Chemistry Education Research and Practice

PAPER

Dual meaning vocabulary (DMV) words in learning chemistry

Cite this: *Chem. Educ. Res. Pract.*, 2014, **15**, 128

Youngjin Song*[a] and Shannon Carheden[b]

Learning chemistry vocabulary that has both scientific and everyday meanings, which we call dual meaning vocabulary (DMV), can be challenging for many students. This qualitative study investigated how college students understand 11 selected DMV words before and after traditional chemistry instruction and to what extent they retain the scientific meanings of them. The challenges these students encountered as they learned DMV words were also examined. Thirteen non-science major students with limited chemistry background were interviewed throughout the study. Data were analyzed by inductive analysis utilizing a grounded theory approach and constant comparative methods. Our results indicate that (1) most college students initially held everyday meanings of the selected DMV words, which were deeply associated with their personal experiences from early years; (2) the everyday meanings of DMV were continuously rooted in students' thinking after instruction so that they struggled with retaining the scientific meanings of it; and (3) the infrequent use of DMV in meaningful contexts, students' rote memorization of DMV, and a lack of prior understanding of other science vocabularies were identified as challenges in learning DMV. These themes are discussed in-depth with various theoretical perspectives in investigating the relationship between everyday and scientific language and understanding. Concrete implications for teaching DMV in chemistry are proposed. The study also calls for further research on the role of the language of science in chemistry education.

Received 9th October 2013,
Accepted 3rd December 2013

DOI: 10.1039/c3rp00128h

www.rsc.org/cerp

Introduction

Academic language is an integral part of learning in any discipline. Academic language can be defined as "the form of language expected in contexts such as the exposition of topics in the school curriculum, making arguments, defending propositions, and synthesizing information" (Snow, 2010, p. 450) although it has been defined in slightly different ways. Vygotsky (1986) emphasized the important role of academic language in his groundbreaking book *Thought and Language* by explaining that learning is a continuous process of exchanging language that presents ideas and understanding the ideas it represents. There is no better place to see the significance of academic language than science (Gee, 2005) because distinctive language is used as a tool for investigating the world, constructing concepts, and communicating complex information in chemistry, physics, biology and earth science (Fang, 2005). Thus, students need to learn the language of science as they learn science. Lemke (1990) described this aspect of science learning in this way:

Learning science means... learning to use this specialized conceptual language in reading and writing, in reasoning and problem solving, and in guiding practical action in the laboratory and in daily life. It means learning to communicate in the language of science and act as a member of the community of people who do so (p. 1).

Due to the complexity of the language of science, science is often times compared to a foreign language (Arons, 1983; Wellington and Osborne, 2001). Michaels *et al.* (2008) state "scientific language is, to some extent, foreign for *all* students. There are no native speakers of science" (p. 97).

Researchers have argued that learning the language of science is central to students' conceptual development and understanding (Arons, 1973; Lemke, 1990; Scott, 1992; Wellington and Osborne, 2001; Fang, 2005; Brown, 2013), success in school (Gee, 2005), scientific thinking ability (Warren *et al.*, 2001), school achievement (Beck *et al.*, 2002; Varelas *et al.*, 2002), scientific literacy (Wellington and Osborne, 2001), performance of science practices (Rosebery *et al.*, 1992; Moje *et al.*, 2001), problem solving ability (Cassels and Johnstone, 1985), and learning opportunities (Lee and Fradd, 1998; Gilbert and Yerrick, 2001; Varelas *et al.*, 2002; Brown, 2004; Brown *et al.*, 2005; Brown and Spang, 2008). However, research on language in science education has been mainly conducted at the pre-college level. Many of these studies have focused on nonmainstream students such as English Language Learners (ELLs) rather than the general population. Furthermore, too little attention has been

[a] *University of Northern Colorado – Chemistry and Biochemistry, Ross Hall 3590, Campus Box 98, Greeley, Colorado 80631, USA. E-mail: Youngjin.song@unco.edu*
[b] *Coal Ridge Middle School, Firestone, Colorado, USA*

paid to the role that language plays in learning chemistry (Pyburn *et al.*, 2013). Therefore, this study seeks to fill in these gaps by investigating the challenges learning chemistry language presents to college level students. Especially, the focus of this study is on the scientific vocabulary as ''a collection of words that are used to represent ideas'' (Brown and Ryoo, 2008, p. 531) in the context of learning chemistry even though the language of science encompasses the diverse genres of language used in academic settings.

Guiding literature

Science vocabulary

Several scholars have noted that learning the language of science is a central part of learning science as well as a huge challenge for students (Lemke, 1990; Halliday and Martin, 1993; Lee, 2001; Wellington and Osborne, 2001; Brown, 2004, 2013; Fang, 2005; Gee, 2005). In the field of chemistry, Gabel (1999) argued that the challenges students encounter in learning chemistry is more related to the way chemistry is linguistically expressed than the subject matter itself. Research conducted in the context of college-level chemistry courses has shown that the language comprehension ability is significantly correlated with various chemistry learning outcomes (Glover *et al.*, 1991; Bunce and Hutchinson, 1993; Lewis and Lewis, 2007, 2008; Pyburn *et al.*, 2013). However, these quantitative studies used Scholastic Aptitude Test (SAT) scores to measure language comprehension, rather than measures of specific chemistry language comprehension.

Within the language of science, there are different types of challenges for students among which is science vocabulary. Students are introduced to new vocabulary words in science far more than their capacity to learn new vocabulary. For instance, a typical high school chemistry text contains over 12 000 specialized science words (Yager, 1983) whereas college students can learn a total of between 3000 and 3500 new vocabulary words per year (Brandwein, 1981). Yager (1983) concluded that the amount of vocabulary words introduced in science classrooms was more than that in foreign language classrooms.

In addition to the size of scientific vocabulary, certain types of words present specific difficulties unique to science classrooms (Fang, 2005; Brown, 2013). Scholars have categorized science vocabulary in various ways to understand the intricacies of it. For instance, Snow (2008) introduced a three-tier system based on Beck *et al.* (2002). Tier-one words are the 5000–7000 most frequently used words that are taught from a very early age and make up the largest component of ordinary discourse. Vocabulary of tier-one is also referred to as ''vernacular'' language or ''lifeword'' (Gee, 1996, 2005, 2008). General academic vocabulary that is used across disciplines is considered tier-two (*e.g.*, compare). Tier-three words are vocabularies that are discipline specific and often technical in nature (*e.g.*, nucleotide). Learning tier-three vocabulary imposes on students the dual challenges of learning both new terminology and new content concurrently (Brown, 2011, 2013). Similarly, Wellington (2000) presented a taxonomy of the words of science at four levels: (1) Level 1, naming words that include the names of real objects or chemical elements (*e.g.*, trachea), (2) Level 2, process words that denote processes happening in science (*e.g.*, evaporation), (3) Level 3, concept words that represent scientific concepts of various types (*e.g.*, force), including sensory concepts, dual meanings, and theoretical constructs, and (4) Level 4, mathematical words and symbols.

Dual meaning vocabulary (DMV)

Although different tiers or levels of science vocabulary provide students with different types of difficulties, there is a set of science vocabulary that needs special attention—what we call dual meaning vocabulary (DMV) in this study. DMV refers to words that can be used in both scientific and everyday contexts. These words are some of the Level 3 words described by Wellington (2000) that have both scientific and everyday meanings. According to Snow (2008), DMV words that have a general meaning in one context and a particular technical definition in another context can belong to several tiers. Examples of DMV words include work, energy, power, salt, theory, mass, *etc.* Scholars have reported the importance and intricacy of DMV words (Eiss, 1961; Cassels and Johnstone, 1980, 1985; Donovan, 1997; Moje *et al.*, 2001; Itza-Ortiz *et al.*, 2003; Gee, 2005; Duschl *et al.*, 2007; Gabriela *et al.*, 1990; Brown and Ryoo, 2008; Brown and Spang, 2008; Snow, 2008; Jasien, 2010, 2011; Short *et al.*, 2011; Brown, 2013) although they didn't use the exact term DMV. For instance, in *Taking Science to School*, Duschl *et al.* (2007) pointed out that DMV words can perplex students because these words have science-specific meanings that differ from or even seem unrelated to their everyday meanings, or are more narrowly defined than everyday usage. With DMV words, it is possible for students to know a common, everyday meaning, but not the particular meaning in the context of science (Short *et al.*, 2011).

