole is but I think is the same as the other amount of marbles or objects you compare it with."
"Is there a specific weight for a mole?"

Which weighs more 1 mole of iron (Fe) or 1 mole of water (H_2O)?

Without knowledge of the mole, students are limited in their ability to reason about the weights of two different substances with equivalent moles as presented in the question comparing one mole of iron to one mole of water. As the teacher noted, "once the students saw the term mole they froze up" which may account for 24% of the answers being blank or "don't know." However 54% of the remaining students chose 1 mole of iron as weighing more than 1 mole of water. Some guessed but many relied on their experience with water and iron in their everyday lives to explain their answers. Their responses included statements that iron is a metal or that solids weighs more than liquids. Yet, 4 students demonstrated more normative responses by reasoning that iron would weigh more by referring to the atomic mass of the substances which is the kind of reasoning about *amount of substance* correctly associated with the mole. Frequencies and examples of student responses and shown below.

Question 1:

Which weighs more one mole of iron (Fe) or 1 mole of water (H_2O)? Explain your reasoning.

Normative Chemistry Answer: One mole of iron weighs more because an atom of iron is equivalent to 54 amu while a molecule of water is equivalent to 18amu. Since each has 1 mole there are an equivalent amount of atoms/molecules so a mole of a substance that has heavier atoms/molecules will weigh more.

$$\frac{54\text{ g (Fe)}}{\cancel{1\text{ mole}}} \times (\cancel{1\text{ mole}}) = 54\text{ g Fe} \qquad \frac{18\text{ g } H_2O}{\cancel{1\text{ mole}}} \times (\cancel{1\text{ mole}}) = 18\text{ g } H_2O$$

Table 4: student responses comparing 1 mole iron to 1 mole water

Categories of student responses	**Frequencies** (out of 35)	**Percentage**	**"Iron"**
Blank--	6	17%	
"Don't know"	2	6%	
Guess with no reason provided	6 (2 iron, 2 water, 2 same)	17%	
1 mole = 1 mole	2	6%	
"heavier weighs more"	4 (3 iron, 1 water)	11%	**54%**
Fe is a solid, water is a liquid	11 (10 iron, 1 water)	32%	
amu	4	11%	

“heavier weighs more”
“1 mole of iron (Fe) because iron is heavy is heavy and weights more than water.” “I think iron are heavier than water.” “1 mole of water because its heavier than iron.”

1 mole = 1 mole
“same because is a mole of each.” “I don’t get it, but if the mole is the same weight for both of them, then they weigh the same”

“Fe is a solid, water is a liquid”
“1 mole of iron weighs more, because it’s a metal. That 1 mole of water” “Iron it’s a solid has more things in it” “I suppose the iron does because it’s a metal” “1 mole of iron because iron is heavy & very strong.” “the iron weights more than the water because iron is a metal and water is a liquid.”

Amu
“Iron (Fe) because it shows on periodic table H_2O = 18.015626 and Fe = 55.847” “1 mole iron because greater atomic mass”

Do you think that the 5 mole vinegar solution has the same mass as the 5 mole sugar solution?

Most of the students (71%) responded that the *amount of substance* whether moles, grams, atoms or molecules would be different between the sugar and vinegar because sugar and vinegar are different substances. Student reasoning included that the differences are because sugar and vinegar are made of different things (atoms/elements/particles), and/or sugar is a solid and vinegar is a liquid. If students responses contained explanations for the difference they typically responded that the sugar would be heavier or “more” depending on the question because it is solid or that it would be heavier or more because it had more atoms. Only 3 students recognized that each amount of substance was not always different and began to reason with ideas about when the *amount of substance* could be the same. These students did not rely on reasoning using solid-liquid explanations but instead applied rudimentary atomic models of chemistry in their explanations that included preliminary understanding of the relationship between atoms, molecules and weight.

