Supporting English Language Learners in College Science Classrooms

Insights from Chemistry Students

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Introduction

General chemistry is a mandatory course for those in pursuit of careers in various allied health and science, technology, engineering, and mathematics (STEM) fields. However, many students find chemistry difficult (Carter & Brickhouse, 1989; Woldeamanuel, Atagana, & Engida, 2014). The mathematical content embedded in chemistry, the abstract nature of chemical concepts, and the specialized language used in the field are among the most common factors listed as making chemistry difficult (Cardellini, 2012).

For English language learners (ELLs), the situation is especially demanding, as these students are required to learn the specialized academic language and concepts of chemistry while simultaneously learning English. Often, ELLs have to go through multiple cognitive processes as they use their first language skills to facilitate the acquisition of information presented in a new language (August & Hakuta, 1997; Francis et al., 2006). Furthermore, in the context of chemistry learning, additional cognitive challenges can be imposed by the fact that some of the terms used in chemistry either are not used in everyday conversation or have specialized meanings (e.g., *stoichiometry* and *stability*, respectively; Chatmot & O'Malley, 1994).

To further complicate the matter, chemistry is also comprehensive in nature, which does not leave much room for error in developing a solid understanding of key concepts. If ELLs develop incorrect understandings about words or phrases used early in the semester, those misunderstandings will negatively impact their learning of chemistry concepts in the future (Carter & Brickhouse, 1989).

Each of the challenges listed in the previous paragraphs can potentially become an impediment to ELLs' future success, and research has suggested that this student group is largely overlooked, particularly in the context of postsecondary science classrooms (Kanno & Cromley, 2013). However, the National Science Teachers Association (2018) stated that "all students can and should have every opportunity to learn and succeed in science."

It is important that we, as educators, address the unique learning experiences and needs that ELL students have in the science classroom to provide them with equitable access to science knowledge and careers. The goal of the current study is to consider the specific challenges that ELL students face in university-level general chemistry courses. We believe that this information can provide college science instructors with insights about how to support the learning of ELLs in their classrooms.

Literature Review

The education system in the United States has seen a considerable growth in the ELL population over the past decade because of both an increase in the number of international students coming to U.S. campuses and an increase in the number of immigrants. For example, the number of international students enrolled in U.S. postsecondary institutions more than doubled from 1990 to 2014, reaching a total of 1.1 million students in the 2016–2017 academic year (Institute of International Education, 2017).

Academic Challenges for ELLs in Science Courses

Although it could be argued that ELLs will find any course taught primarily in English to be difficult, ELLs face unique challenges as they attempt to learn science, challenges that potentially put ELLs at a disadvantage compared with their non-ELL counterparts. This is especially true in historically difficult introductory science courses where the predominant teaching method is lecture (Knight & Wood, 2005). It is not surprising that ELLs struggle with comprehension, participation, and assessment in this style of instruction (Bifuh-Ambe, 2011; Bilbow, 1989). Compared with 34% of native English–speaking undergraduates, only 9% of ELLs reported understanding lecture content well. Furthermore, 22% of ELLs indicated that they did not understand much of

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the content of their lectures (Mulligan & Kirkpatrick, 2000).

Overall, *knowing*, *doing*, and *talking* science imposes unique challenges that can hinder ELLs from achieving academic literacy—and success—in science classrooms. In the paragraphs that follow, we briefly describe some of the challenges that students face in learning science. It is worth noting that most of the research about ELLs' learning of science has been done in primary or secondary educational contexts and not at the postsecondary university level (Lee & Fradd, 1998).

Knowing science refers to developing scientific understanding. ELLs face a triple challenge when they attempt to use language as a tool for learning science concepts in English-based classrooms (Lee & Fradd, 1998). They must learn (a) basic conversational English vocabulary, (b) content-specific vocabulary, and (c) deeper language structures used in inquiry (i.e., the language used in formulating hypotheses, drawing conclusions, making inferences, and asking questions).

