EXPLORING SCIENCE LITERACY OF ENGLISH LEARNERS IN K - 16 LEARNING ENVIRONMENTS

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

WASHINGTON STATE UNIVERSITY
Department of Teaching and Learning

DECEMBER 2018

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To the Faculty of Washington State University:

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ACKNOWLEDGMENT

I would like to acknowledge my deepest gratitude to Dr. William Davis for access to former student assignment papers and his three teaching assistants Liam Caven, Andy Sattler and Brett Vanderweff who helped me verify the appropriateness of Parkinson’s (2017) lab report codes to complete the second study in this dissertation.
This dissertation explores science literacy for English learners (ELs) in secondary and university contexts. The two studies conducted for this dissertation focus on the reading comprehension abilities of secondary school ELs, and the writing of ELs for a university introductory biology course. The first study reveals some inequity in public school education that ELs face when they arrive at the secondary school level. ELs can be placed into low-track streams limiting their options for college preparatory courses, and thus limiting their access to university. The transition chapter between the two studies highlights some areas where English for academic purposes (EAP) or intensive English program (IEP) books may not prepare students for the linguistic rigor of university writing course work. The second study identifies that ELs perform in between the work of their non-EL peers at the top 10% and the bottom 10% of the course. The study also indicates that all students could benefit from more genre instruction before writing lab reports. As all three groups of students struggled in similar areas of the lab report format, the study indicates that it takes time for all students to develop the skills needed for science writing. The final chapter highlights areas to improve science literacy instruction for
ELs at both the secondary and university levels. These suggested ways to improve science literacy for ELs would also benefit all students to develop science literacy. Overall, this dissertation gives insight to the needs of ELs at secondary and university level science instruction.
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Dedication

I dedicate this dissertation to my former students in China who inspired this line of research to help other non-native English speakers learn to use science in English.
CHAPTER ONE: INTRODUCTION

Students who pursue studying in the sciences may be surprised at the language that they need to learn in order to function and sound like a scientist. Science expository texts are written at a different register (a “generalized functional variety of modern English language;” Halliday, 2003, p. 54) than normal everyday English (Fang, 2005, 2008). Some educators may even say that learning science is like learning a new language (William Davis, January 23, 2017, personal communication). As the expository writing makes science more difficult to read and understand, the vocabulary used is another limiting factor for comprehension as science has its own specialized vocabulary (Fang, 2008; Snow, 2010). If this is true for native English speakers, what extra burdens may the learning of the language of science place on English learners (ELs) who want to pursue studying science?

Since science, technology, engineering and mathematics (STEM) subjects are those disciplines where money is most available, it is important to encourage all students to have access and opportunities to learn STEM subjects. Within the K – 16 school system, there is interest to help ELs to develop competence in English to pursue these subjects. As will be seen in chapter 2, there are systemic structures limiting ELs’ access to learning science subjects in such a way that will allow them to pursue those subjects at the university level (Callahan, 2005; Callahan & Schrifer, 2016; Umansky, 2016).

Further, once an EL student gets to the university there are limited language services within the disciplines. Subject instructors may not feel prepared to address the language needs of ELs or know how best to meet their EL students’ needs (Arkoudis & Tran, 2010). Yet at the same time, language specialists may not feel comfortable teaching language geared for the STEM. This can leave ELs without the resources to navigate STEM subjects.
Since there are growing numbers of English medium instruction at global university instruction (Doiz, Lasagabaster & Sierra, 2012; Hu & Lei, 2014), it is necessary to provide additional support for the learning of English for STEM subjects. Students who study at a university within their home nation, may be expected to publish in an English medium journal (Li, 2006) to graduate with a PhD. This puts additional pressure on an EL to master the English language.

The interest in developing researcher and student competence in English for the sciences is growing. Cargill, O’Connor and Li (2012) discuss the steps taken in China to help faculty and students have the English skills to publish in English medium journals. Hannauer and Englander (2013) describe how researchers of science in Mexico address the language needs of having to publish in English or communicate their findings in English. Some university curricula are addressing the needs of academic writing to raise rhetorical awareness for the documents being written (Kumari, 2016). In other words, the interest in developing researcher and student competence in English for the sciences is growing globally.

Linguists have spent time analyzing the language of science (Halliday, 2003; Swales, 1990), looking at the history of written science and how it is used. Over time, the genre of science has developed specialized grammar and vocabulary to address the needs of scientists to express their ideas with precision, objectivity, and conciseness (Halliday, 2003; Swales, 1990). Science vocabulary can be difficult for learners as many of the science words have been borrowed from Greek and Latin (Hogben, 1970). Further, the grammatical structures employed in science writing can make it difficult for learners to understand (Fang, 2005, 2008; Snow, 2010). Snow shows how popular science articles are written in such a way to make the topic accessible for students. In contrast, textbooks are not written to allow for easy understanding.
Being aware of the language needs of ELs is necessary to help them succeed in their desired fields or disciplines.

Often science classes in the United States prefer to incorporate discovery pedagogy allowing students to discover the science content on their own (Wilson & Chavez, 2014; Adams, 2009). This approach allows students to discover the value of inquiry; however, it may put ELs at a disadvantage by not having the vocabulary to describe their inquiries. Even though the discovery approach seems as if it would beneficial to EL students, it can often be implemented in such a way that alienates the backgrounds and/or language needs of ELs. Hence, Lyons et al. (2016) addressed the need to bring more inclusive practices into science classrooms to meet the needs of the ELs. Exploring how to raise EL comprehension and understanding in STEM fields has increased in importance over the years, as ELs typically do not pursue studying STEM subjects.

In light of the interest in raising EL participation in STEM subjects, this dissertation is composed of two studies to observe the performance of ELs in secondary school science reading comprehension as well as in writing for a university biology course. The first study addresses aspects of reading science in a middle school classroom and the structures in place that could cause ELs to have less access to courses allowing further study of the subject in high school and/or university.

The International Journal of Bilingual Education and Bilingualism has accepted this article for publication. It was a collaboration led by Anna Karin Roo who performed the main analyses and composed the literature review exploring tracking for ELs and the iniquities that can result from tracking for ELs. Yuliya Ardasheva provided access to the data (part of a larger grant-funded study) and mentored through the statistical analysis stages of the manuscript.
Margarita Vidrio Magaña contributed to the literature review by providing a base of articles on tracking in mathematics as a starting place to explore tracking in science. Sarah Newcomer contributed to the final version of the article after the 'major review' decision by the journal contributing to some of the requested additions to the literature. This journal stipulated that the authors use the Chicago Style Guide as opposed to American Psychological Association (APA) typically used in the field of education.

The second study addresses the writing of EL students in an introductory biology major course at a U. S. university where the final laboratory (lab) section assignment is to write a full lab report. The study explored lab report writing following Parkinson’s (2017) genre analysis of lab reports focusing on the writing features of the nine ELs in the large lecture course.

As will be seen in these two studies as well as in the connecting chapter that there are areas of need for the ELs to have equitable opportunities for learning science. The K – 12 school system itself has built-in systems that can hinder the ability to learn and succeed in science education through tracking (Callahan & Schrifer, 2016; Callahan, 2005; Umansky, 2016).

There are structures in the university system as well that can challenge ELs from having equitable learning environments as well. Technical communication textbooks may have biases towards humanities norms of communication (Wolfe, 2009). Also, James (2010) notes limited transfer for science and business majors with the assignments for students in a general English for academic purposes course (James, 2010). ELs may have additional struggles to master the register norms expected for science literacy. ELs have struggles separate from their non-EL peers.

Addressing the needs of ELs is important for learning in the STEM fields. STEM literacy or lack thereof could be a reason that ELs tend to be underrepresented in STEM fields.
As this underrepresentation is an area of concern to increase ELs in STEM fields and careers. Understanding the needs of ELs within the K – 16 environment will allow them to have greater opportunities to enter into STEM fields and/or careers.
REFERENCES


https://doi.org/10.3102/00028312042002305


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CHAPTER TWO: STUDY ONE

Contributions of Tracking, Literacy Skills, and Attitudes to Science Achievement of Students with Varied English Proficiency

Abstract

This study examined contributions of academic ability tracking, disciplinary attitudes (science anxiety and self-efficacy), and discipline specific literacy skills (science and academic vocabulary knowledge) to students’ science achievement in a sample of 104 Grade 8 students (78% current or former English learners [ELs]) enrolled in high- versus low-track (50/50) classrooms at a Pacific Northwest urban junior high school. The final regression model explained 46% of the variance in students’ science reading comprehension scores; 11% of the variance in reading scores was uniquely explained by science vocabulary knowledge, above and beyond anxiety, self-efficacy, and tracking. Similarly, the final regression model explained 41% of the variance in students’ end-of-the unit science test scores; 20% of the variance was uniquely attributed to science vocabulary knowledge above and beyond anxiety, self-efficacy, academic vocabulary knowledge, science reading comprehension, and tracking. From a practical perspective, the results suggest that students need more explicit science vocabulary instruction to perform better on reading and achievement tasks, regardless of their track designation. From a policy perspective, current ELs’ underrepresentation in higher-track classes calls into question the equity of instruction provided to students. Recommendations to increase ELs’ access to academic content are discussed

Key Words

English learners, integrated classrooms, tracking, science and academic vocabulary, science achievement, science reading comprehension, science anxiety and self-efficacy
Contributions of Attitudes, Literacy Skills, and Tracking to English learners’ Science Achievement

Anna Karin Roo, Yuliya Ardasheva, Sarah N. Newcomer and Margarita Vidrio Magaña

1. Introduction

We would like to open this paper with an excerpt from an interview with Hector, an English learner (EL) participating in a research project documenting EL learning experiences in science classrooms (Braden et al. 2016). In the following exchange Hector elaborates on the things that he does not like about his science class:

Hector I think, trying to figure out what they’re talking about sometimes.

[Interviewer] What they’re talking about? [...] if the teacher’s just explaining something or if it’s written down in the book?

Hector If it’s in the book.

[Interviewer] If it’s in the book, okay. Is there anything that Ms. Anderson does that helps you to figure out what [the book says]?

Hector I’m just trying to put it in simple words. Because in English, there’s a lot of big words that mean some small words. But when you use the small words, it makes sense.

(Braden et al. 2016, 448)

As noted in this exchange, Hector finds it difficult to understand the ‘big words’ of the science texts and has not much to say about the teacher’s support to overcome this issue. Rather, this EL student relies on his own ability to translate/break down the big, difficult-to-understand words into smaller, more familiar words.

This description of Hector’s experience may be relevant for many EL and non-EL students when it comes to learning science in upper grades, where vocabulary demands are
substantially higher (Hiebert, Goodwin, and Cervetti 2017; Nagy et al. 2012). Both students’
general vocabulary and science vocabulary knowledge could cause students to struggle with the
concepts being presented in class or in textbooks thus undermining their comprehension and
achievement (Ardasheva et al. 2016; Groves 2016); this is particularly discouraging provided the
importance of this age bracket for disciplinary attitude formation (Engberg and Wolniak 2013).
The resulting achievement gap may lead to students – especially EL and low socio-economic
status students – being disproportionately placed into lower academic tracks, which, in turn, may
result in inequities in students’ future outcomes including increasingly limited course options as
students progress from middle to high school (Callahan 2005; Umansky 2016), limited access to
higher education opportunities (Kanno and Cromley 2013), and limited access to higher income
careers, particularly in science, technology, engineering, and mathematics (STEM) fields
(Callahan 2005; Callahan and Shifrer 2016; Kanno and Cromley 2013; see also Melguizo and
Wolniak 2012).

Thus, there is a need to examine malleable factors (factors under the control of
educational systems) that may minimize the negative effects of tracking early on and, potentially,
increase students’ chances to exit lower tracks. The present study will focus on two sets of such
factors, namely, disciplinary-specific literacy skills (vocabulary, reading comprehension) and
disciplinary attitudes (self-efficacy, anxiety), which are discussed after a brief summary of
evidence regarding the impacts of tracking on students’ academic careers. Before proceeding, it
is important to note that in addition to regular science curriculum, which included lectures,
readings, and hands-on investigations, students in the present study experienced extended
science and academic vocabulary instruction as part of the Science Vocabulary Support program
(described in greater detail in the methods section), which informed our interest in examining
vocabulary contributions to achievement, in relation to tracking and other variables of interest suggested by the literature.

2. Study background

2.1. Tracking

As described by Oakes (2005), tracking refers to an institutional-level grouping of students based on their academic ability. There are two types of tracking, namely, within- and between-groups. Within group tracking refers to classrooms with heterogeneous ability students being sub-grouped into more homogeneous ability groups (e.g. reading level groups). Between-group tracking refers to situations where students are separated into homogeneous ability groups at a classroom level (e.g. advanced placement versus regular education classrooms). The within-group ability configuration primarily occurs in elementary school classrooms. As students transition into secondary school, the between-group ability configuration, also known as tracking, becomes more prominent and can exist in the form of streaming, ability grouping of students for all classes, or banding, grouping of students for some subjects but not for others.

Track placement decisions are primarily based on students’ academic performance history; other factors such as academic specialization, teacher judgment, or general ability may influence students’ track placement (Oakes 2005). The main goal of tracking is to provide students with instruction ‘tailored’ to their abilities (Slavin1990). Yet, research- primarily conducted in mathematics classrooms– suggests that although high-achieving students tend to benefit from tracking, the opposite is true for low-achieving students (Hallam and Ireson 2005; Oakes 2005). Further, and most pertinent to our study, research suggests that middle school is a particularly important time in regards to tracking. Newton (2010), for example, found that students placed in a low-track classroom in middle school had lower achievement and an overall
slower learning rates by their senior year. Similar results were reported in Cheung and Rudowicz (2003). In other words, once assigned, it may become difficult or even impossible for the student to leave the assigned track.

This disproportionality affects ELs (Callahan 2005; Zuniga, Olson, and Winter 2005) and low socioeconomic status students (Boaler 2008; Oakes 2005), as immigrant and low-income families may be less aware of how to avoid low-track placements for their children (Oakes, 2005). As noted in the introduction, limiting content course options for ELs in middle and high school may then lead to students’ not pursuing post-secondary education (Callahan and Shifrer 2016; Kanno and Cromley 2013) thus undermining not only students’ academic but also their professional career choices.

Thus, there is a need to examine malleable factors under the control of educational systems that may minimize the negative effects of tracking. Building on the literature discussed in the next paragraphs, we identify two sets of such student-level factors of interest to the present study, namely, discipline-specific literacy skills (vocabulary, reading comprehension) and disciplinary attitudes (self-efficacy, anxiety), to examine whether or not these factors contribute to students’ science performance above and beyond track designation.