Vygotsky (1986) provided a rich theoretical framework for understanding how students develop different meanings of DMV words and why DMV words can be difficult for them to learn. He assumed that the meaning of a word, which is a concept, evolves in context and that everyday and scientific meanings of a word undergo different developmental pathways. Using Piaget's notion of a spontaneous concept, which is a student's self-developed mental idea of reality, Vygotsky gave the following description:

Spontaneous and scientific concepts evolve under entirely different inner and outer conditions. The relation of the child's experience to scientific concepts differs greatly from its relation to spontaneous concepts. Scientific concepts that originate in classroom instruction could not but differ from the concepts evolving in everyday life (pp. 157–158).

That is, with the same DMV word, students could have two different experiences, which in turn yield two different meanings of the word. Therefore, as they learn DMV words, students need to either switch from an everyday meaning to a scientific meaning of a word or bridge two different meanings by connecting two distinctive experiences to these meanings. Gee (2005) echoed Vygotsky's idea by proposing *situated meanings* of words, which means the meaning of a specific word ties to one's specific experience of the world at a given place and time.

The empirical research on DMV words is currently at an early stage in the area of Chemistry, especially at the college level, though anecdotal papers in science can be found as early as the 1960's. Eiss (1961) described possible challenges that could be caused by differences in word meanings among the various fields of science (*e.g.*, the different meaning of *weight* in Physics and Biology). In the 1980's, Cassels and Johnstone (1980, 1985) chose 95 non-technical words that are used in everyday and scientific situations to investigate the comprehension ability of secondary students in the U.K. Their collection of words were mostly tier-two words (*e.g.*, effect, classify) rather than DMV words as defined in our study, but their work provides a useful insight.

Chemistry education researchers began to document issues with DMV words in the 1990's. In the qualitative study of 14 fourth-year undergraduate students, Gabriela and co-workers (1990) investigated how the everyday meaning and chemical meaning of the words *reaction* and *spontaneous* appeared in their understanding. They concluded that the students preferred to select familiar everyday meanings rather than abstract, difficult, and unfamiliar chemical meanings when they were confronted with a new context to apply the chemistry meanings they had been taught. The latest studies with the DMV words *dense, energy, strong, and neutral* reported that college students were able to identify the colloquial meaning of the words but had issues with distinguishing between the everyday meaning and the scientific meaning of the words (Jasien and Oberem, 2008; Jasien, 2010, 2011). Similar findings were reported with the DMV words *force, momentum, and impulse* in Physics (Itza-Ortiz *et al.*, 2003).

All of the above studies came to the same conclusion: everyday meanings of DMV that students bring into the classrooms are barriers to their learning. However, a few studies have attempted to examine how instruction—whether it is traditional or interventional—influences students' learning of DMV or why students find it so difficult to adjust or expand their understanding to accurately accommodate the scientific meaning of DMV. Understanding to what extent new scientific meanings of DMV words are retained or how everyday meanings continuously affect students' thinking of chemistry concepts provide valuable implications for teaching chemistry. Retaining scientific meanings does not mean memorizing a verbal or definitional meaning of DMV but rather understanding DMV words conceptually. This perspective is supported by functional logisticians who argue that learning science is identical to learning the language of science (Christie, 1989; Halliday and Martin, 1993; Wellington and Osborne, 2001; Schleppegrell, 2004; Fang, 2005). Gee (2005) explicitly mentioned that understanding a set of verbal definitions or general meanings of scientific words is not useful for students engaging in scientific practices using a specialized science language. That is, students need to adopt scientific meanings of DMV words for their own use and understanding in the scientific context (Bakhtin, 1981; Rosebery *et al.*, 1992), which is one of the foci of our study.

Research questions

Our work tries to build on current research on the role of language in learning chemistry. In addition, it contributes towards the limited volume of research currently available on DMV in Chemistry at the college level in chemical education literature. The following research questions guided this study:

(1) What are the college students' initial understandings of DMV words before being introduced to the scientific meanings? What are the original sources of their initial meanings of DMV words?

(2) How do college students change their everyday initial meanings of DMV words after instruction? To what extent do college students retain the scientific meanings of DMV words?

(3) What kinds of challenges do college students encounter when they learn DMV words in chemistry?

Research methods

Research context

A qualitative study approach (Patton, 2002) was used to answer the research questions. The research was conducted at a university located in the Rocky Mountain region of the United States, which has approximately 12 000 undergraduate students. The population of the institution consisted of 62% female, 38% male, and 15% minority students at the time of the study. The chemistry course chosen for this study was *Fundamentals in Biochemistry*, denoted as CHEM 281, which is a five credit course offered in the traditional semester system. The class met four times a week for a 50 minute lecture and once a week for a three-hour laboratory. The course was broken into three roughly equal sections covering general chemistry (GC), organic chemistry (OC), and biochemistry (BC) and is conventionally known as a GOB class. We purposefully chose this class because it is primarily taken by non-science majors, who are either pre-nursing, pre-health, or sports and exercise science students. It was necessary to find a course for non-science majors in which students have had limited chemistry background because it is possible that students with a chemistry/science background may have already developed understanding of scientific meanings of DMV words.

The same instructor (neither of the authors) taught two sections of the course, so as much as possible, instructor and class subject material variance was eliminated. The course was primarily taught through lecture, with the laboratory providing practical application of the concepts learned in class. New vocabulary was presented within the context of the concepts being taught and real world examples of it were discussed. According to the instructor, students were not necessarily tested on memorizing the definition of vocabulary, but were expected to know how it applies to a concept and to use it appropriately in the context of course work. The textbook used in the course was *General, Organic, and Biological Chemistry* by Stoker (2008).

Participants

A purposeful sampling approach was used in selecting participants (Patton, 2002). Students were solicited for participation

Table 1 Number of students and their chemistry experiences

Chemistry experiences	Number of students (N = 13)
High school chemistry only	5
High school chemistry and CHEM 103[a]	6
High school chemistry and CHEM 111[b]	1
CHEM 103[a] and CHEM 111[b]	1

[a] CHEM 103 is a basic non-lab chemistry course designed for students with limited chemistry background. It most often serves as a preparatory course for the CHEM 281 or CHEM 111. [b] CHEM 111 is the first semester of general chemistry.

the first day of class. Of the 150 students petitioned, 63 signed the informed consent documents approved by the Institutional Review Board at the first author's institution and were given a short questionnaire to ascertain their chemistry experience. Based on their answers to the questionnaire, 30 students were selected to obtain a range of chemistry experiences. Eighteen students (16 females and 2 males) replied to the request for interviews and chose to participate in the first interview. Thirteen of the 18 finished the study and only their results are presented in this paper. All 13 students finishing the research were females. A breakdown of participating students' chemistry experiences is shown in Table 1. All of them had a year or less of both high school and college chemistry experiences at the time of this study. For confidentiality, each participant was given a number as an identifier, therefore Student 1 would be denoted as S1.

DMV selection

An initial list of DMV words was developed based on college students' suggestions. Students not associated with the research project in the CHEM 281 during the previous semester of this study were asked to develop their own list of chemistry words that were confusing due to the dual meanings. These DMV words were tabulated and the chemistry education research group at the institution, consisting of graduate students and professors, downscaled the number of words. Then, the second author and two course instructors analyzed the list and chose DMV words for the study based on three criteria: (1) words that are repeatedly identified as difficult by the students, (2) words that are considered challenging for students' conceptual understanding by the instructors, and (3) words that could be frequently used in an everyday context. As a result, eleven DMV words were selected for the study, six from general chemistry and five from organic chemistry. The general chemistry DMV included: *solution*, *polar*, *compound, electrolyte, base*, and, *salt*. The organic chemistry vocabulary words were: *reduction*, *sugar*, *organic*, *aromatic*, and *alcohol*. The selected DMV words and their definitions used to compare with student responses are shown in Table 2.

Data collection

The major source of the data was in-depth interviews (Patton, 2002) with each participant in a one-on-one environment. We used semi-structured interviews, that is, developed an interview protocol with pre-established questions (Appendix 1), but also asked follow-up or clarification questions if a participant's answers were unclear. When interviewed, students were shown the vocabulary word on a flashcard as well as read the word. Students were also furnished with a piece of paper and a pen. They were instructed that they could either provide the meaning of the word orally or draw to represent it if they found drawing easier. The drawing provided the students with an opportunity to express their understanding in multiple ways. This increased the trustworthiness of the study by adding data triangulation described in Lincoln and Guba (1985) and Patton (2002).