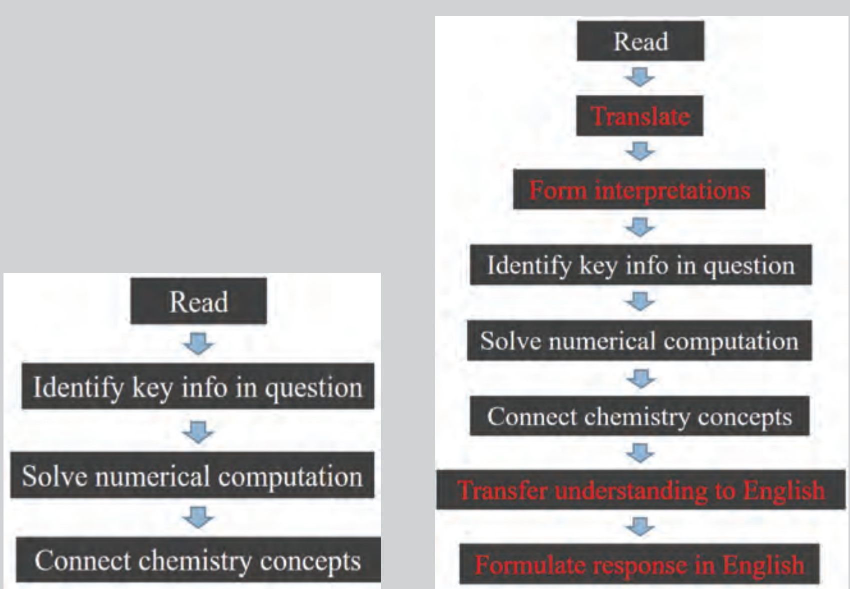
The types of difficulties ELLs encounter when trying to learn and convey science content in English are especially pronounced during course exams in timed settings, when students are often required to read and solve word problems. Most students, including native English speakers, find science exams to be challenging. For ELLs, however, additional cognitively demanding steps must be taken to understand the text and formulate a written output in the English language (Abedi & Lord, 2011; Chatmot & O'Malley, 1994; Francis et al., 2006). These steps are shown visually in Figure 1.

Doing science involves "manipulating materials, making observations, proposing explanations, interpreting and verifying evidence, and constructing ideas to make sense of the world" (Lee & Fradd, 1998, p. 16). Many aspects of this process involve higher order language functions, such as reflecting, predicting, making inferences, and hypothesizing, all of which require established cognitive academic language proficiency (CALP) in a given science discipline (Cummins, 1984).

CALP is more difficult to develop than is proficiency in basic conversation skills. In fact, students tend to require 5–8 years of education in formal academic settings to develop CALP. As a consequence, it is difficult for ELL students without prior schooling or consistent support in language development to develop higher order skills like comparing, classifying, synthesizing, evaluating, and inferring at the same pace as their non-ELL counterparts (Collier, 1995).

Figure 1

Processes involved in solving chemistry problems with computations:
Steps that native English speaking students take to solve chemistry problems involving computations (left).
Steps that ELLs take to solve chemistry problems involving computations (right, with steps unique to ELLs highlighted).



Talking science means to communicate in the language of science and act as a member of the scientific community (Lemke, 1990). The lack of proficiency in academic language mentioned previously also affects ELLs' ability to express themselves effectively in science classrooms. Although research focusing specifically on the challenges of ELLs in science classrooms at the tertiary level is limited, research at the elementary education level has found that ELLs can struggle with expressing ideas in academic language—and, thus, "succeeding" in their science classes—even when they have good basic conversational skills in the classroom language (Francis et al., 2006).

It is reasonable to conclude, then, that ELLs at the tertiary level who seem to be proficient in everyday, conversational English will also experience difficulty in communicating their academic content knowledge effectively in science classrooms. For example, an instructor asking a student to explain the concept of *balance* might expect the student to respond by describing an equal distribution of mass or objects between two sides. An ELL, however, might respond with gestures motioning to two sides and/or using terms like "same stuff on both sides." These differences in communication patterns might cause an instructor to believe that an ELL's responses are less intelligent than those of other students.