2.2. Discipline-specific literacy skills

2.2.1. Academic vocabulary, reading comprehension, and achievement

Science literacy includes multiple components (e.g. habits of mind, plausible reasoning, critical thinking, multimodal representation competence, information communication technology strategies; Lemke 2002; Wilson and Chavez 2014; Yore, Pimm, and Tuan 2007). An essential component of any disciplinary literacy, including science literacy, is the mastery of the academic language of the discipline. Academic language, the ‘specialized language, both oral and written,
of academic settings that facilitate communication and thinking about academic content’ (Nagy et al. 2012, 92), relies on both linguistic (attention to form) and metacognitive (e.g. ‘analyzing texts for relationships’) competences (Scarcella 2002, 219).

One of the distinguishing, but not sole, characteristics of academic language, Nagy et al. (2012) argue, is its higher vocabulary demands (e.g. higher number of content words per sentences, higher prevalence of Latin- and Greek-origin and morphologically complex words). Comparing same grade level informational (academic) and narrative (story) texts from the same publisher, Hiebert and Cervetti (2012), for example, noted that ‘narrative’ words were less frequent in informational texts and that vocabulary (as well as syntactic structures) in informational texts was more complex than that in narrative texts. Many refer to the first type of vocabulary as everyday words (e.g. ‘leaf,’ ‘stem;’ also known as Tier I words) and to the second type as academic vocabulary (e.g. ‘analyze,’ ‘composite;’ also known as Tier II words; Beck, McKeown, and Kucan 2013). Although academic words are commonly encountered across disciplines, they may pose a unique challenge for students due to their lower frequency outside of academic contexts and to their taking a slightly different, content-specific meaning in each discipline (Hyland and Tse 2007).

Secondary school students may be particularly challenged in accessing information presented in texts as there is evidence to suggest that vocabulary demands in informational texts increase in upper grades. Examining Common Core exemplar texts across grade levels, Hiebert, Goodwin, and Cervetti (2017, 5) estimated that the average length of a middle school text was almost two times longer than that of an elementary school text and that academic words ‘accounted for a sizable portion of the vocabularies,’ increasingly so at the secondary school level, with ‘late-appearing words [gaining] in prominence in higher level texts as some
elementary-level words become less frequent’ (Hiebert, Goodwin, and Cervetti 2017, 1; see also discussions in Gabig and Zaretsky 2013).

Non-surprisingly, then, researchers and educators argue that all students need to master academic vocabulary as these words are encountered not only in texts, but also in discussions and assessments (Groves 2016; Kachchaf et al. 2016; Nagy et al. 2012). Indeed, a robust body of research identifies academic vocabulary as a strong predictor of reading comprehension and academic achievement across subject areas among both ELs and non-ELs (e.g. Ardasheva et al. 2017; Lara-Alecio et al. 2012; Taboada 2012; Townsend et al. 2016; Van Orman, Ardasheva, and Carbonneau 2018). In a study of Grade 7 and 8 students, Townsend et al. (2012), for example, found that the amount of the variance explained by different aspects of vocabulary knowledge – above and beyond SES and language minority status – in students’ Iowa Test of Basic Skills scores in reading, science, social studies, and mathematics was 43%, 34%, 29%, and 29%, respectively. Similar results were reported for high school students (Townsend et al. 2016).

2.2.2. Knowing and learning science vocabulary

Many educators (e.g. Harmon, Hedrick, and Wood 2005; Snow 2010) argue that the ‘big words’ of science – as Hector calls them in his interview discussed earlier – include not only general academic vocabulary words, but also discipline-specific, technical terms. Such terms refer to scientific concepts, phenomena, and processes (e.g. ‘chromosome,’ ‘photosynthesis,’ ‘erode;’ Harmon, Hedrick, and Wood 2005) and are necessary for students to fully understand in order to be able to access science texts. Science-specific vocabulary contributes to the precision in science texts by avoiding the use of more general, everyday terms thus allowing for easier transfer of ideas from one scientist to another (Arya, Hiebert, and Pearson 2011). Yet, the
resulting high level of technicality in science texts may pose comprehension issues and alienate students of science (Arya, Hiebert, and Pearson 2011; Snow 2010).

Knowing (‘in the absence of instruction’) and learning (‘in response to instruction’) science terms, poses great challenges to all learners (Cervetti et al. 2015, 165). In their review of the topic, Cervetti et al. identified seven specific characteristics that may contribute to students’ difficulties with learning science vocabulary, namely: (1) low frequency in the English language per million words of text; (2) change in word meaning depending on part of speech (e.g. ‘force’ functioning as a noun [‘energy’] or as a verb [‘to make do’], each having a distinct, discipline-specific meaning); (3) words’ having different science versus everyday meanings (i.e. polysemy); (4) greater word length (i.e. greater number of syllables); (5) low versus high frequency within the domain (i.e. domain specificity); (6) low frequency of a word’s morphological family per million words of text (i.e. morphological frequency); and (7) low concreteness (i.e. the level of difficulty with which a word can be matched with a concrete picture, also referred to as high abstractness). Understanding the challenges associated with knowing and learning science vocabulary and the concomitant need for explicit vocabulary instruction is of particular concern in secondary schools where vocabulary demands may be particularly high. In examining a sample of 10 secondary science textbooks, Groves (2016) estimated the lexical demands of the textbooks to be at the same or higher levels than those in university-level foreign language courses.

Encouragingly, there is evidence to suggest that both general and science-specific vocabulary development can be effectively supported through robust instructional practices (e.g. Ardasheva and Tretter 2017; Lesaux et al. 2014; Snow, Lawrence, and White 2009; Townsend and Collins 2009). Robust science vocabulary instruction integrated with science instruction, in
turn, may translate into better science and literacy outcomes among both ELs and non-ELs (Lara-Alecio et al. 2012; Tong et al. 2014). Yet, with some notable exceptions (Ardasheva et al. 2017; Taboada 2012), research regarding the specific contributions of science vocabulary knowledge per se to student science reading comprehension remains limited. Similarly, little is known about the specific contributions of science vocabulary knowledge to science achievement (as measured by test performance; see a discussion in Kachchaf et al. 2016).

One of the aims of the present study, then, is to contribute to narrowing this gap by examining the specific contributions of vocabulary knowledge to student science reading comprehension and test performance, while taking into consideration academic track and, as we discuss next, disciplinary attitudes.

2.2.3. Disciplinary attitudes: science self-efficacy and anxiety

*Self-efficacy* refers to an individual’s perception of his or her ability to accomplish a given task; higher self-efficacy is believed to enhance self-regulation and performance (Bandura 1993). In science classrooms, Britner and Pajares (2006) argued, a student with higher science self-efficacy is more likely to choose more challenging tasks, to commit more effort to completing these tasks, and to persevere when facing difficulties; such behaviors would ultimately help the student gain more knowledge. By contrast, science anxiety, defined as ‘feelings of tension and stress that interfere with […] the development of science skills and abilities’ (Britner 2008, 690), is believed to undermine student science achievement. Griggs et al. (2013) attributed this to students’ interpreting their anxiety as evidence of future failure on a given task (see also Bandura 1993).

Indeed, previous research, conducted mainly with native speakers of the language of schooling, documented a positive association between science self-efficacy and science
achievement (Baroody, Merritt, and Rimm-Kaufman 2014; Britner 2008; Kupermintz 2002; Pajares, Britner, and Valiante 2000) and a negative association between science anxiety and science achievement (Britner and Pajares 2006; Kupermintz 2002; Pajares, Britner, and Valiante 2000). In a study of 281 middle school students, for example, Pajares, Britner, and Valiante (2000) reported that science GPA had a strong positive correlation of .60 with self-efficacy and a moderate negative correlation of −.30 with anxiety (see Study 2). Similar size (and direction) bivariate correlations were reported in Britner and Pajares’s (2006) study of 319 upper elementary and middle school students; the results of regression analyses, however, indicated that although science self-worth and self-efficacy explained 39% of the variance in students’ science GPA, anxiety did not explain any additional variance in student scores above and beyond student self-efficacy and self-worth beliefs.

Although limited, emergent research suggests that lower English proficiency may be associated with lower self-efficacy and higher anxiety in science (e.g. Ardasheva et al. 2018; Baroody, Merritt, and Rimm-Kaufman 2014; Griggs et al. 2013), with some studies reporting higher self-efficacy impact and other studies reporting higher anxiety impacts. That is, while Baroody, Merritt, and Rimm-Kaufman’s (2014) statistical modeling study found that science anxiety did not have a direct or indirect impact on ELs’ science achievement beyond self-efficacy, Ardasheva et al. (2018) found that only science anxiety had a direct negative effect on science learning. These findings suggest a need for more research on relative contributions of science anxiety and self-efficacy to student science learning across outcomes and student populations, while – most pertinently to our study – taking students’ language skills into consideration.
Overall, knowing more about students’ discipline-specific literacy skills, self-efficacy, and anxiety, and how those interact with tracking, may lead to better preparation of EL and non-EL students for the unique academic and linguistic challenges that can arise in pursuit of STEM subjects.

2.3. Purpose of the study

The purpose of the study was to examine if disciplinary attitudes (anxiety and self-efficacy) and discipline-specific literacy skills (vocabulary knowledge and reading comprehension) contribute to secondary students’ science performance above and beyond their track (low versus high) designation. The following research questions guided this study:

1. What are the relative contributions of ability tracking, science attitudes, academic vocabulary, and science vocabulary knowledge to science reading comprehension?

2. What are the relative contributions of ability tracking, science attitudes, academic vocabulary, and science reading comprehension to science (end-of-the-unit) test performance?

3. Methods

This study draws on a data subset from a longitudinal project evaluating the effectiveness of the Science Vocabulary Support (SVS) program in mixed English proficiency classrooms. The program is grounded in three instructional principles of powerful vocabulary instruction: (1) integration, to facilitate learning, instructed words and ideas need to be linked with other knowledge; (2) repetition, multiple exposures to the targeted words are needed to facilitate word learning, retention, and application; and (3) meaningful use, to develop complex and nuanced understandings, the instructed words need to be used across a variety of contexts (Nagy 1988). These principles are enacted through a set of research-based instructional practices (see Ford-
Connors and Paratore 2015) such as contextualization and decontextualization, teaching of learning strategies, negotiation, and personalization through multi-sensory processing. Students in the program experience an extended vocabulary instruction focused on 6 new (+ 4 review) words per week. The SVS program is aligned with regular science curriculum and includes direct instruction of new science and academic words on Monday followed by daily 5–15min word study activities across the rest of the week. More program details are provided in Ardasheva and Tretter’s (2017) study of the SVS program’s initial development and implementation with newcomer (year one in the country) ELs enrolled in a sheltered instruction school in a large Midwestern school district.

As noted earlier, the cross-sectional data for the present study were collected as part of a larger SVS program implementation project in integrated, mixed English proficiency classrooms. Data were collected by participating science teachers during regular school hours at the end of the first in the school year 8-week science unit focused on genetics. The SVS component of the genetics unit focused on 48 words (38 science-specific words such as ‘heredity,’ ‘chromosome’ and 10 general academic words such as ‘link,’ ‘structure’) selected by the teachers, in consultation with research team, based on unit needs analyses. Hierarchical linear regression served as the main analytical procedure for the present study.

3.1. Participants

A total of 104 eighth grade students from a Pacific Northwest public school completed the assignments for this study. The particular subset of the data used in the present study came from two high- and two low-track classrooms for which the end-of-unit test scores were available. The enrollment in high- versus low-track students was 50/50 (52 students in each track). Students are placed in high- versus low-track classes based on history of scoring on state
standardized test in mathematics and language arts, historical grades in mathematics and language arts, teacher recommendations, and grades across all classes (when placing above-grade level students). Students were 12–14 years old (M = 12.8, SD = 0.47); 47% (n = 49) were female. The majority of the students were ELs, including both current ELs (n = 28), students who are eligible for English language support services, and former ELs (n = 53), students who tested out of the English language support services, but whose academic progress is still being monitored. Fourteen students were non-ELs and nine had missing EL-status data. Seventeen students had special education status. There were significantly more current EL and special education students in low track classrooms, χ(1) = 27.667, p < .001 and χ(1) = 15.822, p < .001, respectively. The majority (95%) of the students in the participating school qualified for free or reduced-price lunch. Spanish was the primary home language for most (90%) students.

3.2. Measures

3.2.1. Science anxiety

To measure science anxiety, which we operationalized as science grade anxiety, five items from May’s (2009) Mathematics Anxiety and Self-Efficacy Questionnaire were adapted to better fit the science context (e.g. ‘I worry that I will not get a good grade in my science class;’ all items are listed in Appendix 1). The items asked students to rate their science anxiety levels on a scale from one to five, where one reflects a strong disagreement with the item and five reflects a strong agreement with the item. The Cronbach’s alpha for the scale was .88.

3.2.2. Genetics self-efficacy

Genetics self-efficacy was measured by five items adopted from Midgley et al.’s (2000) Academic Efficacy questionnaire. The items were adapted to better fit the genetics context (e.g. ‘I believe I understand genetics well;’ see Appendix 1). Similar to the anxiety scale, each item
asked students to rate their abilities in science on a scale from one to five. The Cronbach’s alpha was .86.

3.2.3. General Academic Vocabulary Measure (GAVM)

The GAVM (Ardasheva et al. 2017) assessed student’s memory of Grade 7 academic vocabulary chosen by the school’s science teachers, cross-referenced with Coxhead’s (2000) Academic Word List (AWL), and taught as part of the SVS intervention program in that school year. Coxhead’s AWL is a compilation of 570 most frequent general academic word families derived from a corpus analysis of 3.5 million running words of academic text. The list accounts for about 10% of words in academic texts.

Examples of words tested by GAVM included ‘evolve,’ ‘complex,’ ‘process,’ and ‘mechanism.’ Following Schmitt, Schmitt, and Clapham’s (2001) task format, the measure had six stem items, each having six words (3 target and 3 distractor words) to match with three definitions given (see example item in Appendix 1). This format resulted in 18 individual items; each correct response was awarded one point for a maximum total of 18 points. For the analyses, raw scores were converted into percent-correct. The Cronbach’s alpha was .77.

3.2.4. Vocabulary-of-Science Scale–Genetics (VSS–G)

This measure included 20 items aligned with Grade 8 genetics unit. The first five items asked students to identify the best word to match with a given picture. This task followed Duncan and De Avila’s (1994) Vocabulary Subscale of Language Assessment Scales-Oral (LAS-O) format. Identical to GAVM’s format, the remaining 15 individual items asked students to pair words with definitions.

Examples of words tested included ‘mitosis,’ ‘genotype,’ ‘chromosome,’ and ‘gene.’ These words were a representative subset of words covered by the SVS program (about 53%,
with balanced representation across week-by-week curriculum coverage). As noted earlier, all SVS words were selected by the teachers, in consultation with research team, based on unit needs (texts, tasks, tests) analyses. All correct responses were awarded 1 point for a maximum total of 20 points. For the analyses, raw scores were converted into percent-correct scores. The Cronbach’s alpha was .76.