Throughout the semester we conducted three interviews. The first interview (I1) consisted of DMV from general chemistry (GC) and was completed in the first week of school in an effort to interview students about the DMV before it had been introduced in class (pre-instruction interview). The second interview (I2) was conducted after their first exam on general chemistry and included four of the DMV from general chemistry (post-instruction interview) and the new organic chemistry (OC) DVM (pre-instruction interview). The third interview (I3) pertained to organic DMV (post-instruction interview) and the two of general chemistry

Table 2 Selected DMV along with the scientific definitions

Dual meaning vocabulary words	Scientific definition[a]
Solution	A homogeneous mixture of two or more substances with each substance retaining its own chemical identity
Polar (molecule)	A molecule where there is an unsymmetrical distribution of electron charge
Compound	A pure substance that can be broken down into two or more simpler pure substances
Electrolyte	A substance whose aqueous solution conducts electricity
Base	A substance that can accept a proton (H+)
Salt	An ionic compound containing a metal and nonmetal
Reduction	A decrease in oxidation number of an atom or molecule
Sugar	A general designation for either a monosaccharide or disaccharide
Organic (compound)	Compounds that contain both carbon and hydrogen
Aromatic (hydrocarbon)	The molecular structure of which incorporates one or more planar sets of six carbon atoms that are connected by delocalized electrons numbering the same as if they consisted of alternating single and double covalent bonds. After the simplest possible aromatic hydrocarbon, benzene, such a configuration of six carbon atoms is known as a benzene ring
Alcohol	A hydrogen replaced by a hydroxyl group (–OH)

[a] All definitions were taken from the CHEM 281 textbook (Stoker, 2008).

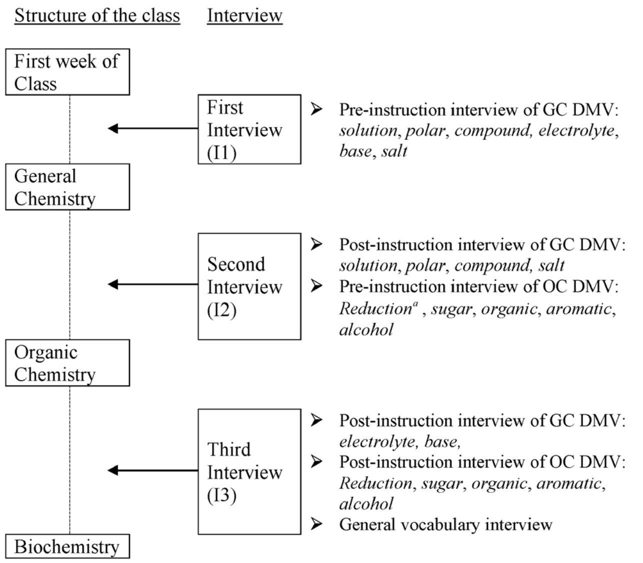

Fig. 1 A graphic overview of the data collection procedures. [a] Students were introduced to the word *reduction* in class two days prior to their interview, so there was no pre-interview about this word.

DMV (post-instruction interview) that had not been covered in class when the second interview was conducted. In the third interview, participants were also asked general vocabulary questions, such as what the major challenges were in learning the DMV and how they studied new science vocabulary including the DMV. All students' interviews were recorded using a digital audio recorder and then transcribed verbatim. Fig. 1 shows the order in which the course was taught, the timeline of interviews and the DMV words that participants were asked about for each interview.

Data analysis

After all interviews were transcribed verbatim, we analyzed students' responses by inductive analysis utilizing a grounded theory approach (Charmaz, 2000, 2002) and constant comparative methods (Glaser and Strauss, 1967) in order to generate themes. We conducted a single case analysis first, that is, analyzed each interview transcription with each participant. Then, cross-case analysis (Merriam, 1998; Patton, 2002) was conducted in search of themes that cut across all participants for each DMV. Both authors discussed all the themes emerging from data until a consensus was reached for investigator triangulation, which built the credibility of our qualitative research (Denzin, 1978).

Students' explanations of the scientific meaning of the DMV were coded for correctness in order to understand to what extent they retained it after instruction. The scientific meaning given by the students was deemed "correct" if it incorporated elements of the definitions given in Table 2. If students could give correct examples but could not provide a correct scientific meaning or reason for the example, the answers were regarded as incorrect. Likewise if a student gave the correct definition, but then an incorrect example their answer was categorized as incorrect.

Students' scientific meanings were also categorized as to whether their explanations included the application of scientific meanings to everyday contexts. Explanations of how the scientific meaning was different or contradicted everyday meaning or usage were included in this category. Also included were answers where students provided an everyday example to further illustrate the scientific meaning. However, when students were unable to provide the scientific meanings or explain their everyday example, those answers were not included.

Research findings

We demonstrate our findings along with three themes with respect to the research questions. Distinctive excerpts from the interviews were selected to illustrate the themes in depth.

Theme 1: most college students provided everyday meanings of the DMV before instruction

Before students were introduced to the DMV in the classroom, they most often defined the DMV by its colloquial or everyday meaning. For example, one student's spontaneous response to the word *base* was "the bottom, like a podium or stand" (S10, I1). Another student replied that *base* was a "...home base or a military base" (S6, I1). When asked about the words *salt*, *sugar*, *organic*, and *alcohol* most students at first came up with the foods associated with those words: Student 5 mentioned *salt* as "stuff you put on your food" (S5, I1); Student 1 described *sugar* as "candy, or the stuff I bake with" (S1, I2); Student 7 said of *organic* was "vegetables and stuff that is grown without fertilizers" (S9, I2); and Student 12 provided the everyday meaning of *alcohol* such as "beverages, like beer and wine" (S12, I2). All of these meanings pertained to how the DMV was used in the student's normal activities and daily conversations. Table 3 shows representative samples of original meanings participants provided when asked what would be the meanings of the DMV words when they heard or read them, most often pertaining to everyday meanings.

Prior to classroom instruction, many students did not have a scientific meaning for the DMV or could only say it was related to science. Participants would provide "NaCl" (S3, I1) as an example of a *salt*, but could not explain why it was an example of *salt* or the scientific meaning of a *salt*. When asked what *alcohol* means in its scientific context, one student said "it's like fermentation or whatever, that goes along with that." (S4, I2). While fermentation produces *alcohol* the student could not describe the process or what was being converted to *alcohol*. Likewise, when students were asked about *base* in the scientific context, they often replied, "I think of *acids* and *bases*, like reacting" (S8, I1) without further scientific explanations.

The following interview excerpt about the word *base* reveals the student brought everyday meaning of the DMV and did not have scientific meaning although the terms *acids* and *bases* were mentioned.

R: What do you think of when you read or hear the word *base*?

S2: I think of like, basement, like the bottom of something, its *base*.

Table 3 Representative examples of students' initial meaning of the DMV words

DVM words	Students' initial meanings
Solution	"Answer to a problem." (S7, I1) "In a bottle." (S8, I1)
Polar (molecule)	"Cold, I think of a polar bear." (S7, I1)
Compound	"I think of like a compound sentence." (S13, I1) "I would think of something that is like, added together, and like there's like, something is made bigger" (S5, I1)
Electrolyte	"I think of like athletes that need electrolytes and that they are in Gatorade®." (S5, I1) "Like electrolyte, like Gatorade® and Powerade® and stuff." (S8, I1)
Base	"... a base in baseball." (S5, I1) "Like a starting point, like a base or platform." (S8, I1)
Salt	"Salt, like salt that you put on your food." (S11, I1) "Like stuff you put on your food." (S5, I1)
Sugar	"I think of table sugar, sugar that I put in my cereal." (S5, I2) "I automatically think of the food, like candy, or the stuff I bake with." (S1, I2)
Organic	"Healthier, because I think of organic food... because they talk about it all the time on T.V. Try, try organic food, it is healthier for you, and I think more expensive." (S12, I2) "...like organic foods that don't have processing, or don't have like any sprays sprayed on them, like fruits that don't have anything put on them, they are just grown naturally." (S7, I2)
Aromatic (hydrocarbon)	"I don't even know, I guess aroma, like a smell." (S6, I2) "Candles... because candles generally smell good, they give off nice aromas." (S2, I2) "Airplanes...because it has *aro* in it and that is like aerial, like air, yeah." (S7, I2)
Alcohol	"Drinks." (S8, I2) "Either rubbing alcohol or drinking alcohol." (S13, I2) "People getting drunk." (S2, I2)

R: Why do you think of that?