The Current Study

It is clear that ELLs encounter unique difficulties developing scientific literacy. However, as previously mentioned, most of the literature about ELLs in the context of the science classroom has been done in primary or secondary educational contexts (Abedi, 2002; Brown, 2005; O. Lee & Fradd, 1998; Noble et al., 2012). The current study was designed to highlight the types of challenges that ELLs face in learning chemistry (in both lecture and laboratory) at the postsecondary level to inform efforts to support the learning of these students in college science classrooms.

We surveyed ELLs enrolled in general chemistry about how they believe their language proficiency influenced (a) their learning experiences and (b) the learning techniques they employed to be successful in the course. The following research questions guided the study:

Research Question 1: What types of challenges do undergraduate ELLs report experiencing in terms of their learning, participation, and assessment?

Research Question 2: Which learning techniques do ELLs report using to support their learning needs?

Methods

Research Setting and Participants

This study was conducted at a large, public university in the southwestern region of the United States. We employed convenience sampling to recruit ELLs enrolled in a general chemistry course at the university. A total of 28 of the 45 (62%) ELL students enrolled in the course volunteered to participate in the study. Pseudonyms were assigned to all participants. The following first languages were represented: Spanish (40%), Korean (23%), Vietnamese (15%), Tagalog/Filipino (12%), Mandarin (6%), Hindi (3%), and German (<1%). The student participants ranged in age from 18 to 27 years.

Materials

An open-ended questionnaire was used for this study because it allowed participants a greater degree of freedom in the description of their experiences than would closed-ended questions (Roulston, 2008). The questionnaire consisted of two sections: (a) demographics and (b) questions about the participants' experiences in the course.

The first section asked students to identify their current age, the age at which they arrived in the U.S., and their first language. The second section asked the participants to describe how they believe their English language proficiency influenced learning, participation, and performance in the contexts of (a) lecture, (b) laboratory, and (c) assessments in the general chemistry course. The second section also asked students to report any techniques or tools they employed during lecture, laboratory, and assessments to support their learning, participation, and/or performance in the course.

Procedure

After receiving approval from the institutional review board, we advertised the study to all students in the lecture and laboratory sections of the two-semester general chemistry course and requested that students who spoke a language other than English as their first language participate. Students were approached after they completed their second midterm exam so that they had enough time to become familiar with the format of the course and to form their own impressions about their learning behaviors in the course. The questionnaire was administered by the researchers during the laboratory sections of the course. Participants took approximately 15–20 min to complete it.

Data Analysis

We analyzed the open-ended written responses using the constant comparative method (Corbin & Strauss, 2008). This was an iterative process in which we looked for patterns in each questionnaire and developed codes (e.g., "can't understand instructor" and "professor talks too fast"), which were grouped into categories (e.g., instructor-related issues). Categories were further grouped into overarching themes (e.g., extrinsic and intrinsic challenges).

After the authors individually analyzed the responses, they met to compare their analyses, resolving any discrepancies through discussion. The results that follow represent our consensus of codes, categories, and themes present in the students' responses.

Results and Discussion

The participants identified a number of language-related challenges that they believe impacted their learning, participation, and performance in the lecture, laboratory, and assessment components of the general chemistry course (see Table 1). Some of these challenges were *extrinsic* to the students, meaning that they occurred or were controlled outside of the students but still influenced the students' chemistry learning. These included, for example, the instructional style of the course and class size.

Other identified challenges were *intrinsic*, challenges that the students believed were related to their internal abilities to understand or process information presented to them in English, such as their knowledge of specialized vocabulary or their ability to comprehend written English.

In the sections that follow, we present both the extrinsic and intrinsic challenges identified by the students, organized by the context in which the students reported experiencing the challenges: lecture, laboratory, and assessment (see Figure 2). We chose to present the results in this manner to emphasize the nature of challenges participants reported in each context of the course.

Extrinsic Challenges

Our participants identified two main extrinsic challenges to their learning, participation, and performance in the general chemistry course: instructional style and class size. These factors are discussed in the context of both the chemistry lecture and laboratory learning environments.

The students who participated in the current study did not identify any extrinsic challenges to their learning, participation, or performance in the context of assessments.