3.2.5. Science Reading Comprehension (SRC)

Students’ ability to comprehend scientific text was assessed with 18 items (α=.71). Each item was presented in a multiple-choice format with four items gauging students’ understanding of vocabulary within context and 14 items gauging students’ comprehension after reading two expository passages, ‘Genetics’ and ‘Genome’ (adopted from Howell, Rogers, and Henderson [2003] and Ridley [1999], respectively). Comprehension items included global comprehension, inference, and detail questions. The SRC format was adopted from Lesaux et al. (2010). Example items for detail and vocabulary included, respectively: ‘According to paragraph 8, which set of bases listed below makes up RNA?’ ‘In paragraph 4 of the selection, the word “blending” is closest in meaning to […]?’ Questions were scored as correct (1 point) or incorrect (0 points) and a total percentage correct was used in the analysis.

3.2.6. End-of-the-unit genetics test

Student genetics knowledge was assessed by curriculum-specific end-of-the-unit tests. Questions were developed by the school science teachers based on released items (available online) from the state’s Grade 8 standardized science assessment. The tests were tailored to high-versus low track groups’ language proficiencies in that the test assessed the same content, but used less linguistically demanding format (matching, multiple choice, short answer) for low-track classrooms, requiring primarily the use of receptive (reading) rather than productive
(writing) language skills. Although both receptive and productive skills are important for academic success (Bridgeman, Cho, and Di Pietro 2016; Deygers, Van den Branden, and Van Gorp 2017), it has long been established that the development of productive skills is characteristic of more advanced stages of language development (see Gass, Behney, and Plonsky 2013). Indeed, productive skills require not only the ability to accurately understand, but also to effectively use language on morphological, syntactic, and semantic levels.

In particular, the high-track test had 8 open-ended, extended-answer questions (e.g. ‘Many dog breeders use purebred animals to have offspring. Why would a dog breeder want to use purebred animals for their business? Use a Punnett Square as part of your justification’). Each answer was scored holistically on a 0–4 points scale for a maximum of 32 points. The low-track test had 10 definition-match items (e.g. ‘Punnett square’ to match with ‘A chart that helps predict the probability of trait in offspring;’ up to 1 point per each correct answer); 5 multiple-choice items (e.g. ‘What is the genotype of the grandmother: FF, ff, Ff, or f? [Use the pedigree chart to the right];’ up to 2 points per each correct answer); and 4 short response items (‘A homozygous critter with the dominant trait of blue tails bred with a heterozygous critter of the same trait. (a) What phenotype does the heterozygous critter possess? (Use T and t) (b) Create a Punnett Square that shows the possible genotype of their children;’ up to 10 points per correct answer). The test had a maximum of 50 points. The raw test scores were converted to percent correct to allow for comparison across groups.

4. Results

4.1. Preliminary analyses

Assumptions related to normality and missing data were addressed before completing any analyses. Because data were missing completely at random, $\chi(54) = 62.957$, $p = .189$, missing
data on academic and disciplinary variables (range: 2.9%–12.5%) were imputed using the expectation maximization method. Results conducted on non- and imputed data sets yielded similar results.

Table 1 summarizes descriptive statistics disaggregated by track. Low track students tended to have higher science anxiety and lower self-efficacy and academic achievement scores than did high track students. The differences were statistically significant (as indicated by confidence intervals not including zero) and moderate to large in size (Cohen’s effect size range: −0.60–1.52; see Table 1). Appendix 2 provides descriptive statistics for the study variables.

Table 2.1

<table>
<thead>
<tr>
<th>Variables</th>
<th>Track</th>
<th>Cohen’s Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low M</td>
<td>SD</td>
</tr>
<tr>
<td>Science anxiety</td>
<td>3.25</td>
<td>0.93</td>
</tr>
<tr>
<td>Genetics self-efficacy</td>
<td>3.14</td>
<td>0.71</td>
</tr>
<tr>
<td>Science vocabulary</td>
<td>52.61</td>
<td>16.88</td>
</tr>
<tr>
<td>Academic vocabulary</td>
<td>46.86</td>
<td>17.94</td>
</tr>
<tr>
<td>Science reading</td>
<td>37.77</td>
<td>13.77</td>
</tr>
<tr>
<td>Science test</td>
<td>63.18</td>
<td>15.49</td>
</tr>
</tbody>
</table>

Note. N = 104. CI = confidence interval.

4.2. Research question 1

Table 2 reports the outcomes from the first hierarchical linear regression to determine the contributions to students’ science reading comprehension of, in blocks: (1) track, (2) science anxiety and genetics self-efficacy, and (3) academic and science vocabulary knowledge. To establish a baseline, Step 1 regression model had track as the solo predictor, which had a significant contribution to the model at \( p < .001 \) and explained 30% of the variance in student science reading comprehension scores. A lower track designation predicted lower science reading comprehension scores by about 21 percentage points.

Step 2 added science anxiety and self-efficacy to the model. Adding these disciplinary attitude variables explained an additional 5% of the variance in student science reading...
comprehension scores (ΔR² = .05, p < .05). Track remained significant at p < .001; science anxiety and self-efficacy had marginally significant effects at p < .10. Taking science attitudes into consideration, the predictive power of track designation was reduced by about 4 points.

Step 3 added academic and science vocabulary to the model and the contribution of science anxiety and self-efficacy became non-significant. In this final model, only track and science vocabulary were significant predictors of science reading scores at p < .001. Yet, the relative contribution of science vocabulary to reading comprehension was bigger than that of track, as indicated by standardized regression coefficients (B = .43 and B = .34 for vocabulary and track, respectively). A science vocabulary score increase by 10 percentage points (corresponding to the knowledge of 2 additional science words) predicted an increase in science reading comprehension scores by 4.2 percentage points (corresponding to about 1 correct response on the reading test). Taking science vocabulary into consideration, the predictive power of track designation was further reduced by 4 points.

The final Step 3 model explained 46% of the variance in student science reading comprehension scores; 11% of this variance was uniquely explained by science vocabulary scores (ΔR² = .11, p < .001), above and beyond tracking, academic vocabulary, and science attitudes.

Table 2.2

Hierarchical Regression Model Results with Science Reading Comprehension as the Outcome

<table>
<thead>
<tr>
<th>Variables</th>
<th>Step 1 F(1,102) = 42.86***</th>
<th>Step 2 F(3,100) = 18.03***</th>
<th>Step 3 F(5,98) = 16.77***</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B (B)</td>
<td>B (B)</td>
<td>B (B)</td>
</tr>
<tr>
<td>Track</td>
<td>21.21 (.54)***</td>
<td>17.36 (.45)***</td>
<td>13.06 (.34)***</td>
</tr>
<tr>
<td>Science anxiety</td>
<td>-3.05 (-.16)†</td>
<td>0.13 (.01)</td>
<td></td>
</tr>
<tr>
<td>Genetics self-efficacy</td>
<td>4.52 (.17)†</td>
<td>3.24 (.12)</td>
<td></td>
</tr>
<tr>
<td>Academic vocabulary</td>
<td>-0.03 (-0.03)</td>
<td>-0.03 (-0.03)</td>
<td></td>
</tr>
<tr>
<td>Science vocabulary</td>
<td>0.43 (.43)***</td>
<td>0.43 (.43)***</td>
<td></td>
</tr>
<tr>
<td>Total R²</td>
<td>.30</td>
<td>.35</td>
<td>.46</td>
</tr>
<tr>
<td>ΔR²</td>
<td>.30***</td>
<td>.05*</td>
<td>.11***</td>
</tr>
</tbody>
</table>


4.2. Research question 2
Table 3 shows the results from the second hierarchical regression model to determine the relative contributions to science end-of-the-unit test performance, in blocks, of: (1) track, (2) science attitudes, (3) science reading comprehension, and (4) academic and science vocabulary. To establish a baseline, Step 1 regression model had track as the solo predictor, which had a significant contribution to the model at $p < .01$ and explained 8% of the variance in student test scores. Step 2 added science anxiety and genetics self-efficacy. In this model, track remained marginally significant at $p < .10$; science anxiety became another significant contributor to the model at $p < .05$ and explained an additional 8% in student test scores ($\Delta R^2 = .08, p < .05$).

Step 3 added science reading to the model. Self-efficacy and science reading became the only significant contributors to model at $p < .05$ and $p < .01$, respectively. At this step, as indicated by standardized regression coefficients, the relative contribution of science reading comprehension was the largest, almost two times larger than that of anxiety, $B = .30$ and $B = -.19$, respectively. Adding reading comprehension to the model explained an additional 6% of the variance in student test scores ($\Delta R^2 = .06, p < .01$).

In the final Step 4 academic and science vocabulary were added; science vocabulary became the only significant contributor to the model at $p < .001$. The results from this final model explained 41% of the variance in student end-of-the unit test scores; 20% of this variance was uniquely explained by science vocabulary scores ($\Delta R^2 = .20, p < .001$), above and beyond tracking, science attitudes, academic vocabulary, and science reading comprehension. A science vocabulary score increase by 10 percentage points predicted an increase in science test scores by 5.4 percentage points.
5. Discussion

This study examined the contributions of anxiety, self-efficacy, and vocabulary to students’ science achievement in high- versus low-track classrooms. The results of the final science reading comprehension regression model indicated that, although tracking remained significant, the relative contribution of science vocabulary to explaining student reading comprehension scores was larger than that of tracking (as indicated by standardized regression coefficients). The results of the science academic performance model indicated that – despite the end-of-the-unit science assessments’ being less linguistically demanding for the lower-track students – the role of track remained significant as the sole predictor of science test performance in Step 1 and a marginally significant predictor once science anxiety was introduced into the model in Step 2. Track lost its significance, however, once science literacy skills (reading, vocabulary) were introduced into the model in Steps 3 and 4. Overall, science vocabulary knowledge emerged as the strongest predictor of students’ science reading comprehension and the only significant predictor of end-of-the-unit science test performance. This study has three
main implications, one practical and two related to policy.

From a practical perspective, this study highlights the important role that science-specific vocabulary plays in science reading comprehension and test performance and provides an empirical justification for specifically targeting science-specific, technical vocabulary for instructional interventions. This may be particularly important as the results of our study—needing replication across populations, measures, and methodological approaches—suggest that disciplinarily, science-specific vocabulary knowledge may be more important than track designation, disciplinary attitudes, or academic vocabulary when it comes to understanding student science performance. Yet, typical classroom practices in upper grades rarely feature explicit instruction of science terminology (Ardasheva and Tretter 2017; Miller 2009; see also Scott, Jamieson-Noel, and Asselin 2003). This, in part, may be due to a frequent argument among educational researchers and scholars that teaching academic rather than technical vocabulary may be more beneficial for students as the former vocabulary type occurs more frequently and across subject areas (see Nation 2001). This argument has been strongly contested by a number of scholars researching science teaching and learning (Arya, Hiebert, and Pearson 2011; Cervetti et al. 2015; see also Ardasheva et al. 2017; Ardasheva and Tretter 2017).

Indeed, improving science vocabulary knowledge has the potential to provide students with a greater foundation in the language of science. Giving access to content-specific vocabulary instruction in the disciplines would give students, EL students in particular, a better chance to comprehend textbooks (Groves 2016) and to complete required standardized examinations (Kachchaf et al. 2016). With a greater level of vocabulary available, students will be afforded a greater chance at success, which should, in turn, translate into minimizing science anxiety and building science self-efficacy and achievement (Ardasheva et al. 2018; Britner and
Pajares 2006). Because science topics recur from grade level to grade level, with science understandings building on each other (Fazio and Gallagher 2014; Harmon, Hedrick, and Wood 2005), gradually and consistently building science vocabulary knowledge over time is essential, especially for ELs (Ardasheva et al. 2018; Tong et al. 2014).

Of course, ‘learning science vocabulary is not simply a matter of learning a list of terms; it is a process of developing an understanding of relationships between terms and meanings’ (Lee, Fradd, and Sutman 1995, 798–799). Indeed, diSessa (1993, 2008) argued, science concepts represent complex knowledge systems. For example, students may learn the scientific term ‘force’ and yet, understanding this concept as a physicist does require the activation of a web of interrelated terms, experiences, and intuitive knowledge. To complicate the matter, the intuitive (‘common sense’) knowledge often leads to misconceptions. For instance, from everyday experience one may know that pushing a smaller, lighter object is easier than pushing a larger, heavier object, which may lead one to equate force with effort. Yet, such an understanding leaves out key ideas related to force, such as friction and inertia. Such complexities have important instructional implications. By engaging students in an inquiry of force across multiple contexts, through various experiences, and by talking about not just the ‘what’ but the ‘why,’ diSessa argued, can help students reorganize their misunderstandings and develop a more robust and accurate conception. This implies that students need a wide range of experiences with science concepts and corresponding vocabulary, such as experimenting with moving various kinds of objects and then talking about what they think is happening and why. Through these kinds of activities and discussions, teachers can gradually help students think about the many other factors related to force.
Similar to diSessa’s (1993) proposal that eliciting students’ everyday understandings can act as a bridge to developing more sophisticated scientific understanding, Brown and Ryoo (2008) found that teaching scientific concepts in everyday language first and providing instructional scaffolds to help students translate this understanding into scientific language can promote students’ conceptual understandings of scientific phenomena and their ability to explain those concepts in both everyday and scientific language. In their study conducted with mixed English language prophecy elementary students, participants were presented with a computer learning module focused on the concept of photosynthesis; after an initial explanation of the scientific terms, the control group was presented the content only through scientific terms, such as ‘glucose’ and ‘chloroplast,’ while the treatment group was given the opportunity to first learn the entire process of photosynthesis through the use of everyday language, such as ‘sugar’ and ‘energy pouch.’ This gave students in the treatment group the opportunity to process the information before learning the key terms associated with the information. On the post-assessment, the treatment group performed statistically better, suggesting the need for explicit and distinct conceptual and discursive instruction. Disaggregating results by English proficiency levels in a study of Grade 8 students, Van Orman, Ardasheva, and Carbonneau (2018) found that regular science instruction – a combination of lectures, readings, and inquiry activities – resulted in a substantial science vocabulary growth among proficient English speakers, but there were no statistically or practically meaningful gains for current ELs. Supplementing science instruction with extended vocabulary support (SVS program activities), on the other hand, did generate a large gain for current ELs and doubled gains for proficient English speakers, suggesting that SVS-like activities may be a good language support for students, when/if they need it.
Overall, there is a growing consensus in the literature that disjointed instruction of content with no attention to the domain-specific language demands and of language forms with limited to no connections to academic subject matter would undermine meaningful learning (Ardasheva, Norton Meier, and Hand 2015; see also Buxton and Lee 2014). Thus, education for all students, but particularly so for ELs, must be multifaceted, promoting both science and academic language and literacy development. Still, a lot remains to be learned about how to design instruction to increase students’ science vocabularies in meaningful ways.