Student responses fell into the following categories: "blank," "don't know," "just different," "solid different than liquid," "different C and H's," "more atoms are heavier" and "relating amounts." Note that most of the categories describe student reasoning around the idea of difference rather than similarity. Only students in the group "relating amounts" recognized the idea of sameness of amount that could exist between two different substances on a particulate level. Frequency and examples of student responses and shown below (table 4).

Question 2

The molecular formula for vinegar is $C_2H_4O_2$ and the chemical formula for sugar is $C_6H_{12}O_6$.

a) Do you think that the 5 mole vinegar solution has the same mass as the 5 mole sugar solution? Explain your reasoning. (Assume both solutions have the same number of water molecules.)
b) If you had exactly 1.0g of vinegar solution and 1.0g pure sugar solution, would you have the same number of atoms in each sample? Why or why not?
c) If you had exactly 1.0g of pure vinegar and 1.0g of pure sugar would you have the same number of molecules in each sample? Why or why not?

Answer:

a) 5 moles of sugar have a greater mass than 5 moles of vinegar because a molecule of sugar is larger than a molecule of vinegar. Since both solutions have the same moles this means that the solutions have the same number of molecules so the solution with the larger molecule will weigh more.
b) Yes, the two solutions have the same number of atoms because it is the number of atoms that determine the weight. In this case both solutions are made with the same ratios of atoms so the weight and therefore the number of atoms are equivalent.
c) The solutions would not have the same number of molecules because it takes more atoms to make a sugar molecule than it does to form a vinegar molecule. Since a sugar molecule has more atoms there will be fewer molecules in 1g of solution of sugar than 1g solution of vinegar.

Table 5: Frequency of student responses comparing vinegar to sugar.

Categories	Frequencies (out of 35)	Percentages
Blank	5	14%
"don't know	2	6%
Just different	1	3%
Solid/liquid	13	37%
Different particles	6	17%
More atoms = heavier	5	14%
Not always different	3	9%

"different"	Examples of Student Response
No reasoning beyond noting the difference.	a) "No, because" b) "No because have different" c) "No because"

"Solid different than liquid"	Examples of Student Responses
Students are relying on common sense/ experience with macroscopic properties (solid/liquid) of the substances to explain the differences	a) "No because vinegar is a liquid and sugar is a solid so that means they won't ? have same mass. And liquid expand and sugar don't I mean by that is liquid is more moveable than sugar." b) "No because there both different substance" c) "No because there both different substance"
	a) "I think that the vinegar will have less mass than the sugar because vinegar is liquid." b) "No, because the sugar are granols and the vinegar is liquid" c) No, because the vinegar is a liquid it tends to have more molecules than the sugar.
	"No because viniger is a liquid and sugar is a substance, so their difference makes ther moles diffirent"
	a) "I think the vinigar solution has more mass because it has more of each element, and liquid is heavier" b) "I don't know, I suppose but they wouldn't be the same atoms." c) "No, but I don't know why"
	a) "The sugar will have a greater mass because it is a solid. On the other hand, the vinegar is liquid." b) "No you wouldn't have the same number of atoms because you wouldn't have the same object. They're both different items." c) "No because sugar is a solid & vinegar is a liquid."

Different C and H's	Examples of Student Response
Students may refer to atoms/particles/elements but are not sure how the atoms account for the differences beyond recognizing that they are different.	a) "No, because sugar has more numbers stacked onto it." b) "No because there have to be the proper ratios to be the specific compounds & stuff" c) "Probably because it says that they both have 5 moles in 11a.
	a) "No, The C and H are not the same" b) "no they are each a different partical" c) "no they are each different particles"

"More atoms = heavier"	Examples of Student Responses
Students recognize the different numbers of atoms between sugar and vinegar and relate a larger number of atoms to a greater mass.	a) "No, the 5 mole sugar solution has more mass because it has more atoms of each element" b) "No, because in the original formulas, the sugar solution had more atoms." c) "Yes"
	a) "No, because the chemical formula for sugar all ready obviously has a larger mass than the vinegar's since it has more atoms of Carbon, Hydrogen and Oxygen. Hence, with the same amount of water added to each, the ratio will remain the same and sugar will stave have more mass than vinegar." b) "No, I would not because both the solutions have different ratios of element composition and so the number of atoms in each solution would differ; weights of the solutions do not have an effect on their masses." c) "No, because like I have answered above, the weight of the solutions do not affect their masses and so the number of molecules in the 2 solutions do not necessarily have to be equal."