Figure 2
Summary of Challenges That ELLs Experience in General Chemistry

Extrinsic	*Intrinsic*
Lecture	**Lecture**
Instructional style	Academic language
Large class sizes	Verbal expression
Laboratory	**Laboratory**
Instructional style	Reading comprehension
Assessment	**Assessment**
None	Complex wording
	Cognitive overload

***Lecture: Instructional style*.** A majority of the participants (72%) indicated experiencing significant challenges during the lecture portion of the course. Some of these challenges were attributed to the instructors' teaching styles. Participants (36%) indicated that instructors often spoke too fast and needed to provide more examples and explanations to convey topics clearly.

The pace of instructors' speech is a particular problem for many ELLs because real-time processing of academic English imposes a high-level cognitive load on working memory (Collier, 1995). Jaime said,

> If there are certain words that are not understood during lecture, I have to make a note to look it up later, which can definitely delay my understanding of the material since the instructor is not going to stop just based on one word that I didn't understand.

Lecture: Large class sizes. Approximately 13% of participants mentioned that it is difficult for them to "raise my hand" and speak up in lecture rooms with 100 or more students present. Roma reported, "It reduces the chance of being involved in class participation. . . . You become indifferent and less likely to come to class and listen."

While courses with large class sizes affect the willingness of all students to engage and participate in class, students who have limited English fluency must confront a language barrier in addition to the higher social pressure faced when communicating in this setting.

Laboratory: Instructional style. Our findings suggest that ELLs encounter different challenges in the laboratory compared with lecture. Most of our participants (61%) indicated that the laboratory environment was a better learning experience than lecture primarily because of its smaller and more interactive setting. Although most participants' experiences in the lab were relatively positive, some (18%) stated that the laboratory instructor's speaking style can be challenging when he or she speaks quickly.

Another challenge for learning in the laboratory is the presentation of the laboratory procedure. These protocols typically contain dense and technical information embedded in key, detailed steps that must be understood to run the experiment successfully. Our participants (14%) suggested that it is helpful when instructors can demonstrate the experimental protocol. "I need to be shown how to do it," stated Rosa.

Intrinsic Challenges

Participants also identified intrinsic challenges related to reading, comprehending, and using the academic language of science that impacted their learning in the course. These challenges are discussed in the context of lecture, laboratory, and assessment.

Lecture: Academic language. The specialized language of chemistry was highlighted by 36% of participants as being challenging. Participants specifically mentioned that vocabulary used in the course was "very advanced" and "very different" from words that they would use in everyday talk. They also reported that many chemistry words cannot be directly translated into their native languages. Participants noted that they felt as if they had to study longer than native English-speaking students in the class because it was like "learning a new language, with math."

Lecture: Verbal expression. In addition the extrinsic challenge of *participating* in large class sizes discussed previously, ELLs experience difficulty *talking* during class because of their own intrinsic negative self-perception of their verbal language skills. We found that more than half (54%) of our participants struggled with talking during class. They were reluctant to speak during class because they were unsure of how they sound to others and/or they perceived a risk of social embarrassment.

Seojun mentioned, "Sometimes I am a little bit afraid of participating in lecture because of the potential grammatical error while I am speaking." Manuel noted that when he is asked a question, he is "hesitant to respond because of my accent and efficacy in [English] speech." Diem noted, "I would rather not [speak] because of fear of how I sound to others."

Laboratory: Reading comprehension. Although many participants reported that the laboratory was generally a better class environment to interact verbally with instructors and peers compared with lecture, many participants (43%) found reading and interpreting the experimental procedures in the lab manual to be particularly difficult. Students reported that the specialized chemical language and technical words were not readily translatable and that alternate definitions of such terms were not provided, which made it especially hard to follow the instructions in the lab manual.

Hyun reported that "there are many terminologies related to specific lab topics that we cannot translate into our language." Shalin added, "There are new words in the lab manual that I've never seen before [which is hard because] I need to first understand it in my native language to have a general idea of what does it mean." There were also concerns of safety, as Roma stated: "It may be a safety or hazard issue if I misunderstood something."

Assessment: Complex wording. Because language plays an integral role in learning, any test of academic achievement, to some extent, is a test of language ability (Kieffer, Lesaux, Rivera, & Francis, 2009). Previous studies suggested that ELLs are more likely than non-ELLs to answer science assessment items incorrectly despite demonstrating knowledge of the content outside of the exam environment (Noble et al., 2012).