From a policy perspective, this study has two main implications. First, the substantially narrower gap on end-of-the unit assessment than on the reading assessment is consistent with emergent, yet still limited body of work documenting benefits of EL accommodations (e.g. bilingual texts, subject specific glossaries, simplified English, extended time, scribed responses) during testing. Siegel (2007), for example, documented positive effects of using a combination of 11 accommodations – including linguistic (e.g. vocabulary and syntax simplification), cognitive (e.g. graphic organizers), and visual (e.g. bolding, pictures) – on both EL and non-EL science outcomes. Notably, ELs showed almost twice as much pre-to-posttest gains on accommodated versus non-accommodated science assessments. In their review on the topic, Buxton and Lee (2014) argued that ‘assessments of science achievement require consideration of fairness to different student groups’ by giving all students a fair chance to demonstrate what they know and understand about the content being tested (879). Yet, Buxton and Lee argued, research on science assessment and accommodations for ELs is still very limited and there are few definitive answers as to what accommodations are most effective and under what circumstances (see also a discussion in Ardasheva et al. 2015).
The results of this study suggest that assessments that rely more heavily on receptive skills may give students a better chance to demonstrate their knowledge, at least for current ELs, who, as we discuss next, constituted a majority of low-tack classrooms. Indeed, whereas matching/multiple choice questions allow students to simply select the correct answer, provided that they understood the question correctly (see Kachchaf et al. 2016), constructed response items require not only question comprehension, but also the use of advanced language skills to convey understandings—a more complex task for ELs, which may lead to students’ generating more content- and language-specific errors. That said, beyond accommodations to current English proficiency levels, we argue, ELs should also be gradually prepared for taking non-accommodated assessments required for grade promotion and graduation. This could be achieved by integrating 1–2 open-ended questions in earlier assessments and gradually increasing the number of this assessment type items over and across the school year(s). This would be most beneficial for ELs if meaning- and form-focused feedback is consistently provided regarding their constructed responses (see Bailey 2008), which could involve whole class or small group reviews, teacher conferencing/written feedback, and/or expert text analysis. Building foundational oral language skills through meaning negotiation and making reading and writing a regular part of science curriculum would also be beneficial (Ardasheva, Norton-Meier, and Hand 2015). Additional research is needed on contributions of other discipline specific literacy skills to science achievement.

Second, this study calls into question the equity of instruction provided to ELs. Similar to Callahan and Shifrer (2016), current EL students in this study were overrepresented in lower-track and underrepresented in higher-track classes, which, as Callahan and Schrifrer point out, may prevent ELs from receiving equitable education in content areas thus contributing to
perpetuating the vicious cycle of the ‘poor getting poorer’ and long-term EL status. Indeed, students in the low-track classrooms may not be getting the best instruction for their needs and school careers (Callahan and Shifrer 2016; Umansky 2016) and may never be able to exit out of the low-track status, limiting their future options as they move on to high school or beyond (Kanno and Cromley 2013). As Umansky (2016) pointed out, ELs come to schools with vulnerabilities, but also with unique sets of strengths such as cross-linguistic, cross-cultural, and international competencies and skills. Yet, all too often ‘schools interpret these assets as weaknesses as schools become focused on students’ lack of English proficiency and the implications this may have on students’ ability to participate in schools that are structured for native English speakers’ (1825). Course access stratification through tracking becomes the key contributor to limiting ELs’ opportunities.

‘Fortunately, many of the factors that are limiting ELs’ access to content are malleable to changes in policy and practice’ (Umansky 2016, 1825). These may include greater emphasis on discipline specific literacy skills (as suggested by the results of our study), greater emphasis on the overall quality of academic preparation (Callahan and Shifrer 2016), bringing culturally responsive practices into the classroom (see Lyon et al. 2016), and removing nonlinguistic barriers to educational opportunities such as investing time and effort into building school/family connections, providing financial assistance, and eliminating the practice of tracking all together (Kanno and Cromley 2013). If the goal of education is to be equitable to all students, it may be time to address the structures in place that could be limiting educational opportunities at the secondary school level for EL students by urging educators to ‘think in terms of their students’ postsecondary preparation’ (Callahan and Shifrer 2016, 487).
REFERENCES


doi:1080/0737000802391760.


Appendix A: Sample of Study Measures’ Items

Science anxiety (full list of items)
1. I worry that I will not be able to do well on science tests.
2. I get tense when I prepare for a science test.
3. I get nervous when taking a science test.
4. I worry that I will not be able to get an “A” in my science class.
5. I worry that I will not be able to get a good grade in my science class.

Genetics self-efficacy (full list of items)
1. I believe I am good at genetics.
2. I believe I understand genetics well.
3. I believe I can learn genetics well.
4. I feel that I will be able to do well in future genetics classes.
5. I believe I can understand the content in genetics classes.

GAVM example item (Directions: Choose the right word to go with each of the three definitions. Write the letter of that word next to its definition.)

| _______ to change something | A. manipulate |
| _______ to judge the value or condition of something | B. respond |
| _______ to react to something | C. transfer |
|                                  | D. coincide |
|                                  | E. design |
|                                  | F. evaluate |
Table 2. Appendix B

Descriptive Statistics and Correlations among Study Variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>M</th>
<th>SD</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
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<tbody>
<tr>
<td>1. Track</td>
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<td>3. SPED status</td>
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<td>-.39***</td>
<td>.31**</td>
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<tr>
<td>4. Anxiety</td>
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<td>-.29**</td>
<td>.27**</td>
<td>.06</td>
<td>--</td>
<td></td>
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<tr>
<td>5. Genetics self-efficacy</td>
<td>3.37</td>
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<td>.32**</td>
<td>-.17</td>
<td>.07</td>
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<td>6. Science vocabulary</td>
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<td>.44***</td>
<td>-.34**</td>
<td>-.30**</td>
<td>-.52***</td>
<td>.30**</td>
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<td>7. Academic vocabulary</td>
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<td>-.38***</td>
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<td>.25**</td>
<td>.69***</td>
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<td>8. Science reading</td>
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<td>.54***</td>
<td>-.35***</td>
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<td>-.33**</td>
<td>.34***</td>
<td>.59***</td>
<td>.50***</td>
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<td>9. Science test</td>
<td>68.07</td>
<td>17.34</td>
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<td>-.32**</td>
<td>.25*</td>
<td>.64***</td>
<td>.46***</td>
<td>.41***</td>
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</tr>
</tbody>
</table>

Note. N = 104 *** p < .001. ** p < .01. * p < .05. † p < .10. Track status: low = 0, high = 1. EL status: proficient = 0 (non- and former ELs), emergent = 1 (current ELs). SPED status: non-special education = 0, special education = 1.
CHAPTER THREE: TRANSITION

The study in previous chapter, which described English learners (ELs) studying in high and low track middle school classroom, highlights the importance of ELs content vocabulary needs. The chapter also included a discussion on the social justice implications involved in preparing students for STEM fields and higher education. Chapter 4 will present a study on the writing abilities of students in an introductory major level biology course at a U.S. university. This current chapter addresses curricular gaps when preparing ELs to study within science, technology, engineering and mathematics (STEM) fields.

The disparity of minority students’ representation in STEM fields and careers is partially a result of the barriers in place that prevent student access to college preparation courses (Kanno & Cromley, 2013; Callahan & Schrifer, 2016). However, the disparity may not be obvious because there are many international students pursuing degrees in those fields at U. S. universities. China, India, and Korea are some of the top nations sending students to study in U. S. universities. Nevertheless, international students face similar struggles in mastering the language of science or engineering in English as U. S. students within the K – 12 system.

Students coming out of an English for academic purposes (EAP) program or an intensive English program (IEP) may not be fully prepared for academic work in certain fields in comparison with other fields of study. Students in a general EAP course at a U. S. university may not develop skills that are easily transferrable to science or business majors in comparison with humanities or social science (James, 2010). This puts ELs in science or business majors at a disadvantage because these students often do not have linguistic support from their major faculty members as they approach writing within their perspective disciplines.
Discussing academic discourse is necessary before addressing the shift from reading to writing, and also the shift from secondary school to university. Academic discourse refers to standards of spoken and written language use in academics (Duff, 2010). Duff (2010) defines academic discourse as the accepted normalized structures for written and oral language and their arrangements for interactions that are anticipated and prized by instructors and educational institutions in professional situations. The struggles ELs have with academic discourse can include incorrect vocabulary use (Coxhead, 2012), or the use of inappropriate socialization features of the discourse (Qian & Krugley-Smolska, 2006), or both. Writing with the correct register requires using vocabulary forms and grammatical structures more challenging than everyday language (Schleppegrell, 2004).

**Intensive English Programs (IEP) focus on general academic discourse**

ELs have difficulty transitioning across different writing contexts – especially transitioning from high school to college (Harklau, 2001). This issue becomes more pronounced when a student transitions from a non-English speaking nation to an English-speaking environment. After reviewing different English for speakers of other languages (ESOL) textbooks written or designed for the IEP or EAP market, even the higher level writing textbooks do not address features from different genres. These books typically focus on the five–paragraph essay structure. Peter S. Gardner’s *New Directions* (2005) focuses only on the five–paragraph essay format. Folse, Muchmore-Vokoun and Solomon’s (2014), *Great Writing 4: Great Essays* focuses on four different essay types. Trudy Smoke’s (2005) *A Writer’s Workbook: A Writing Text with Readings* (4th Edition) focuses on different essay types, but at least mentions literature review writing. The highest level book in Cambridge’s Draft Series: *Final Draft 4*, touches on seven different essay types (Asplin, Jacobe & Kennedy, 2016). With the exception of
Smoke’s (2005) book, all these textbooks for language learners only address different essay types. When textbooks only address essay types, a student could walk away from a writing class thinking that the essay is the only type of academic writing encountered in English speaking academia. This overview is similar to the findings of Wolfe (2009) who argues that students in technical communication courses get short-changed by a humanities bias in technical communication.

Another example of the struggles an EL could face is found in Miller (2011), Miller found that the texts used in a U.S.-based IEP courses did not represent the sentence level language used in university level textbooks. His data showed that, contrasting with the Academic Word List (AWL; Coxhead, 2000), the vocabulary used in university textbooks is more demanding than that in ESOL textbooks. The language used in social science and natural science books had more words that were not on the AWL. These findings suggest that there is room for improvement in the structure and/or presentation of IEP courses related to academic disciplines as disciplines have their own norms of writing.

The vocabulary used in more advanced English courses can become misleading for students planning to study at an English speaking institution. They may get a false sense of their English language ability. This could also put students wanting to pursue STEM fields at a disadvantage in that they may not have the linguistic structures needed to understand and/or produce knowledge in STEM fields.

**Genre differences and English leaners**

Genre often refers to a form of organization. There are different genres of music or writing. Australia has developed a strong background for teaching the purposes behind each written genre and not just the genre itself (based on systemic functional linguistics (SFL,
Halliday, 1994). This Australian form of instruction provides students with knowledge of the written format and the purposes behind its use. Johns (1997) explains genre as a shared knowledge of context for the writing. Unlike literary forms of writing, which are often covered in English courses whether in high school or at the university, non-literature writing is limited in school curricula. If students are only exposed to a literary purpose of writing, they may develop a limited understanding of the usefulness of genres in different contexts.

At the high school level, English teachers are expected to help their students be able to write well for their discipline-specific courses, which may not be the case in reality. Even in an affluent school district in Washington state, ELs may not be getting the instruction they need to write well in the disciplines as well as for college application essays (personal communication, Christina Federighi, December 26, 2017). Often the EL students in Federighi’s class end up in the “danger zone” according to the state standardized Smarter Balanced Assessment (SBA). Even after suggesting additional grammar support Federighi’s ELs are not able to write at the same level as their non-EL peers.

Just as transfer from an EAP course may not happen easily, discipline instructors themselves may not know how to provide support for their EL students. Interviewing four discipline-specific instructors at an Australian university, Arkoudis and Tran (2010) found that the instructors did not necessarily know how to best help their EL students to complete their writing assignments. When comparing student comments from the same larger study, there was a mismatch between what the students understood the criteria to be and what the instructor believed was communicated. All four instructors in the study stated they tried to write clear and explicit instructions for their assignments. The students from those classes, however, struggled to understand the requirements of the assignments. This mismatch seems to have occurred as a
result of the technical conventions used in the discipline not being fully transparent to the students, and the students needing help to address the content for the assignments. Two of the four instructors interviewed referred students to the university’s language support center. James’ (2010) and Arkoudis and Tran’s (2010) studies show that international students may have the English skills needed to study in an English-speaking institution, but may not have the pragmatic skills in English necessary to fully engage in their discipline.

Writing center goals typically aim to help students become better writers focusing on global writing errors (as a guide for the revision process) as opposed to local (sentence level) writing errors (Williams, 2004; 2006). Therefore, instructor advice to use the campus writing center may not provide the desired outcome for ELs. Okuda and Anderson (2017) show how graduate student ELs learn to make a university writing center meet their needs after an unfavorable initial experience for their learning and development as an English writer for their specific discipline. ELs may need to learn how “work the system” to get the writing support that they actually need from a writing center thus placing an additional burden upon ELs as they navigate the university writing environment.

The previously mentioned situations suggest that there may be additional factors affecting EL performance when writing for science whether lab reports or other technical documents at the university level. These factors can include reading science specific textbooks for course materials, as well as not having their English skills easily transfer to the science discourse community. Knowing the difficulties that ELs can face makes it necessary to identify steps and skills that ELs could utilize to be successful in their university level science courses.
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CHAPTER FOUR: STUDY TWO

Genre analysis of English learners writing of laboratory reports in an introductory biology course

Abstract

This study analyzed the writing of first year biology final laboratory (lab) reports with a focus on the abilities of English learners (ELs; n = 9) in comparison with their non-EL apprentice (non-ELs achieving at the top 10% of the lab assignments; n = 9) and novice (non-ELs achieving at the lower 10% of the lab assignments, n = 9) peers according to Parkinson’s (2017) move analysis for student lab reports. Quantitative findings based on analysis of variance (ANOVA) and chi square tests on total word counts, completeness of Parkinson’s (2017) moves and frequency of Parkinson’s moves suggest that the EL writers were typically in between their apprentice and novice peers. Thus signifying that there are differing abilities between the three groups of students in acquiring the science report genre. The qualitative findings highlight some of the differences between ELs and their non-EL peers in the five sections of the lab report. There is evidence that both the ELs and their non-EL peers struggle with fully acquiring the lab report format resulting in an incomplete mastery of the genre in this introductory biology course. Thus suggesting that all students are still learning the art of science writing.

Key Words: genre analysis, English learners, biology, writing, laboratory reports
Introduction

An integral part of learning the biological sciences at the university level is learning to write the laboratory (lab) report. The lab report is different from a research article (RA) in that students write lab reports on existing, confirmed methods and facts to learn the subject (Bhatia, 1993; Parkinson, 2017), as a form of apprenticeship writing (Poe, Lerner & Craig, 2010). In contrast, the RA is written by researchers to present new discoveries to their scholarly peers for review (Bhatia, 1993; Parkinson, 2017).