S2: Cause that is like what you learn first – top and bottom – like *base*.

...

R: When you think of this word in reference to science, does this word have a different meaning?

S2: Yes, like acids and bases and like lower bases are on bottoms, no, you can't help me can you? Well whatever, one is on top or bottom, it is the opposite of acidity (S2, I1).

The student knew the scientific vocabulary *acids* and *bases*, but could not provide the scientific meaning of a *base.* She only mentioned it as the opposite of an acid. Furthermore, the student applied the everyday meaning to the scientific concept. That is, she associated the everyday meaning of a base as the low point of something on the pH scale by mentioning "like lower *bases* are on bottoms." Many students' responses utilized their everyday meanings and understanding of the words when explaining the DMV's meaning in a scientific context, although the everyday meanings often do not correspond to scientific meanings.

Our inquiry about where and when the students learned their everyday meanings of the DMV words revealed that they developed these ordinary meanings at an early age. For instance, Student 2 associated the experiences of the family with the vocabulary *alcohol*: "Because that is like the alcohol you are raised with, like if your parents drink, they drink alcohol, they are not performing experiments with it" (S2, I2). Likewise, when asked where they learned the meaning of *salt*, one student said, "I guess hearing it growing up, like when we're having dinner." (S6, I1). Sample responses of where and when the students learned their initial meanings of the DMV words are presented in Table 4.

In summary, it was clear that the everyday meanings of the selected DMV words were perceptually dominated in these college students' thinking before they were introduced to the scientific meanings of the DMV. The fact that the everyday meaning of the DMV was learned at a young age and deeply associated with students' personal experiences provided the students with an opportunity to apply a known everyday meaning of the DMV into their working meaning when presented within scientific contexts. The challenge for teaching chemistry then is how such everyday meanings of DMV could serve as a foundation for students' learning the chemistry meaning of the DMV.

Theme 2: most college students immediately provided everyday meanings of the DMV and did not retain the scientific meanings of the DMV after instruction

In order to investigate how traditional lecture-based instruction had an impact on students' learning of the scientific meanings of the DMV, students were asked what came to their mind when hearing/reading the DMV after chemistry course presentation and concept examination. Students' instantaneous responses showed that most of their responsive meanings were again everyday meanings of the DMV. For instance, when asked about *aromatic*, one student said, "I think of something that has a smell associated with it" (S10, I3). Moreover, many students were unable to provide correct scientific meanings and substituted or modified their everyday meanings to fit an incomplete understanding of the scientific concept.

The following interview about the word *sugar* illustrates this tendency.

R: What do you think of when you read or hear the word *sugar*?

S11: I think of sweet, cooking.

R: Has the meaning changed for you since learning about it in class?

Table 4 Sources of students' everyday meanings of the DMV words

DVM words	Sources of students' everyday meanings
Solution	"6th or 5th grade when solving math problems." (S2, I1) "Elementary school, when learning math." (S13, I1)
Polar (molecule)	"In class as a kid and books like Polar Express" (S2, I1)
Compound	"I don't know if that is the real meaning, I think I made it up, but maybe science or math class in high school or middle school." (S5, I1)
Electrolyte	"I was on a soccer team for many years, and he says: "to do better in soccer drink more electrolytes and Gatorade®." Or if I am sick or have a fever, my mom always says stay hydrated, drink electrolytes." (S9, I1)
Base	"I don't know how long, it's just part of my vocabulary." (S9, I1) "I guess, just watching baseball or like in P.E. in like second grade." (S5, I1)
Salt	"Probably at the house, when I was putting salt on food." (S5, I1) "At the dinner table, like please pass the salt or salt tastes really good on these mashed potatoes." (S12, I1)
Reduction	"Elementary school." (S5, I2)
Sugar	"Just from like, young, like in cooking." (S6, I2) "Probably when I was little and my mom, like, baked stuff and put sugar in it." (S2, I2)
Organic	"Probably when I was growing up doing the shopping." (S8, I2)
Aromatic (hydrocarbon)	"Commercial, on T.V. it said it was very aromatic." (S9, I2)
Alcohol	"Because it is used everywhere, like on T.V. and in my family, like my dad's side of the family and some of my friends talk about it." (S12, I2) "Cuz, I guess growing up you just learn that alcohol is what you drink." (S8, I2)

S11: Well, it could be used for like a chemical equation and it can be like broken down.

R: What can it be broken down into?

S11: I don't know what, I just know it can be broken down to probably simpler molecules maybe. You could probably add stuff too.

R: Do you think of any types of *sugar*s?

S11: Yeah, but I don't remember any of them.

R: Do you associate any formulas with *sugar*?

S11: Hmmm, um.

R: Do you struggle with this scientific meaning?

S11: Yeah.

...

R: Which meaning do you rely on?

S11: More on the chemical or molecular level (S11, I3).

This student acknowledged she struggled with the scientific meaning of the word *sugar*: she was not able to provide a scientific explanation of the dissociation of *sugar* although she had a vague idea. The molecular formula or structure of sugar was not even in her conceptual understanding. The tendency of immediately providing the everyday meanings with the DMV words was present in all participants even though the scientific meanings had recently been covered in the class. Table 5 presents the examples of students' responsive meanings for all DMV words given during the post-instruction interviews.

Occasionally, students tried to respond to DMV with the scientific meanings or examples instead of their everyday meanings with the help of the researcher's probing questions. However, in this case, they often provided incorrect scientific meanings of the DMV words. For instance, many students gave H_2O as an example of a *polar* molecule, but then incorrectly explained what made water *polar*, such as Student 4: "I know that these, the hydrogen have a positive and the oxygen has a negative, so when the hydrogen is more attracted to the oxygen causing it to be *polar*" (S4, I2). When queried about what is being drawn to the oxygen, she pointed out the hydrogen atom instead of electrons. She had the idea about partially charged atoms in the water molecule, but incorrectly explained why the

Table 5 Representative examples of students' responsive meanings of the DMV words after instruction

DVM Words	Students' responsive meanings
Solution	"Two liquids mixed together." (S8, I2) "The answer." (S10, I2)
Polar (molecule)	"Polar Bear" (S2, I2) "I can think of the north and south poles, which are polar."(S10, I2)
Compound	"Like a car compound, or something, like an enclosed area." (S8, I2)
Electrolyte	"Like a Gatorade® drink, kind of thing, or replenishing electrolytes." (S8, I3)
Base	"Something that is low in pH and then I also think of a base like a platform." (S10, I3) "I immediately thought of baseball, because it is going on right now, it is all over the T.V." (S13, I3)
Salt	"Table Salt." (S9, I2)
Reduction	"Like reducing or minimizing." (S4, I3) "A reduction reaction, taking something away, like when you are given a formula." (S13, I3)
Sugar	"Candy." (S8, I3) "Sweets, because sugar is something that is used to bake with." (S4, I3)
Organic	"Yeah, there could be like organic food." (S4, I3) "Whole Foods® and how their store is all organic products." (S13, I3)
Aromatic (hydrocarbon)	"Like candles burning or incense." (S8, I3)
Alcohol	"Drinks." (S8, I3)

charges occur. Likewise, students were able to give examples of *salt* (*e.g.*, NaCl), but then were unable to define or explain why their example was a salt. The DMV *base* posed a different challenge. Students were often able to tell the researcher that *bases* are at the upper end of the pH scale and would identify NaOH as a *base*, but could not actually provide the scientific meaning of a *base* as a hydrogen acceptor or determine what part of NaOH was the *base*. All these incorrect scientific meanings of the DMV words are presented in Table 6.

In addition, Table 6 includes correct scientific meanings given by the students. This information provides readers an indication of how student responses were classified as either correct or incorrect. Based on the number of students who retained the correct scientific meanings of the DMV words after being introduced to them, we calculated the retention rate for each DMV. Five DMV words that had low retention rates were *polar, electrolyte, base, salt*, and *aromatic.* For these words, less than 31% of students retained the correct scientific meanings. Two DMV, *reduction* and *sugar*, had correct scientific retention rates of 54%, while only four had high retention rates of above 69%, *solution, compound, organic*, and *alcohol*.