The ELLs in the current study perceived that their language skills were a key factor affecting how their chemistry content knowledge was assessed, either because they could not understand what an assessment item was asking them to do or because they could not adequately express their understanding in written English.

A majority of our participants (67%) reported significant challenges that affected their performance on assessments. Of these, the most frequently mentioned concern (42%) was regarding the difficulty associated with understanding the wording on assessment items. Abby expressed, "Wording on exam questions trick me a lot. Even though I understand the matter, if I don't get what the exam questions really are asking, I have no choice but to get it wrong." Marissa stated that using specific words to explain her understanding is also challenging: "Purely math calculations are easy, but explaining details using words and language is where I lose points."

Participants also indicated that they tended to struggle on exam questions that contain complicated/unfamiliar words, especially those that carry multiple meanings (e.g., *state*, which could mean a condition (noun), to express something in speech or writing (verb), or—in the context of chemistry—a phase of matter).

Assessment: Cognitive overload. Participants (25%) also reported feeling overwhelmed by the amount of information they need to process during timed assessments. Jaime stated that he does not perform well because "[there's] too much information to process in a short amount of time." Elara mentioned, "You need to be super quick since you have to translate everything from English to your language in your head." Several others stated that they become "stressed" and "panicked" when they have to provide written explanations because they cannot adequately express their knowledge in English.

Although any student can experience cognitive overload during exams, ELLs have the added steps of reading in a foreign language and translating to their native languages to fully interpret the text, which may disproportionately impact their performance compared with their native English-speaking peers (Kanno & Cromley, 2013).

Learning Techniques

Knowing and using effective learning techniques—such as self-testing and concept mapping—can be the key to overcoming commonly encountered learning challenges (Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013). Notably, research on the academic preparedness of ELL students has indicated that ELLs who are aware of and can use effective learning techniques to support their learning are more likely to be successful than those who are unaware of such techniques (Song, 2018).

As such, an important goal of this study was to understand how ELLs attempt to circumvent the specific extrinsic and intrinsic challenges they reported, as this information can provide useful insights about their awareness and use of effective learning techniques.

ELLs' use of learning techniques. Interestingly, we found that (a) only 48% of our participants reported using any specific techniques to address their learning challenges in the chemistry course and that (b) the most frequently reported technique was careful reading and rereading of notes and assignments that they did not initially comprehend. For example, on exams, participants mentioned that they "read instructions carefully" and "reread the question" multiple times to understand what is being asked.

Unfortunately, research has suggested that when ELLs reread text, they are using context to guess meanings, which can often lead to misunderstandings (Song, 2018), making this an inefficient technique for learning scientific concepts.

A small number of participants (14%) mentioned using translating tools and dictionaries when reviewing lecture materials and understanding experimental procedures. They also mentioned viewing online videos to develop understandings of course concepts and laboratory procedures.

Although our small sample is certainly not representative of all ELL students, the responses of our participants suggest that they are not using particularly effective and efficient learning techniques. Studies have shown that language learners especially benefit from more active learning techniques (i.e., creating mental linkages of concepts) that enable them to organize information and retrieve new information they learn (Oxford, 1990).

Instructors can play an integral role in ELLs' development of effective learning techniques. For the purposes of *knowing*, *doing*, and *talking* science, ELLs benefit from practicing science talk and scientific writing both inside and outside of the classroom. Encouraging ELLs to participate in conversations, read articles, or listen to relevant media helps them rehearse their language skills and actively receive feedback within the context of relevant scientific topics.

Another technique that helps ELLs learn and use new words/phrases appropriately is inference guessing. By intelligently guessing the meanings of key terms using linguistic cues (e.g., grammar) and context or text structure, ELLs are more likely to understand the specialized language of science. Additionally, asking ELLs to evaluate their own learning by promoting self-testing helps them identify errors in their comprehension and measure their progress (Oxford, 1990).

These types of techniques offer ELLs ways to scaffold the practice and use of the English language in the context of science, which plays a key role in overcoming commonly experienced learning challenges.