Efforts to address the challenge of science writing have been approached from two perspectives, namely: science pedagogy and English writing instruction pedagogy (Lerner, 2007). From the science side, Carter, Ferzli and Weibe (2004) found that students often did not understand the science behind the experiment about which the lab report was written. This lack of understanding of the science behind the experiment made it difficult for the instructors to grade the written reports. They also noted that the students performed better in their writing as a result of having a better understanding of the science behind the procedures.

A later study, exemplifying the English writing side, Carter, Ferzli and Weibe (2007) tracked the learning that students were doing when writing for an introductory biology course. In regards to learning the genre of the lab report, the students in the study related that they understood the lab report and its purpose in the course. This study also showed that the participants were more likely to pay attention and learn from the laboratory exercises because they had to write a lab report.

University faculty recognize that students struggle with the lab report format and writing according to the scientific method. Some solutions for this struggle have included required technical writing courses in conjunction with the university’s English department (Colton &
Surasinghe, 2014) or courses geared to teach students the steps involved in the research process (Colabroy, 2011). Other solutions that do not include creation of new courses have been to have pre-lab assignments (Morgan, Fraga & MacCauley, 2011), extensive genre exposure in class (Kelly-Laubscher, Muna, & van der Merewe 2017), peer reviews of the lab reports before final submission (Walker & Sampson, 2013), progressive writing of the full report (Van Bramer & Bastin, 2013), making the lab reports shorter (Simmons, Lario-Sanz, Shiva, & Rosell, 2014) and even providing example reports (Corradi, 2011).

Identifying the rhetorical structures common in lab reports will provide faculty with additional tools to help their students write better lab reports and become members of their respective discourse communities – something that would especially benefit English learners (ELs). One method of identifying rhetorical patterns and structures is to conduct a genre analysis.

**Genre Analysis**

Paltridge (2014) defines a genre as “a class of communicative events, such as academic essays, research articles, theses and dissertations” (p. 303). With this definition in place it becomes easy to think of the science RA and the student lab report as a single genre since they both follow the introduction, methods, results and discussion (IMRD) format. However, they serve different purposes (Bhatia, 1993; Parkinson, 2017). The IMRD format itself is set up to communicate research findings easily to the research community. This structure easily lends itself to quick reading by fellow researchers because they can quickly read through the results and discussion sections without having to read the introduction or methods before determining if the study is relevant to their own work. Some variations exist in the IMRD format based on the specific disciplinary norms (Lin and Evans, 2012).
One method of determining the rhetorical structure within a given genre is to conduct a move analysis. Move analysis was pioneered by Swales (Swales, 1990) on introduction sections in RAs. Biber, Connor and Upton (2007) refer to a move as “a section of text that performs a specific communicative function” (p. 35). The moves found within a specific genre work to promote the rhetorical function of that genre. Often it is the experts within a genre community that determine the genre’s function and can identify whether a writer is an insider or outsider to the community based upon the specified genre conventions. Moves may be broken into smaller steps to allow for the various elements that need to occur to attain the function of the move (Biber et al., 2007).

Swales’ pioneering work on genre analysis for the RA introduction sections focused on the moves to achieve the purpose of the section (Swales, 1990), demonstrates what should be in an RA introduction section. This allowed him to develop the ‘create a research space’ (CARS) model for introduction sections, composed of three moves achieved through different steps. The first move is to “establish a territory” which is accomplished through three steps: “claiming centrality,” “making topic generalization(s),” and “reviewing items of previous research.” The second move “establishing a niche” can be achieved through one of four steps: “counter-claiming, indicating a gap, question raising or continuing a tradition” (Swales, 1990, p. 142). The third and final move of the CARS model is to “[occupy] the niche” which can be accomplished through of two options. Step 1A is to “[outline] purposes” and Step 1B is to “[announce] present research” and then to “announce principle findings” and “indicating research article structure” (Swales, 1990, p. 142). However, Parkinson (2017) states that the CARS model is not entirely appropriate for students follow to write lab report introductions, as
students do not necessarily need to occupy or establish a niche as it has already been established, and the work being completed is to learn the science.

Others have worked to expand Swales’ work on science RA introduction writing by analyzing other variations of research writing. Samraj (2002) compared the features of introduction sections in environmental science and wildlife biology RAs following the Swalesian method. Kanoksilapatham (2005; see also 2007) expanded the Swales’ move analysis to the entire RA. Peacock (2011) analyzed the moves in methods sections and ended with pedagogical suggestions for teaching the importance of this section. Basturkmen (2012) analyzed discussion sections in dentistry identifying two patterns of argumentation in how researchers make comments on the findings. Recently, Parkinson (2017) completed a move analysis on student lab reports.

Aside from these previously mentioned authors, work using Swalesian genre analysis has focused more on business or linguistics RAs and not articles in the hard sciences: Lim (2006) on management RAs, Yang and Allison (2003) on applied linguistics RAs, and Lores (2004) on abstracts in linguistics journals. Having information about each section of a RA provides students with a greater ability to write for their respective fields. Thus it is important to continue to expand the base of knowledge in science writing to help students studying in those fields.

Table 4.1

<table>
<thead>
<tr>
<th>Moves identified by Parkinson (2017; pp. 5, 6, 7, 8 &amp; 9) in science lab reports.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Abstract</strong></td>
</tr>
<tr>
<td><strong>Move A1 – Stating aim</strong></td>
</tr>
<tr>
<td><strong>Move A2 – Introducing topic</strong></td>
</tr>
<tr>
<td>Move A3 – Stating method</td>
</tr>
<tr>
<td>-------------------------</td>
</tr>
</tbody>
</table>

**Introduction**

<table>
<thead>
<tr>
<th>Move I1 – Establishing topic</th>
<th>Move I2 – Advancing hypothesis</th>
<th>Move I3 – Introducing experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1 – Claiming importance</td>
<td>Step 1 – Stating purpose</td>
<td>Step 2 – Describing procedures</td>
</tr>
<tr>
<td>Step 2 – Referring to known information</td>
<td>Step 2 – Describing procedures</td>
<td></td>
</tr>
<tr>
<td>Step 3 – Referring to literature</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Method**

<table>
<thead>
<tr>
<th>Move M1 – Listing materials</th>
<th>Move M2 – Describing experimental procedures</th>
<th>Move M3 – Detailing statistical information</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Step 1 – Detailing procedures</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Step 2 – Referencing procedure in laboratory manual source</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Step 3 – Illustrating procedure with a diagram</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Step 4 – Providing background to the procedure</td>
<td></td>
</tr>
</tbody>
</table>

**Results**
| Move R1 – Restating methodology                  | Step 1 – Listing procedures                      |
|                                               | Step 2 – Justifying methodology                  |
| Move R2 – Announcing results                  | Step 1 – Pointing to results                     |
|                                               | Step 2 – Displaying results                      |
|                                               | Step 3 – Explaining results                      |
|                                               | Step 4 – Calculating results/stating chemical equation |
| Move R3 – Commenting results                  | Step 1 – Explaining results                      |
|                                               | Step 2 – Evaluating results                      |

**Discussion**

| Move D1 – Contextualizing discussion          | Step 1 – Restating methodology                  |
| Move D2 – Interpreting results                | Step 2 – Stating selected findings              |
|                                               | Step 3 – Interpreting results                   |
|                                               | Step 4 – Comparing results with literature      |
|                                               | Step 5 – Displaying figure/graph/table/equation  |
|                                               | Step 6 – Accounting for (un)expected/unsatisfactory results |
|                                               | Step 7 – Substantiating results                  |
|                                               | Step 8 – Making claims/drawing conclusions      |
Move D3 – Stating limitation
Move D4 – Making suggestions for improvements

Conducting a genre analysis in and of itself is not the most important objective. According to Basturkmen (2014) replicating comparative genre studies imparts a greater understanding of the phenomena identified. This is the main reason to replicate Parkinson’s (2017) work using a corpus of American biology undergraduate students’ lab report writing and comparing the moves of non-EL students with those of ELs. The needs of ELs are different from their non-EL counterparts, and it is useful to know whether they writing comparably with their non-EL peers for the same assignment. Focusing only on lab reports from biology helps to narrow the results of this study to a specific field as there are differences across disciplines for RAs (Kanoksilpatham, 2015; Lin & Evans, 2012). These differences can also be noted in lab report guidelines and expectations for students as indicated in the Parkinson (2017) results. Using a corpus of American English texts will help identify any differences between American and British expectations for student lab reports.

For the present study, predetermined discourse units have been determined by Parkinson (2017) using Biber et al.’s (2007) approach to analyze 27 lab reports from the British Academic Writing in English corpus. The specific research questions for this study will address the features of EL student writing of lab reports from both a quantitative and qualitative perspective. From the quantitative perspective: How do EL writers’ lab reports compare to those of their non-EL peers? From the qualitative perspective: What elements distinguish EL student lab report writing from that of non-EL peers? Do these elements of EL writing meet the assignment requirements by the course instructor?
Methodology

Data Sources

Twenty-seven student lab reports were collected from the fall 2016 term from an introductory biology course focusing on cell biology and genetics for the purpose of conducting a genre analysis. The reports were split into three categories apprentice writers (non-ELs achieving at the top 10% of the lab assignments; \( n = 9 \)), novice writers (non-ELs achieving at the lower 10% of the lab assignments; \( n = 9 \)) and EL writers (\( n = 9 \)). This latter category is the primary focus of the study.

Determining EL status occurred through reviewing student records to see if the student was designated to take the university’s English 105 instead of English 101 composition course. The university’s writing assessment office website describes English 105 as follows: “This course provides instruction designed to develop academic writing, critical thinking, reading, library skills, and rhetorical strategies for non-native speakers of English. It is an equivalent course to English 101 and carries [WRTG] credit” (Writing Placement Process, n. d.).

The introductory cell biology and genetics course is a large lecture- and lab-based course offered every semester. It is a requirement for students who major in the biological sciences. The lab report is the main assignment in the lab section of the course. Students work on completing experiments throughout the semester that will allow them to write the report. Students submit two drafts of particular sections throughout the semester, one draft after the week four lab section (focusing on the introduction, finding references and avoiding plagiarism) and the other draft after the week eight lab section (focusing on methods, results and discussion). The teaching assistant (TA) gives the students feedback on their writing according to the course expectations. The assignment has two drafts, which students submit to their TAs for feedback.
The TA gives feedback on the drafts, which the student is supposed to use to write the final draft towards the end of the semester. The final draft does not receive any feedback; it is only graded. All paper submissions are done online through Blackboard, a learning management system. The papers are automatically checked for plagiarism through SafeAssign software. The TA grades the final draft of the assignment and the score is later added to the lab portion of the course’s final grade.

The semester from which the writing samples were collected included twenty lab sections taught by eight different TAs. The length of the semester did not allow enough time for grade moderation to occur among the TAs. The twenty-seven reports were collected from the five sections (taught by five different TAs) that had EL students. Limiting the sections from which the samples were collected helped control, to some extent, for any grading variation among the TAs.

Table 4.2
Descriptive data for the initial analysis of the 27 lab reports.

<table>
<thead>
<tr>
<th>Lab Section</th>
<th>Score Range</th>
<th>Number of ELs registered (out of 20) on the Final Lab</th>
<th>Number of “apprentice” non-EL papers in the section</th>
<th>Number of “novice” non-EL papers analyzed (scores in parentheses)</th>
<th>Number of EL papers analyzed (scores in parentheses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>13 – 20</td>
<td>1 (17)</td>
<td>2 (20, 20)</td>
<td>1 (13)</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>9.5 – 19.75</td>
<td>1 (15.5)</td>
<td>1 (19.75)</td>
<td>2 (9.5, 11.75)</td>
<td></td>
</tr>
</tbody>
</table>
Lab Report Requirements

The written instructions for writing the lab report include a brief summary of what the students should include in each section. These instructions for each section are presented in Table 3. The students get instructions for the report in two stages. They complete the first draft of the introduction section with references following one set of instructions and then are given a second set of instructions to complete the material and methods, results and discussion sections of the report at a later stage in the semester. The lab TA grades and gives feedback on the two drafts, and the students then submit a final draft including all the sections of the IMRD format along with an abstract.

Table 4.3
Instructions given to student for each section of the lab report (Davis, 2016 a & b).

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
<td>This section is where the author tells the reader what the paper is about and why it is important. This involves giving important background and references as well as the objective of the experiment. This section should end with a</td>
</tr>
<tr>
<td><strong>approximately 2-3 pages</strong></td>
<td></td>
</tr>
</tbody>
</table>

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65
A statement of the hypothesis along with predictions of the results. (Davis, 2016a, p. 1)

| Materials & Methods | The purpose of this section is to describe what you did, in enough detail so that another person can replicate the experiment. You shouldn’t explain every single step, but you should mention all the important points in paragraph form, written in your own words. It may help you to remember that a reader will reference the Materials and Methods section of a paper not only as a guide for replicating experiments, but also to assess if the experiments were done properly. Thus, the Materials and Methods section gives readers some insight into the rigor of your data. This section can also serve as a learning tool that readers can reference to learn how to perform new protocols. You must include the following protocols, each with its own heading:  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>approx. 2-3 pages</td>
<td>____ Isolate a Novel Phage from the Environment</td>
</tr>
<tr>
<td></td>
<td>____ Enriched Isolations</td>
</tr>
<tr>
<td></td>
<td>____ Direct isolations</td>
</tr>
<tr>
<td></td>
<td>____ Purify the Phage: The Spot Test and [t]he Plaque Assay</td>
</tr>
</tbody>
</table>
Results:

This section of the paper is where the results of the experiments are reported. It is necessary to report the results in both a written and visual form (tables and figures).

Tables and figures should have labels, including a title at the top and a legend describing the table/figure at the bottom. In the written portion, state the results, but do not interpret them yet. […]

Subtitles for each experiment can help organize this section. Furthermore, the reader should be reminded about the reason for performing each experiment. One or more introductory sentences should be used to justify each experiment. Once the focus of each experiment is made clear, the information sought in the experiment should be restated. Then the actual results can follow.

The following is the list of images and tables to be included in the final lab report. Note that you will not have results for all of these items at the time of this submission. Use this list to help you organize your results, but only include the work you have actually accomplished in lab up to this point:
Table with the morphology of plaques after each round of purification (streak protocols)

Image of a plate to show plaque morphology (the last streak assay or from the HTL Titer Assay is usually a good candidate)

A titer series documenting variable morphology if relevant: Were different plaque morphologies observed in the High-Titer Lysate (for the most concentrated plates)?

Electron microscope image

Agarose gel-restriction enzyme digest (Davis, 2016b, p. 1)

Discussion

This is approximately 1-1.5 pages. This is where the results of the experiment should be interpreted. First, briefly restate the information sought by the research. Other essential things to include here are the conclusions from your results, explanations for unexpected or ambiguous results, and discussions of error.