Relating amounts	Examples of Student Response
Students are beginning to appropriately recognize atom/molecule relationships reasoning.	a) "The sugar solution has greater mass because it has more paricles." b) "No. It takes less sugar atoms to weigh 1.0g than It does for vinegar to" c) "No. Less sugar molecules are needed to weigh 1.0g"
Students do not demonstrate a clear understanding of particle/mass relationships.	a) "Sugar ways more because it has more atoms" b) "Sugar would have more because it takes more atoms to form it." c) "They wouldn't have the same molecules because they have different mass for one molecule"
Students are recognizing that it is not always different and begin to reason with ideas of "same" and different.	a) "I think that's not the same" b) "Yes, Because they both have the same numbers of atoms, but the difference is the number of atoms is used in a different way." c)"No, coz pure vinegar have a more number of molecules than sugar."

V. Analysis

Categories of student ideas about amount of substance

The analysis focuses on the commonalties found in students' understanding of *amount of substance* to form generalizable categories. Overall, many students reason that different substances consistently produce different amounts which is not always consistent with a chemically normative explanation. Yet, it is important to recognize how clever and resourceful the students are in utilizing the information they do have in their explanations. The students in this study are operating with limited domain knowledge so they rely on the information that they do have. Students explain the perceived differences in amounts based on the properties of the substances or the numerical values associated with the different substance. Regardless, students are not demonstrating a conceptual understanding of the relationship between macroscopic observable properties, like mass, and a representation of amount in terms of numbers of atoms or molecules in a substance.

Based on the student responses, categories were developed to describe student prior knowledge of *amount of substance*. The purpose of defining categories is to reflect on how this prior knowledge affects students' developing understanding of the mole. The categories that emerged from this study of student ideas about *amount of substance* are: 1) "macroscopic properties," 2)"numerical patterning," and 3) "relating amounts." Furthermore the hypothesis is that there is a progression of understanding along these categories and that students who are farther along this continuum will be more successful in learning about the mole. The progression of student responses range from blank responses and "I don't know" to reasoning using some models of chemistry. In the first level, students just guess without reason. In the next levels students use common sense ideas about matter or patterns in the chemical notation while at a more advanced level of understanding students began to relate somewhat correct knowledge of atoms and particles in their reasoning about *amount of substance*. Descriptions of categories of student reasoning follow below.

Blank, "don't know" and guesses

This is being noted to substantiate that the students do not know and/or are not willing/comfortable to take a guess at an answer because they do not know what to base it on or that if they do guess they are unable or unwilling to explain their reasoning for their answer.

Macroscopic properties

Students are using their experience with macroscopic properties. Student ideas about *amount of substance* in this category indicates an intuitive sense, probably from experience of the materials in their daily lives. Student explanations include iron is a metal, solid weighs more than liquid, there are different atoms and molecules because one solution is a solid and one is a liquid. The majority of student reasoning in this category relies on the properties of solids and liquids to explain the differences. In both questions students using this reasoning tended to explain their answers with ideas that solids are heavier. For example "iron because it a solid and it has more mass the H_2O" and "I think that the vinegar will have less mass than the sugar because vinegar is liquid." For these students explanations of amount are considered in terms of their experience with these substances at the macroscopic level.

Numerical patterning

Students use quantities presented in the question to reason about *amount of substance*. For example a student states "Same because is a 1 mole of each." or another student writes "No because the number of carbon and oxygen are different." Instead of reasoning using macroscopic properties of the substance, the students are referring to the numbers from the problem to reason with limited interpretation of what the number quantities represent. Student ideas about *amount of substance* are directly related to the data provided in the problem. It can be argued that students who use this reasoning do not have a solid foundation of atom to mass relations because when asked if the solutions of the same weight would have the same amount of atoms they stated that the sugar would have more. Yet the same weight results in the same number of atoms in this question. However, none of the students using just numerical patterning demonstrated this level of interpretation for *amount of substance*.