Conclusion

The results of the current study indicate that most ELLs experience extrinsic and intrinsic challenges that hinder them from adequately following lectures, participating in class, understanding lab procedures, and demonstrating their content knowledge on course assessments. Relatedly, ELLs reported re-reading material as the main technique they employed to help them get through the course; however, research has indicated that simply re-reading material does not foster meaningful learning.

Interestingly, most native English-speaking students could also experience these challenges and utilize similar learning techniques; however, literature on language acquisition (Cummins, 1981; Francis et al., 2006) has implied that these challenges affect ELLs differently because general chemistry heavily depends on the ability to practice and use language in a specialized manner (Chatmot & O'Malley, 1994).

In fact, research has indicated that ELLs generally perform lower than non-ELLs in reading, science, and math because of the additional language demands embedded in these content areas (Abedi et al., 2005).

Supporting ELLs in the Science Classroom

The challenges that ELLs face in learning in science classrooms potentially place them in an unfavorable position to succeed relative to native English speakers. As instructors, we must be cognizant about ways to make our courses more accessible and meaningful for *all* students, including students from different language backgrounds. Fortunately, our results and the findings of other studies with ELLs indicate that college science instructors can take some relatively simple steps to better support and foster meaningful learning for the ELLs in their classrooms (see Figure 3).

If the goal is to make science accessible to *all*, then integrating appropriate measures to acknowledge and rectify unique challenges that students experience in our classrooms is imperative. Traditionally, science and math are considered bodies of knowledge that

Figure 3
Classroom Strategies for Supporting ELLs in the Science Classroom

Lecture *Integrate opportunities for face-to-face interactions among students to naturally enhance language development.*

Involve students in small-group activities using the "think, pair, share" strategy, conversational role-plays, and/or cooperative learning projects (Shih & Reynolds, 2015).

Teach how to use and apply scientific vocabulary in context.

Require that students organize or classify new terms in a concept map.

Ask students to sort vocabulary words by category.

Review terms that have been previously introduced.

Have students act out or use new words or terms in a given context (Tamimi Sa'd & Rajabi, 2018).

Model effective reading: Help students make meaning of text.

Discuss how to page through a text ahead of time by looking at headings or pictures to begin activating prior knowledge.

Ask students to make predictions about what will come next in a reading.

Teach students to monitor and question their own reading comprehension by asking questions like "What are the authors talking about?" "What does this word mean here?"

Connect texts to personal experience, other concepts, or prior knowledge using phrases like "this reminds me of . . ."

Ask students to summarize or explain the text to peers: Have students work in partners to read and explain the "gist" of the passage (Calderón, Slavin, & Sánchez, 2011).

Laboratory *Modify the text in the lab manual.*

Find ways to cover the same concepts at a lower reading level.

Reserve a few copies of texts specifically for ELLs and highlight the overarching ideas, key concepts, and summary statements.

Support the development of writing skills.

Allow students to discuss their experiment before writing the lab report to activate ideas and vocabulary.

Provide model lab reports and point out headings, topic sentences, and other key features of the report (Olson, Scarcella, & Matuchniak, 2015).

Provide preview videos, virtual labs, and Web sites of experiments that build knowledge and an understanding of what to expect during lab (Powers, 1998).

Assessment *Make assessments more equitable.*

Add visual representations as part of the question (e.g., an illustration of a process, graph, or table describing data; Martiniello, 2009; Pappamihiel & Mihai, 2006).

Make exam items more accessible by reducing linguistically complex features of the text using the Equitable Framework for Classroom Assessments (Gandhi-Lee, 2018; Siegel, 2007).

Use alternative forms of assessment that are less language dependent.

Ask students to create a model or visual display to demonstrate understanding of a topic.

Ask students to give oral presentations as part of a culminating project (Wygoda & Teague, 1995).

Engage students in creative exercises (Lewis, Shaw, & Freeman, 2010).

are universally valid and "culture-free"; however, this conception of science is incompatible with a multicultural approach to science education (Lemke, 1990). As science instructors, we are in a unique position to empower traditionally underserved students in our classrooms by providing inclusive measures to teach science in a way that fosters their growth and learning.

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