This section should be a sophisticated narrative and analysis of the research findings and not simply a summary of the data. The author should explore questions such as, “How do the results advance the field? What are the implications of this research? What is the relevance?” This is an opportunity to connect the current research being
reported with the information presented in the introduction section. Finally, the author should suggest what future studies need to be done based on the information gained from the research. (Davis, 2016b, p. 2)

This lab report assignment is rooted in the inquiry science method allowing students some control over their laboratory experiences in that they have some autonomy in making decisions based on the results of their work over the course of the semester (Adams, 2009). This is evidenced in that the students all follow the same procedures in the first four weeks of the semester, and then they are given time to adjust to the needs of their experiment for a few weeks. In the last few weeks of the semester, all the students again follow the same set of procedures to finish the aims of the course’s lab experiment. This structure did not work as planned for this particular semester in that the original bacterial host was not common enough in the region surrounding the university. The students had to redo the first few weeks of the lab procedures due to the unsuccessful bacterial host.

Analytical Procedures

The biology lab reports were coded following the moves determined by Parkinson (2017) for lab reports. Each report was coded for each IMRD section. Parkinson (2017) began her analysis by following the steps outlined by Biber et al. (2007) and determining the moves used in comparison with the fifteen moves identified by Kanoksilapatham (2005, 2007) for RAs. Biber et al.’s (2007) bottom up approach consists of a seven step process (1) identifying discourse units, (2) segmenting the corpus text into discourse units, (3) labeling and categorizing the discourse units, (4) analyzing the units for their linguistic characteristics, (5) describing the linguistic
characteristics according to its type within the corpus, (6) describing the sequence of the discourse units have to compose the text, and finally (7) describing the organizational patterns found in all texts that comprise the corpus.

After analyzing the papers for their moves, the frequency of the different moves was tallied. Following Kanoksilpatheram (2005) who determined that if a move occurred more than 60% in the corpus, it was considered to be conventional. If a move occurred less than 60% within the corpus, it was considered to be optional. Determining conventional moves helps to establish the standard expectations for students to achieve the accepted norms of the genre.

**Discipline Expert Consultation.**

Parkinson’s (2017) codes were checked with a biology discipline expert to verify that moves were being identified for the correct rhetorical purpose. In the same way, three TAs from the biology course were asked to review three apprentice papers and to check Parkinson’s coding schema for appropriateness to biology assignments. Then a final verification occurred with the course instructor. A majority of the TAs concluded that “Move M1: Listing Materials” (Parkinson, 2017) did not apply in biology. This was confirmed with the course instructor. Therefore, Move M1 was not considered in coding the lab reports for this particular study. Also the final review of the analysis was provided to the course instructor for feedback.

**Coding.**

Coding took place after multiple readings of each lab report to allow for a complete understanding of what was being communicated. Following both the Biber et al.’s (2007) and Parkinson’s (2017) approaches to working with lab reports allowed for a richer analysis of the differences between EL and non-EL writers of biology lab reports.
Inter-rater Reliability

To ensure the accuracy of coding, 25% of the reports were coded by a Biology PhD student. After an initial individual coding, of two lab reports (the training stage) the coders met to reconcile any differences. The remaining reports were coded independently. The inter-rater reliability was calculated using Cohen’s Kappa statistic (Viera & Garrett, 2005) for each section of the report between each rater. Cohen’s Kappa was selected for being a more robust measure than percent agreement as it accounts for chance agreements.

For each section of the lab report for the researcher and the biology TA Cohen’s Kappa ranged of .61 and .89 (percent agreements of 80.4 and 95.2, depending on the section). There was the least agreement in the results sections and the most agreement in the methods sections. The average Cohen’s Kappa was .72 (an average percent agreement across all sections of the report was 86.7). The researcher chose to follow the Biology TAs interpretation of the codes when coding the remaining papers.

Data Analysis.

After coding the 27 papers, each paper category (apprentice, novice or EL) were compared with the others using chi-square for comparison of move frequencies. In addition, the reports’ elaboration (word counts per section), and completeness (presence or lack thereof each IMRD section) were compared for the three groups of students using an analysis of variance (ANOVA) and the Scheffe post hoc test. Also, the grades of lab reports were compared using an ANOVA for the three categories of papers. The Scheffe post hoc test was selected due its conservativeness since the sample size of papers was limited by the number of ELs in the registered in the class (Tabachnick & Fiddell, 2012; Tabachnick & Fiddell, 2007).
Findings

Quantitative Findings

*Research Question 1.* The statistical results are discussed in the following order: a comparison of elaboration, completeness, and move frequency across the three groups of students. Using a one-way ANOVA of the total words used in each section (Table 4), there was a significant difference in the abstract $F(24,2) = 3.460, p < 0.048$, introduction, $F(24,2) = 11.894, p < 0.001$, methods, $F(24,2) = 5.320, p < 0.012$, and discussion, $F(24,2) = 6.124, p < 0.01$, sections. A post hoc Scheffe revealed that only the introduction, methods, and combined sections differed significantly between the EL (introduction $M = 363.00, SD = 146.04$, methods $M = 970.67, SD = 345.01$, and combined sections $M = 2,081.22, SD = 715.67$) and the apprentice (introduction $M = 559.33, SD = 88.96$, methods $M = 1,640.56, SD = 506.65$, and combined sections $M = 3,520.89, SD = 1,553.24$) papers at $p < 0.05$ for all outcomes.

Table 4.4
ANOVA results for elaboration (word counts) per IMRD section, comparison among ELs, apprentice and novice papers.

<table>
<thead>
<tr>
<th>Section</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>388333.852</td>
<td>2</td>
<td>194166.926</td>
<td>3.460</td>
<td>.048*</td>
</tr>
<tr>
<td>Introduction</td>
<td>470498.000</td>
<td>2</td>
<td>235249.000</td>
<td>11.894</td>
<td>.000***</td>
</tr>
<tr>
<td>Methods</td>
<td>2205588.222</td>
<td>2</td>
<td>1102794.111</td>
<td>5.320</td>
<td>.012*</td>
</tr>
<tr>
<td>Results</td>
<td>615489.852</td>
<td>2</td>
<td>307744.926</td>
<td>2.584</td>
<td>.096</td>
</tr>
<tr>
<td>Discussion</td>
<td>1354342.889</td>
<td>2</td>
<td>677171.444</td>
<td>6.124</td>
<td>.007**</td>
</tr>
<tr>
<td>All Sections</td>
<td>15770110.300</td>
<td>2</td>
<td>7885055.148</td>
<td>7.315</td>
<td>.003**</td>
</tr>
</tbody>
</table>

*Note:* *p < 0.05; **p < 0.01; ***p < 0.001
Table 5 reports the one-way ANOVA results on the completeness of the lab reports in this study using Parkinson’s (2017) moves. The abstract, $F(24,2) = 8.826$, $p < 0.001$, introduction $F(24,2) = 18.932$, $p < 0.001$, and discussion $F(24,2) = 6.872$, $p < 0.004$ sections were significantly different among the three groups. A post hoc Scheffe revealed that the abstract and discussion had significance between the EL (abstract $M = 3.00$, $SD = 1.80$, discussion $M = 1.67$, $SD = 1.32$) and the apprentice (abstract $M = 3.78$, $SD = 0.97$, discussion $M = 5.33$, $SD = 1.00$) papers at $p < 0.05$ for all outcomes, and that the EL ($M = 3.89$, $SD = 1.67$) and novice ($M = 1.11$, $SD = 1.83$) papers were significantly different in the introduction section at $p < 0.05$.

Table 4.5
ANOVA of Parkinson (2017) move completeness per IMRD section among the EL, apprentice and novice papers.

<table>
<thead>
<tr>
<th>Section</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>35.630</td>
<td>2</td>
<td>17.815</td>
<td>8.826</td>
<td>.001**</td>
</tr>
<tr>
<td>Introduction</td>
<td>72.222</td>
<td>2</td>
<td>36.111</td>
<td>18.932</td>
<td>.000***</td>
</tr>
<tr>
<td>Methods</td>
<td>.519</td>
<td>2</td>
<td>.259</td>
<td>1.400</td>
<td>.266</td>
</tr>
<tr>
<td>Results</td>
<td>8.296</td>
<td>2</td>
<td>4.148</td>
<td>1.939</td>
<td>.166</td>
</tr>
<tr>
<td>Discussion</td>
<td>44.667</td>
<td>2</td>
<td>22.333</td>
<td>6.872</td>
<td>.004**</td>
</tr>
</tbody>
</table>

Note: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

The chi square frequency analysis (Table 6) shows no statistically significant differences between the three groups of students except for Moves A3: Stating Method, A4: Stating Result, D2S3: Interpreting Results, and D2S7: Substantiating Results. There were statistical differences between the apprentice and novice papers as well, but since that is the main population of interest to this paper those results will not be discussed here. The apprentice writers employed sixteen of the moves at a frequency greater than 60% of the time, whereas the ELs only employed nine and the novice students only three of the moves at a frequency greater than 60%. With this in mind, it
appears that the moves used by the apprentice papers at a frequency greater than 60% are the obligatory moves for these biology lab reports.

Table 4.6
Frequency of Parkinson (2017) moves and Chi Square analyses between the English learners (EL) and the Apprentice and Novice counterparts.

<table>
<thead>
<tr>
<th>Move</th>
<th>Frequency</th>
<th>Chi Square</th>
<th>EL v Novice</th>
<th>EL v Apprentice</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>4 (44.4%)</td>
<td>3 (33.3%)</td>
<td>6 (66.7%)</td>
<td>0.234</td>
</tr>
<tr>
<td>A2</td>
<td>5 (55.6%)</td>
<td>2 (22.2%)</td>
<td>6 (66.7%)</td>
<td>2.104</td>
</tr>
<tr>
<td>A3</td>
<td>5 (55.6%)</td>
<td>3 (33.3%)</td>
<td>9 (100%)</td>
<td>0.900</td>
</tr>
<tr>
<td>A4</td>
<td>1 (11.1%)</td>
<td>1 (11.1%)</td>
<td>9 (100%)</td>
<td>0.000</td>
</tr>
<tr>
<td>A5</td>
<td>0 (0%)</td>
<td>1 (11.1%)</td>
<td>4 (44.4%)</td>
<td>1.059</td>
</tr>
<tr>
<td>I1S1</td>
<td>7 (77.8%)</td>
<td>6 (66.7%)</td>
<td>9 (100%)</td>
<td>0.277</td>
</tr>
<tr>
<td>I1S2</td>
<td>8 (88.9%)</td>
<td>6 (66.7%)</td>
<td>9 (100%)</td>
<td>1.286</td>
</tr>
<tr>
<td>I1S3</td>
<td>6 (66.7%)</td>
<td>5 (55.6%)</td>
<td>8 (88.9%)</td>
<td>0.234</td>
</tr>
<tr>
<td>I2</td>
<td>5 (55.6%)</td>
<td>3 (33.3%)</td>
<td>6 (66.7%)</td>
<td>0.900</td>
</tr>
<tr>
<td>I3S1</td>
<td>4 (44.4%)</td>
<td>3 (33.3%)</td>
<td>8 (88.9%)</td>
<td>0.234</td>
</tr>
<tr>
<td>I3S2</td>
<td>5 (55.6%)</td>
<td>2 (22.2%)</td>
<td>5 (55.6%)</td>
<td>2.104</td>
</tr>
<tr>
<td>M2S1</td>
<td>9 (100%)</td>
<td>9 (100%)</td>
<td>9 (100%)</td>
<td>0.000</td>
</tr>
<tr>
<td>M2S2</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0.000</td>
</tr>
<tr>
<td>M2S3</td>
<td>2 (22.2%)</td>
<td>1 (11.1%)</td>
<td>0 (0%)</td>
<td>0.400</td>
</tr>
<tr>
<td>M2S4</td>
<td>8 (88.9%)</td>
<td>8 (88.9%)</td>
<td>8 (88.9%)</td>
<td>0.000</td>
</tr>
<tr>
<td>M3</td>
<td>1 (11.1%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1.059</td>
</tr>
<tr>
<td></td>
<td>7 (77.8%)</td>
<td>5 (55.6%)</td>
<td>7 (77.8%)</td>
<td>1.00</td>
</tr>
<tr>
<td>---</td>
<td>-----------</td>
<td>-----------</td>
<td>-----------</td>
<td>------</td>
</tr>
<tr>
<td>R1S2</td>
<td>1 (11.1%)</td>
<td>2 (22.2%)</td>
<td>4 (44.4%)</td>
<td>0.400</td>
</tr>
<tr>
<td>R2S1</td>
<td>5 (55.6%)</td>
<td>5 (55.6%)</td>
<td>6 (66.7%)</td>
<td>0.000</td>
</tr>
<tr>
<td>R2S2</td>
<td>9 (100%)</td>
<td>8 (88.9%)</td>
<td>8 (88.9%)</td>
<td>1.059</td>
</tr>
<tr>
<td>R2S3</td>
<td>8 (88.9%)</td>
<td>7 (77.8%)</td>
<td>9 (100%)</td>
<td>0.400</td>
</tr>
<tr>
<td>R2S4</td>
<td>4 (44.4%)</td>
<td>0 (0%)</td>
<td>4 (44.4%)</td>
<td>5.143*</td>
</tr>
<tr>
<td>R3S1</td>
<td>5 (55.6%)</td>
<td>5 (55.6%)</td>
<td>7 (77.8%)</td>
<td>0.000</td>
</tr>
<tr>
<td>R3S2</td>
<td>2 (22.2%)</td>
<td>5 (55.6%)</td>
<td>5 (55.6%)</td>
<td>2.104</td>
</tr>
<tr>
<td>D1</td>
<td>4 (44.4%)</td>
<td>4 (44.4%)</td>
<td>7 (77.8%)</td>
<td>0.000</td>
</tr>
<tr>
<td>D2S1</td>
<td>6 (66.7%)</td>
<td>3 (33.3%)</td>
<td>6 (66.7%)</td>
<td>2.000</td>
</tr>
<tr>
<td>D2S2</td>
<td>8 (88.9%)</td>
<td>4 (44.4%)</td>
<td>9 (100%)</td>
<td>4.000</td>
</tr>
<tr>
<td>D2S3</td>
<td>5 (55.6%)</td>
<td>5 (55.6%)</td>
<td>9 (100%)</td>
<td>0.00</td>
</tr>
<tr>
<td>D2S4</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0.00</td>
</tr>
<tr>
<td>D2S5</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (11.1%)</td>
<td>1.059</td>
</tr>
<tr>
<td>D2S6</td>
<td>2 (22.2%)</td>
<td>2 (22.2%)</td>
<td>5 (55.6%)</td>
<td>0.000</td>
</tr>
<tr>
<td>D2S7</td>
<td>1 (11.1%)</td>
<td>0 (0%)</td>
<td>6 (66.7%)</td>
<td>1.059</td>
</tr>
<tr>
<td>D2S8</td>
<td>1 (11.1%)</td>
<td>2 (22.2%)</td>
<td>4 (44.4%)</td>
<td>0.400</td>
</tr>
<tr>
<td>D3</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0.00</td>
</tr>
<tr>
<td>D4</td>
<td>0 (0%)</td>
<td>1 (11.1%)</td>
<td>1 (11.1%)</td>
<td>1.059</td>
</tr>
</tbody>
</table>

Note: *p < 0.05; ***p < 0.001. Obligatory moves (frequency above 60%) are bolded.

