LEARNING SCIENCE, TALKING SCIENCE: THE IMPACT OF A TECHNOLOGY-ENHANCED CURRICULUM ON STUDENTS' SCIENCE LEARNING IN LINGUISTICALLY DIVERSE MAINSTREAM CLASSROOMS

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ABSTRACT

The significant increase of English Language Learners (ELLs) in the United States raises complex questions about how to provide these students with access to high quality education that can improve both their content knowledge of school subjects and their English proficiency, particularly their academic English proficiency. The development of proficiency in academic English is a central challenge in science education because science has a unique language of its own which includes extensive technical vocabulary, specialized grammatical forms, and unfamiliar discourse patterns fundamentally different from the everyday English that ELLs use in their daily lives. Additionally, in order to become scientifically literate, students not only need to understand scientific phenomena, but also must be able to communicate their ideas in scientific ways, both of which require an appropriate level of proficiency in scientific language.

Although acquiring both scientific content and language simultaneously is already demanding for most students, the challenges that ELLs face are even more serious. Most ELLs are still developing English proficiency while learning science subjects, and even after ELLs become fluent in conversational English, they may still lack the scientific language proficiency necessary to engage in science subjects. ELLs generally require a minimum of five to seven years to develop the appropriate grade level of academic language (of which scientific language is a sub-category) and to catch up with their English-proficient counterparts. Not surprisingly, the largest

achievement gaps – on average, 39 points – in science subjects persist between ELLs and English-Proficient Students (EPSs).

This study explored effective instructional approaches that can help ELLs master both the content and the language of science and possibly close the achievement gaps between ELLs and EPSs. The study specifically examined the impact of a technology-enhanced curriculum that consisted of two teaching approaches to ELLs' science learning: teaching science in everyday English (the Everyday Language approach) and using computer simulation to solve scientific problems (the Simulation approach). For this study, the technology-enhanced curriculum was carefully constructed based on the actual curriculum design, five design-based research studies, and consultation with fifth-grade teachers.

The randomized experimental study was conducted with 220 fifth-grade ELLs and EPSs from four public elementary schools. Before the study began, all students took pretests and three students randomly selected from each class took pre-interviews. All students participated in six one-hour long consecutive science sessions about the concepts of photosynthesis and respiration. For the first three sessions, students received individual science instruction about the scientific concepts using a computer program. Students in the Everyday-Language condition (the Everyday-Simulation and the Everyday-Website groups) were taught in everyday language prior to the introduction of scientific language. By contrast, students in the Hybrid-Language condition (the Hybrid-Simulation and the Hybrid-Website groups) were taught simultaneously in both everyday language and scientific language (hybrid language). For the last three sessions, students were randomly assigned to triads stratified by gender and English proficiency, and each triad participated in a series of problem-solving activities. Students in the Simulation condition (the Everyday-Simulation and the Hybrid-Simulation groups) used a computer simulation program, whereas students in the Website condition (the Everyday-Website and the Hybrid-Website groups) used a simple website. After the study, all students took the posttests, and the same three students participated in post-interviews.

Overall, the results of this study suggest that both teaching science in everyday language and using computer simulation to solve scientific problems can be beneficial for ELLs' science learning. However, in order for ELLs to master both the content and the language of science, it is important to provide them not only with access to scientific language, but also with multiple opportunities to use this scientific language in different academic contexts because only understanding scientific language alone does not always prepare ELLs to be able to use the language to communicate their understanding of scientific ideas appropriately. In this study, ELLs taught in everyday language prior to the introduction of scientific language significantly outperformed ELLs taught in hybrid language. Among those ELLs taught in everyday language, ELLs who used computer simulation during problem-solving activities demonstrated both a more improved understanding of scientific phenomena and a superior ability to use scientific language accurately for different purposes, compared to ELLs who used the website to solve scientific problems.

The results of the study also indicate the potential advantage of computer simulation for decreasing the learning gap between ELLs and EPSs. The use of computer simulation was more effective in enhancing ELLs' scientific knowledge and their use of scientific language than the use of the website, but the simulation was not beneficial for EPSs' science learning. Since ELLs' performance improved so markedly with the use of computer simulation, while that of EPSs remained roughly the same, this form of pedagogy resulted in no significant achievement gap between ELLs and EPSs taught in this manner.

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CHAPTER 1: INTRODUCTION

The number of English Language Learners (ELLs) in the United States, those who speak a language other than English as primary language and have limited proficiency in English, has dramatically increased over the last ten years. The percentage of total school-age ELLs grew 57% between 1995 and 2005, while the general K-12 population increased only 3.66% in the same period (National Clearinghouse for English Language Acquisition [NCELA], 2007). According to the NCELA, in 2005, there were more than 5.1 million ELLs in K-12 public schools, making ELLs approximately 10.5% of the total U.S. student population. In some areas, however, the numbers are much higher; in California, for example, 25% of K-12 students are identified as ELLs. And nationally, although 72% of ELLs speak Spanish as their primary language, there are more than 50 languages spoken by ELLs overall (National Center for Educational Statistics, 2008).