One of the interesting findings was that many students stated they did not struggle with understanding of the scientific meanings of the DMV even though they were not able to provide/retain the scientific meanings. In addition, when asked which meanings they relied on, most declared the scientific connotation although they often could not provide the correct meanings. For instance, 12 students indicated no issues with the scientific meaning of the word *salt*, but all of them provided incorrect meanings. Furthermore, five of those 12 students declared that they relied on the scientific meaning of *salt* when it was used in class. This informs that all five students relied on incorrect scientific meanings.

The following interview excerpt about the word *organic* provides a good example.

R: What do you think of when you read or hear the word *organic*?

S13: Whole Foods® and how their store is all *organic* products.

Table 6 Representative examples of students' scientific meanings of the DMV words and retention rate after instruction

DVM words	Incorrect scientific meanings	Correct scientific meanings	RR[a] (%)
Solution	"I think of solution and solute. When you add a solution to a mixture to get a solute" (S12, I2)	"That a *solution* is a homogeneous mixture. That the entire *solution* is transparent, that there is no evidence of any particles in it." (S10, I2)	84.6
Polar (molecule)	"Well I know that these, the hydrogen have a positive and the oxygen has a negative, so when the hydrogen is more attracted to the oxygen causing it to be *polar*." (S4, I2)	"It is the type of bond that happens if one molecule is pulling the other one's electrons towards it with its electronegativity... [oxygen] has a higher electronegativity than hydrogen, so it is, like, pulling the hydrogen's electrons towards it." (S2, I2)	30.8
Compound	"I just think of the phrase compound molecules, I don't know." (S6, I2)	"Now it is like, like the forming up of two elements, like water or something." (S8, I2)	69.2
Electrolyte	"I still don't really understand *electrolyte*s all that well, just that they are needed in the body and they, yeah..." (S4, I3)	None[b]	0
Base	"I don't know how to explain it. There is just acidic, basic, and neutral *solution*s. I don't know how to explain it." (S3, I3)	"...[B]ecause NaOH is a base, I think, and OH can accept a hydrogen, so it is an acceptor." (S5, I3)	23.1
Salt	"Now more I think of NaCl, not just table *salt*, more like chemical *compounds*, I guess." (S6, I2)	None[c]	0
Reduction	"A *reduction* reaction, where you reduce, but that is the same word. In a chemical reaction when something is removed from the reaction." (S3, I3)	"Yeah, like when we are doing reactions, like the gain of electrons." (S9, I3)	53.8
Sugar	"Yeah, I don't know... It is, well I know there is a hydroxyl group, yeah... I don't really see a formula." (S4, I3)	"Just the different types of sugars: glucose, fructose, glutamine, yeah, all the different ones... I see glucose $C_6H_{12}O_6$." (S7, I3)	53.8
Organic	"I know that we are talking about organic chemistry right now, but I am not really, I don't think I do [have a scientific meaning]." (S6, I3)	"I think it is, like, mostly like carbon, hydrogen, oxygen, nitrogen, and sulfur maybe, I think those are like the main components of organic chemistry and saturated and unsaturated parts." (S5, I3)	69.2
Aromatic (hydrocarbon)	"I am still shaky on it, but we were learning about like aromatic amines and the different smells of them. And then in lab we did stuff with butanoic acid and I definitely remembered aromatic because it smelled really bad... I think of an amine, I am not even sure it is an amide or amine, like NH_2." (S9, I3)	"It is an aromatic ring, which is a benzene ring I think. It is carbons and hydrogens and it is almost 3 bonds but not really, it is like 2.5." (S2, I3)	15.4
Alcohol	"There is different compounds and such that contain alcohol... I don't know, well usually if it is an alcohol it will have an *ol* at the end of the each word, like butanol, and triglycerol, well something like that. Methanol, ethanol, just stuff like that." (S12, I3)	"It is something people drink, but more scientifically it is a hydroxyl group connected to a carbon." (S4, I3)	76.9

[a] RR = retention rate. [b] Respondents could give examples of electrolytes such as magnesium and potassium, but could not explain what they were. [c] Nearly all students could give NaCl as an example of *salt*, but no student could explain why NaCl was a *salt*.

R: What does that mean?

S13: All natural and no chemicals.

R: Where did you learn that?

S13: Through ads or going green.

R: Has the meaning changed for you since learning about it in class?

S13: Yes, just that, well kind of, it is all like *organic* is all natural. Just has a different meaning in a sense that it is more like carbohydrates and proteins and stuff in chemistry, more than I think about going green or *organic* in the store.

R: Do you associate any formulas with it?

S13: Not really, no.

R: Do you struggle with this scientific meaning?

S13: Not too much.

R: Which definition do you rely on?

S13: Probably like in class, which do I rely on? The chemistry term of it being all natural, well shoot, I can't explain, just like the carbohydrates is what I think of (S13, I3).

Again, Student 13 responded to the word *organic* with the everyday meaning at first. The researcher tried to induce the scientific meaning of it, but the everyday meaning was so dominant in her thinking. She considered her everyday meaning of *organic* as being as correct as a scientific meaning and thus believed there was no issue. Furthermore, she mentioned that she relied on this incorrect scientific meaning in the scientific context. The interview segment above with Student 11 regarding the word *sugar* also illustrates the same trend.

Taken together, the college students in this study immediately responded to the DMV words with their familiar, everyday meanings even after learning the scientific meanings of them in class. The average retention rate of the selected DMV words for correct scientific meanings was 43%. With the help of the researcher, the students sometimes made an effort to provide the scientific meanings of DMV, which were incorrect in many cases. Moreover, they seemed to rely on their incorrect meanings of DMV words in the scientific context.

Theme 3: the challenges the college students encountered in learning the DMV were related to the infrequent usage of it, their study habits, and the lack of prior knowledge of other scientific vocabulary

One of the challenges that the students mentioned in learning and retaining the scientific meanings of the DMV words were that they didn't have many opportunities to use them in scientific contexts. For instance, all participants had difficulty with understanding the concept of electrolyte, which had a zero retention rate. The reason many students cited for their struggle with the word was the lack of the amount of class time spent on the DMV: ''We just talked about it [*electrolyte*] briefly'' (S3, I3); ''Just because it [*electrolyte*] wasn't talked about a whole lot in class'' (S5, I3). The students had little opportunity to engage in discussion about how the DMV works to represent a scientific meaning in chemistry. They further believed that understanding the DMV that was not frequently used in class was not critical to learning chemistry: ''I think it was more of a side point and not a big focus'' (S1, I3).

Students also described having difficulties with learning the scientific meanings of DMV because they did not use the scientific definitions in their everyday discourse. This aspect is presented in the interview with Student 9:

When you learn English words there is more of a chance that it comes up in conversation, so it kind of solidifies it. In chemistry unless I am in a study group or in class, usually it won't happen because like when I call my mom, she is not going to mention it (S9, I3).

She identified her lack of using the scientific meanings of the DMV outside of the chemistry classroom to be a major challenge in retaining the scientific meanings and why general English vocabulary is easier to learn than science vocabulary. Another student echoed this aspect by mentioning ''With chemistry, a lot of definitions go with like molecules and formulas, and when you are studying for just regular English vocabulary, you can relate it to a sentence that is more relative to you'' (S11, I3). Infrequent use of the DMV words in everyday contexts caused students to perceive that science is not relevant outside the classroom. However, some students pointed out the importance of application of DMV to their life in learning those words. That is, they considered that learning DMV could be easier if they were able to make a connection between the DMV and their everyday life: ''It [difficulty with learning the DMV] depends if they [DMV words] are related to the outside world or not'' (S10, I3).

The fact that the scientific meanings of the DMV were not used by the students both in chemistry class and everyday context had an impact on students' study habit, which gave rise to another challenge in learning the DMV. When asked how they studied new chemistry vocabulary including the DMV, 11 of the 13 participants answered that they made flashcards or knew they should make flashcards. In addition, there was a tendency that students only studied the DMV and other vocabularies for an exam or quiz. The following interview exemplifies this tendency.

R: How do you usually study [new vocabularies]?

S6: Usually with flash cards. And then, yeah, I will do flash cards.

R: How do you study flashcards?