ANOVA results on the lab grades of the papers indicate that the three groups were significantly different $F(24,2) = 25.731, p < 0.0001$, and a post hoc Scheffe reveals significant difference between the apprentice ($M = 19.92, SD = 0.18$) and EL ($M = 15.14, SD = 4.01$) papers.

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at \( p < 0.05 \) and between the novice \( (M = 10.31, SD = 2.86) \) and the EL \( (M = 15.14, SD = 4.01) \) papers at \( p < 0.05 \). These differences suggest that the EL papers diverge from both the apprentice and novice papers and their differences probably lie in how they are writing the papers and not just the use of the moves.

These statistical findings indicate that there is statistically significant differences between the apprentice and novice writers as well as their EL counterparts. This suggests that there are differing abilities in achieving mastery of the lab report format and the science register at the undergraduate level. ELs may have grasped parts of the science register, but not all. Examples of their attempts at mastery will be discussed in more detail in the next section of the paper.

**Qualitative Findings**

**Research Question 2.** This section analyzes the qualitative features of the ELs’ writing of the lab reports in comparison with their non-EL peers. The majority of students followed the instruction handouts. Even though the handout for the first draft of the paper clearly states that the lab reports should be written in third person (Davis, 2016a), there were examples from all three comparison groups where students wrote using first person pronouns. Some ELs and novice papers even included a few second person pronouns\(^1\). The use of first person pronouns could also represent that the students have not yet acquired the authoritative stance in science writing (Fang, 2005).

The majority of students (from all three groups) struggled with proper use of the accepted standards for bacteria nomenclature. Proper nomenclature standards state that the first mention of a species, the full genus and species names should be given in italics \((Genus species; \) i.e. \(1\) There were no statistically significant differences between any of the groups related to the use of first or second person pronouns.
Microbacterium foliorum. In all subsequent mentions of the species name, the genus name can be initialized with the full species name in italics (G. species; i.e. M. foliorum; Savory, 1962; De Vos & Trüper, 1999). The inconsistent adherence to standard conventions caused difficulty in comprehending mentions of the bacterial host.

Students often did not properly refer to the host bacterium’s species name. As can be seen the examples provided in Table 7, students struggled using italics. Students did not italicize the species names, causing confusion to identify whether the author was actually mentioning the bacterial host. Students would routinely italicize the genus name and not the species name, or not italicize at all. It did not matter if it was the original bacterium host name or the second bacterium host name. Furthermore, the writers frequently failed to use the initial for the genus name in subsequent mentions of the particular species. The change in host during this particular semester could have led to a greater struggle in using nomenclature standards. These types of errors could result from cognitive overload of the students as they learn to write the IMRD format (Perrault, 2011; Condon & Kelly-Riley, 2004) as well as the science content and corresponding nomenclature standards.

Table 4.7
Examples of the use or misuse of biological nomenclature from the English learners (ELs), apprentice and novice groups of students.

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>ELs</td>
<td>a. Other host cells that are used to isolate phage is the <em>Gordonia terrae</em> which is to isolate phage from soil (Pope WH, 2016).</td>
</tr>
<tr>
<td></td>
<td>b. There are 8 types of food poisoning that people must avoid such as Campylobacter enteritis, Cholrea, E. coli Enteritis, Ciguatera, Listeria, Staphylococcus and Salmonella (Kapadia, 2012)</td>
</tr>
</tbody>
</table>
Apprentice  

a. 50µL of the filtered supernatant fluid (direct plating) or enrichment filtrate (enriched isolation) was added to 0.5mL of *M. smegmatis* (*Gordonia Terrae* was used until we switched to *M. smegmatis*) and left to sit undisturbed for ten minutes to allow infection.

b. A Phage is a genetically diverse virus that cannot replicate by itself. In order to function and replicate properly, it needs a host bacterium (*Gordonia Terrae*).

Novice  

a. Mycobacterium *smegmatis* is added in order. Samples are labeled and placed into a shaking incubator for one hour at room temperature.

b. After a week of cultivation on the Mycobacterium smegmatis agar lawn, spots of dead Mycobacterium smegmatis plaque should appear on the agar and be labeled as such.

The IMRD section most likely to be omitted was the abstract. When the abstract section was present, rarely were all five of the Parkinson (2017) moves included in the abstract except in one-third of the apprentice papers and only one of the novice papers. Two thirds of the novice papers did not include abstracts at all, nor did a third of the EL papers. One possible reason for not including the abstract is that it was only worth two out of the twenty points for the graded assignment.

Another possibility for omitting the abstract could be that the students did not know where to begin to write one. Because abstracts require summarization skills, the lack of an abstract could reflect the writer’s discomfort with summary writing. A student’s lack of summary writing skills may be a viable explanation for not including an abstract. Improving genre awareness can help EL students have more linguistic options when writing summaries (Yasuda, 2015, 2017). The lack
of abstracts could justify the need for more genre-specific summary writing activities for ELs in particular.

When students made reference to literature in the introduction sections, often it was for background information that seemed to come from the lab manual. Sometimes references were to previous studies related to bacteriophages. Other times, the references were for historical information about who actually discovered bacteriophages. A study by Timmerman, Strickland, Johnson and Payne (2011) on a rubric for lab reports indicates that the students at their university did not improve much in the ability to meet the context portion of their rubric suggesting that practice is required to identify appropriate and relevant information to include in introduction sections.

Interestingly, few papers included a clear hypothesis statement (Move I2: Advancing Hypothesis). Roughly, half of the apprentice papers included move I2 at the end of the introduction section, about where it would be expected in a RA (Swales, 1990). One paper however employed move I2: Advancing Hypothesis in the discussion section (Table 8). Only a third of the novice papers and a third of the EL papers included move I2. Two of the nine EL papers made attempts at an I2 but the statements were not clearly a hypothesis and were thus coded as Move I1: Establishing a Topic. These two EL statements in Table 9 seemed more like thesis statements than a hypothesis, and were difficult to code because they did not fit any of Parkinson’s (2017) moves even though they were close to move I2.

Timmerman et al. (2011) identified that improvement in hypothesis statements occurred over the semesters studied, indicating that it takes time to learn how to write clear hypotheses. With this study’s course being early in students’ biological careers, students may still need to learn how to write hypotheses to meet Parkinson’s (2017) I2 move partially explaining the lack of a
clear hypothesis for some papers or the more thesis statement like sentences by two of the EL writers. The lack of hypothesis statements may be partially attributed to the differences between RAs and lab reports (Parkinson, 2017; Kanoksilpatham, 2005, 2007; Swales, 1990).

Table 4.8

*Examples of Move I2: Advancing Hypothesis from the English learners (ELs), apprentice & novice groups of students.*

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL</td>
<td>a. By studying and performing this lab, detecting a new phage should be used for curing diseases in the medical fields that cause by mycobacterium.</td>
</tr>
<tr>
<td></td>
<td>b. We hypothesize that we may discover some phages we already know.</td>
</tr>
<tr>
<td>Apprentice</td>
<td>a. I predict that bacteriophages will not be isolated from soil obtained in the Pacific Northwest while using G. terrae as the host bacterium.</td>
</tr>
<tr>
<td></td>
<td>b. In this lab, the goal was to successfully isolate bacteriophages from a soil sample found on [name deleted] campus and have them infect the bacterial host, Gordonia terrae, and produce multiple phages as the result.</td>
</tr>
<tr>
<td>Novice</td>
<td>a. The purpose of this lab is to try and isolate bacteriophages in order to discover new types, which could possibly be used in the medical or environmental field to breakdown different types of bacteria that could not be killed before.</td>
</tr>
<tr>
<td></td>
<td>b. My prediction is that through isolation and enrichment of phage we would be able to isolate and characterize the phage in our area.</td>
</tr>
</tbody>
</table>
Table 9

*Examples of the two English learner (EL) attempts at an I2: Advancing Hypothesis statements but coded as I1: Establishing Topic.*

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL a.</td>
<td>The purpose of this information is that it is easily can be touched with the people and animals infected by bacteria.</td>
</tr>
<tr>
<td>b.</td>
<td>How does isolating phage and extracting DNA are related with phage therapy?</td>
</tr>
</tbody>
</table>

In a study of the British Academic Written English (BAWE) corpus of student lab reports, Gardner (2012) found that the majority of the assignments were designed more for the purpose of learning procedures than to engage with previous literature. The majority of the biology lab reports in the current study followed this pattern as the methods section (if included) was typically the longest section. The students covered multiple weeks of in class lab protocols in the methods sections accounting for the majority of the text included. A focus on learning the science involved in the laboratory experiments may put a greater necessity on the students to account for the methods and results as opposed to the introduction and discussion. A TA from the semester the papers were collected suspects that the students feel the need to add length to their papers and that the methods section is the easiest section for adding length (person communication). A perceived need to add length to the lab report could account for the methods sections sounding similar to a recounting of all the work to complete the experiments.

Out of Parkinson’s (2017) moves, usually only two moves were employed (M2S1: Detailing Procedures and M2S4: Providing background information) by all students. However,
one of the apprentice papers only used M2S1 as a move in the methods section. Move M2S3: Illustrating Procedure with Diagram was employed only by two EL papers and one novice paper. The M2S3 move used in these papers was an illustration of the plaque streaking\(^2\) procedure. One could theorize that apprentice papers’ authors were confident in their explanations of the plaque streaking process to not use a diagram. Overall the students’ focus on methods details is related to the rhetorical purpose of the assignment (Bhatia, 1993; Parkinson, 2017) to show learning of the science covered has occurred.

For the results sections, sometimes students barely had sentences in paragraphs in their results section keeping with the expectation that visual representation of the data is important. In some cases, the results section header was followed by a few sentences and then there were multiple figures with captions. In this type of situation, the figure captions gave more information about the experimental results than the paragraph sentences thus meeting the moves identified by Parkinson (2017). In such a scenario, the caption texts were not brief as the instruction handout stated (Davis, 2016b). One reason for the students’ lack of brevity is that brief is a relative term. For example, Smith, Mackiewicz, Hanson, Flanning and Doan (2016) noticed that biology journal captions are typically longer than captions in technical communication journal articles. Students may be interpreting brief compared to another genre, or they may be unaware of the need for brevity in captions due to cognitive overload in learning this genre (Condon & Kelly-Riley, 2004).

Concerning apprentice writers, one did not include any figures in the text, one did not have clear numbered figure labels and one did not bold the figure labels with the rest meeting the instructions provided. Two EL writers did not include any figure labels or captions for the figures

\(^2\) Plaque streaking refers a step in the process of isolating a bacteriophage from a bacterial lawn.
presented in the text, and four did not bold the figure labels. Thus leaving three of the ELs formatting figure labels correctly. The novice writers performed similarly to the ELs with regards to figures and captions. With one third of the novice writers getting figure labels correct, four not bolding the labels, one with no figures at all and one without figure numbers in what is assumed to be captions.

For the most part, students tried to follow the layout for figures and captions provided in the instruction handout (Davis, 2016b). Sometimes the label and figure were in a box as demonstrated on the handout, and sometimes only the label was in a box. This pattern or lack thereof from all the student groups indicates that students need practice with the formatting of figures and writing effective captions (Table 10). It can also be evidence of a need for a technical writing type course to address these types of issues in addition to a composition course.

Table 4.10
Examples of figure labels and captions used in the English learners (ELs), apprentice and novice groups of papers.

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL</td>
<td>a. <strong>Figure 4. Electron microscope image.</strong> This was the image obtained from microscope, showing the flow of electron.</td>
</tr>
<tr>
<td></td>
<td>b. <strong>Figure 2: Picture of the plaques in the plate.</strong> There is small amount of plaques was in our plate, and the plaques are extremely tiny, but we were able to obtain them in order to do the further plaque streak protocol.</td>
</tr>
<tr>
<td>Apprentice</td>
<td>a. <strong>Figure 1. Plaque assay with smegmatis bacteria.</strong> Only one isolate phage was produced on the left hand side of the plate.</td>
</tr>
</tbody>
</table>
b. Figure 5 High Titer Lysate results. Plate 10^-6 shows no signs of bacterial clearings. This dilution of the HTL produced negative results.

Novice

a. Fig. 2: The results of the Gel electrophoresis. Our results are on the left half of the shown gel.

b. Figure 17 #3T5, third round of isolation

Another interesting finding noted in the papers has to do with how students wrote their discussion sections. Three ELs and three apprentice writers ended their discussion sections with introduction type sentences about bacteriophages (Table 11). There was only one writer from the novice category that revisited introduction sentences in her discussion. This limited representation amongst novice papers could result from the fact that many of the novice papers did not include a discussion section. The three EL papers bringing introduction sentences into the end of the discussion section came from the same lab section. These three students also had issues with keeping their introduction section and these ending sentences related to the specific goal of the experiments being conducted over the course of the semester (to isolate and identify a new bacteriophage).

For the students including introduction moves in the discussion, it seemed almost as if the students using introduction section moves in the discussion wanted to include a conclusion-type paragraph to their lab reports. Of interest, two of the ELs seemed to take this practice to a greater extent in that their introduction section shifted focus slightly from identifying a new bacteriophage to discussing bacterial diseases or cancer and how the identification of bacteriophages may help treat either of the aforementioned diseases (Table 11). These two ELs ended their discussion
sections, by returning to bacterial diseases or cancer. It seemed as though these two students wanted to write the typical five-paragraph essay format in the midst of the lab report format.

Table 4.11
Examples of introduction moves in the discussion section between the three groups. English learners (ELs), apprentice and novice. Many of the novice samples did not have discussion sections.

<table>
<thead>
<tr>
<th>Group</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>EL</td>
<td>a. In the future studio the medical people should find the medicine that can kills the disease. Also, many people can do this experiment and found out the ways to help people or animal in either ways.</td>
</tr>
<tr>
<td></td>
<td>b. By performing this experiment, discovering a new phage can be used for curing diseases in the medical fields that cause by mycobacterium.</td>
</tr>
<tr>
<td></td>
<td>c. Like this experiment, to treat cancer with phage therapy, first, the cancer cell has to be purified thus no normal cell can be involved. Then with the phage attacks the cancer cells.</td>
</tr>
<tr>
<td>Apprentice</td>
<td>a. Discovering different bacteriophages can improve many different areas of the medical field.</td>
</tr>
<tr>
<td></td>
<td>b. After phages infect hosts, bacteria are not observed in any protocols afterwards, indicating bacteria are killed after phage replication. This would be considered the most effective method in killing superbugs, which are bacteria that can’t be treated with two or more antibiotics.</td>
</tr>
<tr>
<td></td>
<td>c. Bacteriophages also have the potential to make advancements in the medical field and the environmental field. Due to their ability to infect</td>
</tr>
</tbody>
</table>
bacteria, they may be useful to fight against pathogenic, antibiotic
resistant bacteria or any harmful bacteria at that.