Relating Amounts

Students are beginning to appropriately recognize mass/atom/molecule relationships in their reasoning. They are exhibiting an understanding of the particulate nature of matter that allows them to reason about *amount of substance* in a more sophisticated way than their peers. The relationship between atoms and molecules is clearer than the relationship between these particles and weight. However some are beginning to recognize when the weight can be the same between sugar and vinegar because they are able to reason that the atom number will be the same but the molecule number will be different.

Discussion

The question this study answers is what is the effect of students' prior knowledge in their emerging understanding of the mole. Since students have not had instruction on the mole the analysis focuses on their ideas about *amount of substance*. In summary, it was found that most students are relating *amount of substance* to macroscopic properties and not thinking about atoms or molecules. Therefore the observable properties of materials, like whether the substance is a solid versus liquid or the surface features of a problem like the number quantities, play a large role in student reasoning about *amount of substance*. Research in chemistry education describes the confusion of macroscopic and microscopic properties as a key source of misconceptions in chemistry (Hesse & Anderson, 1992; Ben-Zvi, Eylon & Silverstein, 1986). Ben-Zvi and colleagues (1986) described student attempts to make "the transition from one molecule to many molecules in the understanding of chemical properties as extremely difficult." They found that students attributed properties that only exist at the macroscopic level to individual atoms and molecules. Krnel et al (Krnel, Watson & Glazer, 1998) conclude that students transfer incorrect concepts regarding properties of matter to the micro world of particles so that individual particles (i.e. molecules, atoms and compounds) are described with the same properties as matter. For example students consider atoms as hot/cold or having color. Lacking this understanding it seems natural for student misconceptions to develop that the mole is simply a numerical quantity.

Students have not developed a deep understanding that relates macroscopic properties to an atomic model. Without this link, students will have difficulties understanding the mole conceptually. Thus one can hypothesize that those students who are recognizing the relationship between macroscopic properties of weight and particle number will have a better potential to develop a conceptual understanding of the mole more successfully. Future research can test this hypothesis as a predictor of student success. Currently the questions have been refined and a larger scale study with over 500 high school students is underway to test this hypothesis.

VII. Conclusion

The concept of the mole requires understanding that bridge from quantitative macroscopic measures to an atomic/particulate view. It is the integration of these components that make understanding of the mole difficult. Previous research finds that students tend to quantify the mole as a number without an understanding of its nature as a relative mass. My findings point to students' reluctance to distinguish macroscopic properties (solid vs. liquid) from an atomic model. The hypothesis is that those students who are recognizing the relationship between macroscopic properties of weight and particle number seem like they will have better potential to develop a conceptual understanding of the mole more successfully. Within conceptual change theory, deep understanding is gained when students connect between concepts, experience and strategies, so the question for further research is to determine the relationship between math skills, reasoning, and student prior knowledge of *amount of substance* that support their emerging understanding of the mole.

In summary, students do not have knowledge of the mole until instruction yet they are familiar with ideas about *amount of substance.* More importantly it is this knowledge that can affect their understanding of the mole. This prior knowledge is linked to their ideas of matter and properties that affect their ideas about quantities. Thus, how students think about matter and properties is affecting how they think about *amount of substance.* These two pieces of knowledge are not distinct for students resulting in the over extension of their ideas about properties to the particulate level. Yet of greater consequence is that their knowledge of matter is not well linked to an atomic model of understanding. As Astudillo and Niaz (1996), conclude students who can successfully solve mole–problems demonstrate an understanding of relationships between mass-mole-mass or mass-mole-amounts. Therefore the implication is that instruction needs to focus on linking the atomic model to students' experience with matter to improve their understanding of the mole.

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