S6: I will put the word on the first side and the definition on the other and then look at the words and try to say the definition.

R: Do you ever go backwards, so you read the definition and try to determine the word?

S6: Sometimes, usually, I will study them with just the word and tell what the definition is and like later, the night before the test I will flip them.

R: Do you do structures and formulas the same way?

S6: Yeah, for the exam I did flashcards and I did the structure on one side and what it was on the front. I mixed those up, so some would have the structure on the back and the word on the front.

R: Was this effective?

S6: It was effective when it came to the test, but like now, I don't know – remember – any of them.

R: Do you think your understanding of later material would increase if you retained those scientific meanings?

S6: I think so, because we still work with a lot of those [vocabularies] and are still using them now. I don't remember them, and [instructor] will say write down certain things and I always get confused, if it is one function group or the other. Like if I need a hydroxyl group drawn on it, or whatever, I just always forget which one is which (S6, I3).

This excerpt clearly shows that she used a rote memorization technique as a means to study the DMV without conceptually understanding it. The student acknowledged that her method was not useful for retaining the scientific meanings but only effective for memorizing definitions or structures for a limited time. Throughout the interviews, most students provided evidence that they stored the scientific definitions of the DMV only for a test, which they easily forgot. Another student who struggled with the scientific meaning of the DMV *aromatic* stated,

Once I learn the definition and everything, this sounds bad, but once I learn the definition, well I cram, but I study it all the way up until the exam, but once the exam is over, then I kind of just forget it and move onto the next stuff that we are learning. And so, this [*aromatic*] was like over a month ago, so it is like long gone (S8, I3).

Some of the students did not even make an effort to understand the scientific meaning of the DMV if it was not expected to be tested on the exam: ''Because it [*electrolyte*] wasn't a focus on the test, so it got pushed to the wayside'' (S2, I3).

The last challenge in learning the DMV words was that students didn't have enough prior knowledge of other science vocabularies to explain what the DMV means. For instance, many students mentioned that water was *polar* because either the oxygen or the hydrogen was more electronegative, but then could not explain the meaning of electronegativity or identify that it is the electrons within the bond that are pulled towards the oxygen. Similarly, some students expressed concerns when they discussed *solutions* because they could not remember what solute or solvent meant, such as in Student 5 dialogue: ''I think that I got, but solvent and solute are confused, so I didn't know what was being mixed'' (S5, I2). Often times, many scientific vocabularies are defined by using other scientific terminology. Thus, when they didn't fully understand the scientific meaning of a certain term associated with the DMV words, students created incorrect scientific meanings of the DMV. In the same vein, if the students did not conceptually understand the scientific meaning of the DMV, they apply these words to more complex concepts or meanings of related vocabularies.

In summary, the college students considered the infrequent use of the DMV both in the classroom and everyday life as one of the main challenges in learning and retaining the scientific meaning. Being frustrated by not seeing the DMV utilized in a meaningful context, students then relied on rote learning—memorizing the definitions, structures, or formulae of the DMV—which was detrimental for their conceptual understanding. In addition, students' prior understanding of other science vocabularies was identified as an important factor, which can anchor the scientific meanings of the DMV.

Discussion and conclusion

Understanding the scientific meanings of DMV and the ability to use them appropriately in scientific contexts are critical in learning chemistry. However, as we have shown in this study, the college students' instantaneous meanings of the selected DMV words were predominantly everyday meanings before and even after instruction. Our findings are similar to the conclusions by other research studies that demonstrated students' tendency to select familiar everyday meanings over chemical meanings of DMV and their struggle to contextualize the scientific meanings of DMV (Gabriela *et al.*, 1990; Itza-Ortiz *et al.*, 2003; Jasien and Oberem, 2008; Jasien, 2010, 2011). This is not surprising in that people develop ''vernacular'' language (Gee, 1996, 2005, 2008) to describe phenomena in their lives as they experience them from early years (Sapir, 1949). People create and store the meanings of vocabulary not in a form of proposition but in a form of images or representations of experiences including perceptions, feelings, attitudes, and actions. On this account of *situated meanings* of words (Gee, 2005), students at the college level had already developed the everyday meanings of DMV based upon their personal experiences, which served as a foundation for the use of DMV at first. The students pointed out that it was hard to overlook the everyday meanings of DMV: ''I just got stuck on my original [meaning]'' (S9, I3); ''I naturally think of the other [everyday] meaning first and that makes it harder to think of the chemistry meaning'' (S3, I3).

Due to the everyday meanings that were deeply rooted in their thinking, students often times equated the everyday meanings of DMV with the scientific meanings of it as shown in the example of the DMV *base*. It was believed that *bases* are placed at a lower level in the pH scale because the everyday meaning of base refers to a low point in daily context. This tendency was observed in the study of college students' understanding of solution chemistry concepts, which reported that half of the students associated the *strong acid HCl* with the concept of a molecule that did not dissociate because of the everyday meaning of the term *strong* (Smith and Metz, 1996). Furthermore, students were not able to retain the correct scientific meanings of the DMV even after instruction and relied on inaccurate meanings of it. Brown (2013) pointed out ''without transitioning from a vernacular understanding toward a discourse rich in science terminology, students would only develop partial understandings'' (p. 231). We could conclude that there was no appropriate transition from the everyday meanings to the scientific meanings of DMV in our students' thinking, which yielded low retention rates. This may have a chain effect because if students relied on a partial, incorrect understanding of the DMV, this initial misconception may propagate into other alternative concepts in learning the new vocabulary later. These findings suggest that it is imperative for a chemistry course instructor to design a specific intervention with DMV in order for students to be able to make a transition from the everyday meanings to the scientific meanings, such as contrasting two meanings of DMV in different contexts.

Our analysis provides evidence that everyday meanings of DMV words continuously affected students thinking of chemistry concepts after instruction. It is true that everyday meanings of DMV could cause misconceptions or hinder students' understanding of chemistry concepts. This view actually reflects one academic tradition in investigating the relationship between everyday and scientific language and understanding—students' everyday meanings and ways of using language differ from those of science (Warren *et al.*, 2001). On the other hand, the findings of this study present a possibility to consider students' everyday meanings and ways of using language as linguistic resources for their understanding of chemistry concepts, which is the other tradition surrounding the issue of scientific language (Warren *et al.*, 2001). Although it was not a major theme in our study, two of the students used everyday language to explain the scientific meanings of DMV. For instance, Student 2 described a *solution* in this way: "It's even all the way throughout and parts of it are equal, like you can't tell the difference between, like there is salt and water, and it just looks like water" (S2, I2). We considered her response as a correct scientific meaning even though she didn't use the scientific terminology *homogeneous mixture*. It was clear that she understood the concept of a homogenous mixture by saying, "It's even all the way throughout and parts of it are equal."

Scholars in the science education community have proposed the perspective of framing students' everyday language as an asset instead of a deficit lately (Lemke, 1990; Rosebery *et al.*, 1992; Moje *et al.*, 2001; Warren *et al.*, 2001; Varelas *et al.*, 2002; Brown, 2004, 2006, 2011, 2013; Brown and Ryoo, 2008; Brown and Spang, 2008; Gee, 2008; Brown *et al.*, 2010; Hsu and Roth, 2012). With this view, science teaching and learning is considered as a constant process in which both everyday and scientific language play important roles because the science concepts learned the best are explained in ordinary colloquial language used by students. One of the recommendations is to use students' everyday language initially to teach the main ideas of science content and then teach the scientific vocabularies. For instance, Brown and Ryoo (2008) examined students' linguistic and conceptual understanding of photosynthesis by using web-based software with a "content-first" approach. They found that students retained the vocabulary and concepts better when the scientific meanings were first introduced with students' everyday language before teaching scientific terms. These researchers later elaborated this approach and developed the *Disaggregate Instruction* model in which teaching a conceptual part and a science language part is separated (Brown *et al.*, 2010). This perspective provides implications for college science instructors although it has been empirically tested only at the elementary and secondary levels so far because it will be equally beneficial for college students. College science instructors need to make an attempt to bridge students' everyday language and meanings with those of science by paying particular attention to students' use of everyday language that could provide insightful explanations of the physical phenomena. Gee (2008) emphasized the role of students' everyday language in successful learning by mentioning, "Failing to build on students' conversational dialects is a recipe for destroying their interest in and affiliation with school and schoolings" (p. 69).