Novice a. Continuing research with bacteriophage is very important since this can
be used for a variety of things like medicine and as a form to control
biological waste.

Overall the lab reports examined from this introductory biology course follow Parkinson’s
(2017) moves schema for lab reports. As can be seen from the excerpts included in this paper, the
ELs in this sample performed in a similar manner to the apprentice and novice writers in the
qualitative review of their writings. This indicates that ELs use similar elements in their lab report
writing to their non-EL peers. The examples presented from all the categories show a struggle
with mastery of biological nomenclature. The lack of an abstract section or an abstract with all of
Parkinson’s (2017) moves suggests that ELs may struggle with summarizing scientific content.
The use of M2S3: Illustrating Procedure with Diagram by two ELs in the methods section may
indicate that EL writers might also struggle with being able to explain scientific processes. Also,
the analyzed papers in this study indicate that all students (even the apprentice writers) were still
learning the demands of writing a lab report and writing for science. This is similar to the findings
of Timmerman et al. (2011) and Saitta, Zamliansky and Turner (2015) indicating that the papers
analyzed were still at the beginning stages of learning science writing. In regards to the two
research questions, ELs use similar elements in writing lab reports, sometimes similar to apprentice
writers and other times similar to novice writers. When the ELs perform similarly to the apprentice
writers their writing meets the assignment requirements, but when their writing matches the novice
writers they are not always meeting the assignment requirements.
Study Limitations

The total number of ELs enrolled in the class limited the total population of the study. Also, due to the lack of grading moderation between the TAs when grading the lab reports during the semester, there was a range of variation in final lab report scores making it difficult to determine apprentice or novice student papers for analysis. The twenty-seven reports collected, only came from the lab sections with ELs enrolled as a way to limit the variation between the TAs in this large lecture course. Even with this, the breakdown of the scores on the final report still had a large amount of variation between the TAs. Some sections had a high number of twenty out of twenty points (nine papers in a class of twenty-one) and a low score of thirteen out twenty. Another section the lowest score was only eight and half points out of twenty and very few full scores (only two). One section had no students with a full twenty out of twenty points, in that section the highest score was 19.75 out of twenty points. To account for this discrepancy, the comparison between EL performance and the non-EL population was made by comparing the EL writing with the writing of apprentice students from the same lab section with the same TA. This helped minimize the variation between TA grading styles. Later in comparing the features of all the novice papers and all the apprentice papers was used to see if there were any common features between the student papers represented. The total sample size itself became a limitation by limiting the types of statistical analyses to perform and the best post hoc analyses.

Conclusion

It is interesting to see that the EL students at times outperformed their novice peers. This indicates that EL writers are attempting to overcome their English language barriers as they learn the IMRD format. However, some of the EL writers seemed to make the IMRD format fit more familiar and known writing formats. For example, they might employ more thesis-like statements
as opposed to a hypothesis in the introduction section or include conclusion-type sentences in the discussion section.

This study indicates that it may be helpful for students to raise their genre awareness about what should be included in a lab report beyond the current handout descriptions provided in the course. Doing so would help all writers in the class have strategies for writing to meet the needs of the lab report/IMRD format. Lin and Evans (2012), however, argue that the teaching of the IMRD format itself should only be done within a particular discipline as there are discipline-specific variations to the format that an outside-discipline instructor may not be able to address. These discipline-specific variations can also be noted in Parkinson (2017) and that the biology expert panel stated Move M1 was not appropriate for the biology lab reports used in this study.

Ultimately, all students would benefit from genre writing instruction. Genre instruction would help students identify the discipline specific rules related to the IMRD format for biology. Another possible benefit for students learning the IMRD format would be to have formative assessments on their writing. However, this may be impractical for lab lecture courses with lab sections. Instead it may be beneficial to provide students with a thorough checklist for what to include in each IMRD section (Lee, Woods. & Tonissen, 2011) of the lab report relating to the rhetorical moves necessary. This type of checklist should match the grading rubric and the assessment criteria of the TAs for the course (Timmerman et al., 2011).
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CHAPTER FIVE: CONCLUSION & FUTURE DIRECTIONS

Conclusion

This dissertation has explored the experiences of English learners (ELs) learning science in the K-16 system with a focus on reading comprehension connected to test performance at the middle school level and then writing at the university level. Both studies reveal aspects of the process of learning in science, technology, engineering and mathematics (STEM) fields indicating that EL students may not be getting equitable instruction in comparison with their non-EL peers. As revealed in the first study, ELs were disproportionately placed into low-track classrooms limiting their access to university preparatory classes. The second study shows that even though the ELs had similar types of struggles in mastering the science register to their non-EL peers, their performance was in between the apprentice (writers graded in top 10% of the course) and novice (writers in the bottom 10% of the course) writers of the same class. Thus indicating that the EL writers’ struggles are not just content errors, but that there are additional struggles with English competency.

Science literacy begins to become problematic at the secondary school level when students can be tracked based on their abilities. Often ELs can be tracked into lower streams because of their English language abilities as opposed to their actual science abilities. L2 proficiency can also lead to additional anxiety in learning science. Anxiety in or a limited self-efficacy belief in learning science can limit the ability to learn science in general (Britner & Pajares, 2006) but can be even more limiting for ELs as their L2 proficiency is added for consideration (Ardasheva, Carbonneau, Roo, Wang, 2018). As revealed in Study 1, ELs had anxiety in learning science and their vocabulary affected their ability to comprehend the science content and perform well on the end-of-unit test.
At the university level ELs can still struggle with learning science, and in biology a typical laboratory (lab) assignment is to write a lab report. Students not only need to wrestle with the concepts of the course but also need to be able to produce a written document demonstrating knowledge in the science register. In contrast with Study 1, which focused on English receptive (reading) skills, Study 2 focused on the English productive (writing) skills that EL student writers use to write the lab report. In this study, the EL writers performed differently from both the apprentice and the novice writers. This demonstrates that ELs have their own struggles in comparison with their non-EL peers in the same class.

The linguistic demands of science can make it difficult for ELs to master the content of science courses as well as learn the genre needs for writing in an expository format (Groves, 2016; Fang, 2005, 2008). As can be seen from the first study, ELs can have inequitable treatment in their course placements as well as struggle in their writing in comparison with their non-EL peers. These struggles can be a result of their own L2 proficiencies as well as the language required to successfully study in STEM fields. These course placements can limit access to university level education or cause difficulty for international students to succeed in their courses even if they are adept at the content material. The second study demonstrates the areas of science writing where ELs may have a greater struggle with the unfamiliar genre of lab reports.

Clearly more work can be done to understand the pedagogical needs of ELs in the science classroom. There is a lot that ELs have to overcome to learn and become proficient in science courses beyond what traditional English support courses tend to offer. As can be seen in chapter two, ELs need additional support in learning science vocabulary. In addition, vocabulary instruction could help ELs overcome the anxiety involved in science learning. ELs need the
vocabulary to help them not become trapped in low-track classrooms limiting their access to higher education (Callahan & Schrifer, 2016; Callahan, 2005; Kanno & Cromley, 2013; Umansky, 2016).

Chapter four on the other hand, indicates that ELs try to address the specific writing requirements for science writing but may not get to the same level as their non-EL peers. It is worth noting most of the known literature dealing with science writing is at the elementary school level (de Oliviera & Lan, 2014; Fang, 2014) or the university levels (Colabory, 2011; Lee, Tonissen & Woods, 2011; Colton & Sursinghe, 2014) and the studies on science writing at the secondary school level are limited with only Whitehead & Murphy (2014) the only known study suggesting a need for future research in this area especially for ELs.

Both of the studies in this dissertation indicate a need for more scaffolding of linguistic and generic standards for the science classroom. Some recommended practices are examined in the following. Lyon et al. (2016) discuss how to make culturally responsive changes to the science curriculum to help EL students succeed in science classes. In addition to culturally responsive teaching, graphic organizers can be used in the K-12 science classrooms helping students see the outcomes of the science being taught in the classroom. Such graphic organizers can also help students have the language to complete sentences on their own (Bittlel & Hernandez, 2006; Cuevas, Lee, Hart & Deaktor, 2005; Hand & Choi, 2010). Also using organizers or science writing heuristics can help students develop their scientific argumentation skills.

De Oliviera and Lan (2014) demonstrate how using a systemic functional linguistics (SFL) approach to teaching science writing helped a fourth grade EL better adapt to the demands of science writing. Using SFL’s three steps of deconstruct (analyzing a model), co-construct
(students work together as a class or group to recreate a text based on the model) and construct (individual students write their own text), the approach helps ELs have more tools to write their own texts for their science classes. Using SFL would also help raise students’ awareness of the language involved in different types of writing. It would also be useful to help enhance students’ awareness of the differences between narrative and expository writing at age appropriate levels (Fang, 2005, 2008). Preparing students for the shift towards expository reading and writing in the upper elementary grades will give ELs a better chance at having the skills to potentially stay out of low track science classrooms upon arrival in secondary school.

Examples of other linguistic activities to support EL science learning can include sentence transformation activities where students “translate” technical expository texts into more familiar everyday language (or vice versa) to learn the contrasts between the two registers. Other activities can include summary frames (Berber-Jimenez, Montelongo, Hernandez, Herter, & Hosking, 2008) and sentence completion tasks to help students learn the structures for science writing. Examples of scaffolding strategies also include using visuals to help reading comprehension of science texts (see Ardasheva, Wang, Roo, Odesope & Morrison, 2017) and using concept maps to help represent the hierarchical structures involved in science concepts (Ardasheva, Norton-Meier & Hand, 2015). If using an SFL approach to language, students could also benefit from tasks requiring them to identify the themes and rhemes of sentences in science writing to help students become more familiar with expected forms of the genre.

At the university level in particular, students would benefit from having more exposure to authentic genre pieces or to reading texts for the discipline in English courses (Colton & Surasinghe 2014; Stoller, Jones, Constanza-Robinson, & Robinson, 2005), in doing this students would gain a greater idea of what is expected of them when writing in the genre. As Jackson,
Meyer and Parkinson (2006) found that the undergraduates at a South African university often read textbooks, these same students were required to write lab reports resulting in a mismatch in the input and expected output for the students. Along with exposure to the genre, students would benefit from activities scaffolding writing or text analysis activities such as analyzing an authentic research article to learn more about the purposes of the different sections in the introduction, methods, results and discussion (IMRD) format (Colobroy, 2011).

Scaffolding strategies at the university level can also include activities related to identifying sentences to the corresponding appropriate IMRD section (Swales & Feak, 2012). Glasman-Deal (2010) suggests that students should learn appropriate academic vocabulary that corresponds to different sections of the IMRD format. Wolfe, Britt and Alexander (2011) provide a rationale for using paragraph pattern exercises and sentence combining exercises to help students in science and engineering to develop greater confidence in these aspects of the IMRD format. Pattern practice refers to students finding example sentences or paragraphs from which to learn rhetorical structures. Sentence combining refers to combining simple sentences to practice complex sentence structures. Sentence combining exercises will give ELs more chances to learn how to build the complex sentence structures often used in science writing (Fang, 2005, 2008). Roo and Ardasheva (2018) provide a more thorough review of pedagogical tools to help ELs in K-16 environments develop science literacy skills.

A more macro-level structure solution would be for universities to require both a composition course along with a technical writing course as part of the university writing requirements. Requiring both a course in composition as well as in technical writing will help students see the different forms and functions of writing. This could also help all students (not just ELs) have competence in all forms of writing. Requiring both composition and technical
writing courses at the university could help to eliminate some of the biases that can exist towards humanities’ styles and registers (Wolfe, 2009). When there is a humanities-based bias in assignments or textbooks, students in STEM could get short-changed when needing to learn the discipline specific standards for their given discipline. A humanities bias can also explain why discipline specific instructors may feel frustrated with the writing abilities of students in the discipline major (personal communication) or why certain engineering majors have eliminated English department technical writing courses for courses in technical communication offered by Communications departments (Civil & Environmental Engineering, 2018).

**Future Directions**

The two studies conducted for this dissertation can lead in two separate directions for future research. Within the K-12 secondary school system, it would be interesting to replicate the study in chapter two with a larger number of tracked students to see if there are any differences when it comes to gender or special education. Another possibility would be to conduct a qualitative study on the actual classroom environments between the two types of tracked classrooms. Having a qualitative study on the classroom environment would provide a deeper understanding of the struggles ELs face in the science classroom. Such a study should include interviews with EL students as well as the instructors to learn about the struggles of ELs in the tracked science classroom.

Additional studies could look at different vocabulary building strategies for science classrooms and see if vocabulary building differs among ELs and non-ELs. Depending on the classroom, it might also be of interest to study the writing for the sciences at the secondary level. This could help provide better quality written documents at the university level. Fang (2014)
examined EL science writing in the upper elementary grades, but it would be interesting to see what if anything is happening for ELs writing in science at the secondary school level.

In regards to the university level science writing, there are a couple of possible directions to explore the writing of ELs. First, the biology professor from whom the data were received was inspired by Parkinson’s (2017) article and reframed his assignment handouts to provide more of a genre-based approach to the lab report. It would be easy to replicate the study to see if there are any improvements in the writing of the ELs in the course. There was a statistically significant difference between the apprentice & novice non-EL papers, and it may be interesting to explore the qualitative differences between in the writing between these two groups of students.

Another aspect of comparing apprentice and novice non-EL lab report papers could be to explore the use of first person pronouns in more detail to see if there are any particular patterns in how students use these pronouns in their writing. These patterns could then be compared to the work of Kuo (1999), Hyland (2001), and Martinez (2005) for research articles. Having a larger corpus of papers would ascertain if there are any patterns in how lab report writers use first person in comparison to research articles.

In addition, a separate study could be to recruit students from STEM university courses who write lab reports to learn about the experience of learning the writing process for lab reports. This type of study would also provide insight on how students perceive the instruction of the lab report assignment. Often lab-report writing assignments are introduced by teaching assistants (TAs) who may not have any training in writing instruction.

Another possibility would be to study the summary writing skills of K-16 students in STEM courses. As summary writing is an important skill for all disciplines, and it can become
trickier for science with its specialized vocabulary. With summary writing skills required to write abstracts as well as executive summaries for reports in engineering, exploring aspects of summarization for disciplines may help English learners succeed in any university level discipline. Or it might be interesting to conduct a longitudinal study of ELs as they progress through the K-12 system and then on to university.

All of the afore mentioned options can lead to a clear research pipeline for a future career in linguistics, English rhetoric or science pedagogy to help not just ELs but also all students to have access to what some might consider an occluded genre. It is important to remember that there are discipline-specific variations to the IMRD format, so just teaching the IMRD format may not help students within their respective disciplines (Lin & Evans, 2012). However, giving students autonomy to identify their own examples to develop a pattern to follow will provide students with a chance to learn specifics to their own discipline (Wolfe, Britt & Alexander, 2011).
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