The present work does not identify all of the underlying challenges that college students encountered when learning chemistry DMV words; however, one of the major challenges was the infrequent use of the selected DMV both in scientific and everyday contexts. In critically analyzing how science is taught, Lemke (1990) identified "the lack of practice students get in using scientific language for themselves" (p. 124) as one of the four major problems. It is essential to provide students with experience using science vocabulary words in a meaningful context to enhance their conceptual understanding (Bakhtin, 1981; Lemke, 1990; Rosebery *et al.*, 1992; Gee, 2005, 2008; Miller, 2005; Young, 2005; Snow, 2010). As mentioned in the beginning, learning science means learning the language of science, which means not simply using the right terminology but knowing how to use it appropriately. This process was well described by Bakhtin (1981):

[The word in the language] becomes "one's own" only when the speaker populates it with his own intention, his own accent, when he appropriates the word, adapting it to his own semantic and expressive intention. Prior to this moment of appropriation, the word exists in other people's mouths, in other people's contexts, serving other people's intentions (pp. 293–294).

Thus, college science instructors should immerse their students in rich activities in which scientific language, especially DMV, is modeled and used in purposeful and meaningful ways (Gee, 2008). Lemke (1990) urges the use of talking and communicating about science in order to increase both, student comfort level with scientific vocabulary and understanding of it.

The other challenge revealed in our study in relation to the above issue was that students used rote memorization techniques to study DMV only for a test because of the irrelevancy of DMV to their life. The fundamental problem with this type of study habit could tie to the notion of identity. According to several scholars (Gee, 2005, 2008; Brown, 2004, 2011, 2013), acquisition of the language of science is deeply attached to the issue of how students perceive themselves with regard to science they are learning. When students are willing to take on "the identity of being a scientist" (Gee, 2008, p. 64), they can more easily appropriate the language of science. In contrast, it would be difficult for them to learn the language of science if students see this new role as conflicting with the identities developed outside the science classroom. It was clear that the students in our study did not have opportunities to use DMV in an everyday context, which could cause them not to see the value of learning DMV. In this case, it was highly likely that the students were not interested in accepting the new identity of a scientist because the language of science had no relevance to other identities that they hold important in their everyday life. Consequently, learning DMV for deeper conceptual understanding could become challenging. This interpretation imposes a demand for instructors at the college level—developing students' scientist identity so that they can value the learning of scientific language including DMV. One particular instructional strategy would be connecting the scientific meanings of DMV to real life examples.

So far, we have discussed the implications for teaching DMV in chemistry: contrasting everyday meanings and scientific meanings of DMV explicitly, making an effort to assess students' understanding of DMV in light of their everyday language, providing opportunities to use the scientific meanings of DMV in a meaningful context, and developing students' scientist identity. In addition, the findings of this study have implications for further research on the issues with learning DMV. First of all, we admit that the microlevel analysis of one small group of students at one institution could not be generalized. Thus, we suggest a study with different student populations in various school settings to obtain a broader understanding. This type of study is necessary because different student populations could bring a different everyday meaning for the same vocabulary according to the notion of situated meanings of words. Second, students showed high retention rates for some of the selected DMV and really low retention rates for others. We did not investigate whether this is associated with students' chemistry backgrounds, the frequency of the DMV word used in everyday life, or a certain instructional strategy. It would be interesting to examine these relationships. Additionally, a learning progression or trajectory study may also be of interest, where a group of students identifying themselves as chemistry majors are asked about their understanding of a certain set of DMV each year as they progress through the chemistry courses in order to see how their meanings change over time. Lastly, research on the effect of the "content-first" approach or *Disaggregate Instruction* model on college students would provide valuable insights to the chemistry education research community. Students' everyday meanings and ways of using language have been mostly considered as a barrier or deficit in chemistry education for a long time. Therefore, a study that examines if these new instructional approaches were more effective for students' learning of DMV would provide a new perspective to identify students' linguistic resources. Research on the language of science is at an early stage in the area of chemistry education, so further studies and research will be key to understanding how DMV words can be taught with greater efficacy.

Appendix

Pre-instruction interview for each DMV word:

(1) When you read or hear this word _________ what do you think of? If it helps you can draw a picture.

(2) Where did you learn the meaning of that word? Does it have any significance to you?

(3) Do you use the word often when talking or writing?

(4) When you think of this word in reference to science, does this word have a different meaning? If so, what is that meaning? Again, you may draw a picture if that helps.

(a) Please use the word in a sentence.

(b) If they know both meanings ask: when you hear that word in class which meaning do you think about first?

Post-instruction interview for each DMV word:

(1) When you read or hear this word _________ what do you think of? If it helps you can draw a picture.

(a) Please use the word in a sentence.

(2) Has this meaning changed for you since learning about it in class?

(3) Do you use the word often when talking or writing?

(4) When you think of this word in reference to science, does this word have a different meaning? If so, what is that meaning? Again, you may draw a picture if that helps.

(a) When you hear that word in class which meaning do you think about first?

(b) Please use the word in a sentence.

(5) Do you struggle to identify which meaning is applicable?

(a) If so, why? And which definition do you rely on?

General vocabulary interview:

(1) Why was it hard to retain the scientific meanings of the DMV?

(2) How do you study new vocabulary?

(a) Do you think this is an effective study method? Why?

Acknowledgements

We would like to thank Peter Karnilaw who was the instructor of the Chem 281 course at the time of this study and the students for sharing their thoughts with us. We wish to thank the Chemistry Education Research Group at the University of Northern Colorado for many helpful discussions.

References

Arons A., (1973), Toward wider public understanding of science, *Am. J. Phys.*, **41**, 769–782.

Arons A., (1983), Achieving wider scientific literacy, *J. Am. Acad. Arts Sci.*, **112** (2), 91–122.

Bakhtin M., (1981), *The dialogic imagination: four essays*, Austin: University of Texas Press.

Beck I. L., McKeown M. G. and Kucan L., (2002), *Bringing words to life: robust vocabulary instruction*, New York: Guilford Press.

Brandwein P. F., (1981), *Memorandum: on renewing schooling and education*, New York, NY: Harcourt Brace Jovanovich.

Brown B., (2004), Discursive identity: assimilation into the culture of science and its implications for minority students, *J. Res. Sci. Teach.*, **41**(8), 810–834.

Brown B., (2006), "It isn't no slang that can be said about this stuff": language, identity, and appropriating science discourse, *J. Res. Sci. Teach.*, **43**(1), 96–126.

Brown B. A., (2011), Isn't that just good teaching? Disaggregate instruction and the language identity dilemma, *J. Sci. Teacher. Educ.*, **22**, 679–704.

Brown B. A., (2013), The language-identity dilemma: an examination of language, cognition, identity, and their associated implications for learning, in Bianchini J. A., Akerson V. L., Barton A. C., Lee O. and Rodriguez A. J., (ed.), *Moving the equity agenda forward: equity research, practice, and policy in science education, Cultural Studies of Science Education 5*, Springer, pp. 223–239.

Brown B. A. and Ryoo K., (2008), Teaching Science as a Language: A ''Content-First'' Approach to Science Teaching, *J. Res. Sci. Teach.*, **45**(5), 529–553.

Brown B. and Spang E., (2008), Double talk: Synthesizing everyday and science language in the classroom, *Sci. Educ.*, **92**, 708–732.

Brown B., Reveles J. and Kelly G., (2005), Scientific literacy and discursive identity: a theoretical framework for understanding science education, *Sci. Educ.*, **89**, 779–802.

Brown B. A., Ryoo K. and Rodriguez J., (2010), Pathway towards fluency: using 'disaggregate instruction' to promote science literacy, *Int. J. Sci. Educ.*, **32**(11), 1465–1493.

Bunce D. M. and Hutchinson K. D., (1993), The use of the GALT (Group Assessment of Logical Thinking) as a predictor of academic success in college chemistry, *J. Chem. Educ.*, **70**, 183–187.

Cassels J. R. T. and Johnstone A. H., (1980), *Understanding of non-technical words in science: a report of a research exercise*, London: Royal Society of Chemistry.

Cassels J. R. T. and Johnstone A. H., (1985), *Words that matter in science: a report of a research exercise*, London: Royal Society of Chemistry.

Charmaz K., (2000), Grounded theory: objectivist and constructivist methods, in Denzin N. and Lincoln Y., (ed.), *Handbook of qualitative research*, Thousand Oaks, CA: Sage, pp. 509–535.

Charmaz K., (2002), Qualitative interviewing and grounded theory analysis, in Gubrium J. and Holstein J. A., (ed.), *Handbook of interview research*, Thousand Oaks, CA: Sage, pp. 675–694.

Christie F., (1989), *Language education*, New York: Oxford University Press.

Denzin N. K., (1978), *The research act: a theoretical introduction to sociological methods*, 2nd edn, McGraw-Hill.

Donovan M. P., (1997), The vocabulary of biology and the problem of semantics, *J. Coll. Sci. Teach.*, **26**(6), 381–382.

Duschl R. A., Schweingruber H. A. and Shouse A. W., (2007), *Taking science to school: learning and teaching science in grades K-8*, Washington, DC: National Academies Press.

Eiss A. F., (1961), Problems in semantics of importance in science teaching, *Sci. Educ.*, **45**(4), 343–347.

Fang Z., (2005), Scientific Literacy: A Systemic Functional Linguistics Perspective, *Sci. Educ.*, **89**, 335–347.

Gabel D., (1999), Improving teaching and learning through chemistry education research: a look to the future, *J. Chem. Educ.*, **76**, 548–554.

Gabriela M., Ribeiro T. C., Costa Pereira D. J. V. and Maskill R., (1990), Reaction and spontaneity: the influence of meaning from everyday language on forth year undergraduates' interpretations of some simple chemical phenomena, *Int. J. Sci. Educ.*, **12**(4), 391–401.

Gee J., (1996), *Social linguistics and literacies: ideology in discourses*, 2nd edn, London: Taylor & Francis.

Gee J., (2005), Language in the science classroom: academic social languages as the heart of school-based literacy, in Yerrick R. and Roth W.-M., (ed.), *Establishing scientific classroom discourse communities: multiple voices of teaching and learning research*, Mahwah, NJ: Lawrence Erlbaum Associates, pp. 19–37.

Gee J., (2008), What is academic language? in Rosebery A. S. and Warren B., (ed.), *Teaching Science to English Language Learners: Building on Students' Strengths*, Arlington, VA: National Science Teachers Association press, pp. 57–69.

Gilbert A. and Yerrick R., (2001), Same school, separate worlds: a sociocultural study of identity, resistance, and negotiation in a rural, lower track science classroom, *J. Res. Sci. Teach.*, **38**, 574–598.

Glaser B. and Strauss A., (1967), *The discovery of grounded theory: strategies for qualitative research*, Chicago: Aldine.

Glover D., Kolb D. and Taylor M., (1991), Another option for chemistry dropouts, *J. Chem. Educ.*, **68**, 762–763.

Halliday M. A. K. and Martin J. R., (1993), *Writing science: literacy and discursive power*, Pittsburgh, PA: University of Pittsburgh Press.

Hsu P. and Roth W.-M., (2012), From authoritative discourse to internally persuasive discourse: discursive evolution in teaching and learning the language of science, *Cult. Stud. Sci. Educ.*, 1–25.

Itza-Ortiz S. F., Rebello N. S., Zollman D. A. and Rodriquez-Acharch M., (2003). The vocabulary of introductory physics and its implications for learning physics, *Phys. Teach.*, **41**, 330–336.

Jasien P. G., (2010), You said ''neutral'', but what do you mean? *J. Chem. Educ.*, **87**(1), 33–34.

Jasien P. G., (2011), What do you mean that ''strong'' doesn't mean ''powerful''? *J. Chem. Educ.*, **88**, 1247–1249.

Jasien P. G. and Oberem G. E., (2008), Student contextual understanding of the terms *dense* and *energy*: a qualitative study, *Chem. Educ.*, **13**, 46–53.

Lee O., (2001), Culture and language in science education: what do we know and what do we need to know? *J. Res. Sci. Teach.*, **38**, 499–501.

Lee O. and Fradd S., (1998), Science for all, including students from non-English-language backgrounds, *Educ. Res.*, **27**(4), 12–21.

Lemke J. L., (1990), *Talking Science: Language, Learning, and Values*, Norwood, NJ: Ablex.

Lewis S. E. and Lewis J. E., (2007), Predicting at-risk students in general chemistry: comparing formalthought to a general achievement measure, *Chem. Educ. Res. Pract.*, **8**, 32–51.

Lewis S. E. and Lewis J. E., (2008), Seeking effectiveness and equity in a large college chemistry course: an HLM investigation of peer-led guided inquiry, *J. Res. Sci. Teach.*, **45**, 794–811.

Lincoln Y. S. and Guba E. G., (1985), *Naturalistic inquiry*, Beverly Hills, CA: Sage Publications, Inc.

Merriam S. B., (1998), *Qualitative research and case study applications in education*, San Francisco: Jossey-Bass Publishers.

Michaels S., Shouse A. W. and Schweingruber H. A., (2008), *Ready, set, science! Putting research to work in K-8 science classrooms*, Board on Science Education, Center for Education, Division of Behavioral and Social Sciences and Education, Washington, DC: The National Academies Press.

Miller J. S., (2005), The language of science is in daily conversation, *Sci. Act.*, **42**(2), 3–4.

Moje E., Collazo T., Carillo R. and Marx R. W., (2001), ''Maestro, what is quality?'': examining competing discourses in project-based science, *J. Res. Sci. Teach.*, **38**(4), 469–495.

Patton M. Q., (2002), *Qualitative research and evaluation methods*, 3rd edn, Thousand Oak, CA: Sage.

Pyburn D. T., Pazicni S., Benassi V. A. and Tappin E. E., (2013), Assessing the relation between language comprehension and performance in general chemistry, *Chem. Educ. Res. Pract.*, **14**, 524–541.

Rosebery A. S., Warren B. and Conant F. R., (1992), Appropriating scientific discourse; findings from language minority classrooms, *Journal of the Learning Sciences*, **21**, 61–94.

Sapir E., (1949), The unconscious pattering of behavior in society, in Mandelbaum D., (ed.), *Selected writing of Edward Sapir in language, culture, and personality*, Berkeley: University of California Press, pp. 544–559.

Schleppegrell M., (2004), *The language of schooling: a functional linguistics perspective*, Mahwah, NJ: Erlbaum.

Scott J., (1992), *Science and language links: Classroom implications*, Portsmouth, HH: Heienmann.

Short D. J., Vogt M. and Echevarria J., (2011), The academic language of science, in Short D. J., Vogt M. and Echevarria J., (ed.), *The SIOP® model for teaching science to English learners*, Boston, MA: Pearson Education, Inc., pp. 1–20.

Smith K. J. and Metz P. A., (1996), Evaluating student understanding of solution chemistry through microscopic representations, *J. Chem. Educ.*, **73**(3), 233–235.

Snow C., (2008), What is the vocabulary of science? in Rosebery A. S. and Warren B., (ed.), *Teaching Science to English Language Learners: Building on Students' Strengths*, Arlington, VA: National Science Teachers Association, pp. 71–83.

Snow C. E., (2010), Academic language and the challenge of reading for learning about science, *Science*, **328**(23), 450–452.

Stoker H. S., (2008), *General, Organic, and Biological Chemistry*, 2nd edn, Boston, MA: Houghton Mifflin Company.

Varelas M., Becker J., Luster B. and Wenzel S., (2002), When genres meet: inquiry into a sixth grade urban science class, *J. Res. Sci. Teach.*, **39**(7), 579–605.

Vygotsky L., (1986), *Thought and Language*, Cambridge, MA: The MIT press.

Warren B., Ballenger C., Ogonowski M., Rosebery A. and Hudicourt-Barnes J., (2001), Rethinking diversity in learning science: the logic of everyday sense-making, *J. Res. Sci. Teach.*, **38**, 529–552.

Wellington J., (2000), Teaching and learning secondary science: contemporary issues and practical approaches, New York: Routledge.

Wellington J. and Osborne J., (2001), *Language and literacy in science education*, Philadelphia, PA: Open University Press.

Yager R. E., (1983), The Importance of terminology in teaching K-12 science, *J. Res. Sci. Teach.*, **20**(6), 577–588.

Young E., (2005), The language of science, the language of students: Bridging the gap with Engaged learning vocabulary strategies, *Sci. Act.*, **42**(2), 12–17.