The significant increase of ELLs in the U.S. raises complex questions about how to provide these students with access to high quality education that can improve both their content knowledge of school subjects and their English proficiency, particularly their academic English proficiency. The development of proficiency in academic English is a central challenge in science education because science has a unique language of its own which includes extensive technical vocabulary, specialized grammatical forms, and unfamiliar discourse patterns fundamentally different from the everyday English that ELLs may use in general contexts (Fang, 2005, 2006; Gee, 1992, 2005; Lee, 2005; Lee, Maerten-Rivera, Penfield, LeRoy, & Secada, 2008; Lemke, 1990; Schleppegrell, 2004). Additionally, in order to become scientifically literate, students not only need to understand scientific phenomena, but also must be able to communicate in a scientific way, both of which require an appropriate level of proficiency in scientific language (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). Although achieving academic success in science is already demanding for most students, challenges that ELLs face are even more serious because they are still developing proficiency in their second language, English, and learning scientific language is like learning an additional foreign language within English for them.

The study detailed in this dissertation explored new instructional approaches using technology for ELLs' science learning, with the goal of identifying effective instructional approaches that can prevent ELLs from falling behind their English-proficient peers. In this study, I specifically examined two teaching approaches to technology-enhanced instruction: 1) teaching science in everyday English prior to introducing scientific language (the Everyday Language approach) in order to make scientific language more accessible to students; and 2) using computer simulation for problem-solving activities (the Simulation approach) in order to provide ELLs with more opportunities to engage in scientific discourse. I examined how these instructional approaches could help ELLs better master both the content and the language of science, compared to English-proficient students' (EPSs) performance, and how these approaches could possibly help close the achievement gaps between ELLs and EPSs.

Science Learning

Since the publication of *A Nation at Risk* (National Commission on Excellence in Education, 1983), science education reform in the U.S. has advocated equal access to quality education to promote equity and high academic achievement for all students (AAAS, 1983; NRC, 1996). In order to provide solutions for U.S. students' underperformance in science, the AAAS published a new reform document in 1990, *Science for All Americans*, and advocated equity in science education, arguing that all students should be given the opportunity to become scientifically literate through the use of high-quality, accessible curricula. *Science for All Americans* defines "scientific literacy" broadly as the ability to understand scientific concepts and ways of thinking in natural science, mathematics, technology, and social science.

Following *Science for all Americans*, the documents outlining science standards, such as the *National Science Education Standards* (NSES), also claim the need for equity for all students in science education. The NSES (NRC, 1996) provides more specific guidelines regarding what students should know and rigorous standards for science content, assessment, teaching, professional development, and educational systems. The NSES particularly emphasizes scientific inquiry as a central learning tool in science, arguing that "scientific inquiry is at the heart of science and science learning" (p. 15), and that "inquiry into authentic questions generated from student experiences is the central strategy for teaching science" (p. 31).

According to these major reform documents and national science standards, in order to become scientifically literate, students must not only understand scientific phenomena, but also articulate their understanding using scientific discourse and explore scientific ideas through inquiry, all of which demand heavy use of the spoken and written language of science (AAAS, 1990, 1993; NRC, 1996).

Scientific Language and Science Learning

Many researchers have argued that learning scientific language is an integral part of science learning (Fang, 2005, 2006; Gee, 1992, 2005; Lemke, 1990; Norris & Phillips, 2003; Wellington & Osborne, 2001) and that, without the explicit learning of scientific language, science will "simply remain a foreign language" to most students (Wellington & Osborne, 2001, p.139). Yet, despite its importance in science education, scientific language often presents a barrier to many students' science learning because it is composed of distinctive linguistic features (e.g., technical vocabulary) and unfamiliar discourse patterns (e.g., hypothesis formation) fundamentally different from the everyday language that most students use in general contexts (Fang; Gee; Lemke). In addition to mastering the complexity of scientific language, becoming scientifically literate also requires students' participation in scientific tasks that allow students to use this specialized scientific language accurately and to engage in scientific discourse. Providing such opportunities to students is nevertheless difficult for many schools because it requires highly qualified teachers, who can design meaningful science activities, and the ability for the school to purchase or create supplemental materials for such activities.

Science Learning for English Language Learners (ELLs)

Acquiring both scientific content and language simultaneously is already demanding for most students, but the challenges that English Language Learners (ELLs) face are even more serious because most ELLs are still in the process of developing English proficiency, and they therefore must learn not only the scientific knowledge that is the obvious content of the lesson, but must also simultaneously develop literacy skills and English proficiency (Lee, 2004, 2005; Lee et al., 2008; Echevarria & Short, 2006). Even after ELLs become fluent in conversational English, they are still likely to lack the academic language (of which scientific language is a sub-category) proficiency necessary to confidently and successfully engage in science subjects. ELLs often do not have the same literacy skills or the same level of proficiency in academic English as do native English-speaking students when they enter school (Echevarria & Short). ELLs usually require five years of being exposed to academic language to catch up with native English-speaking students (Cummings 1981, 2000, 2003; Hakuta, Butler, & Witt, 2000; Thomas & Collier, 2002). In other words, when learning science, ELLs need to master the new content of scientific phenomena while simultaneously processing the new linguistic information of scientific language in English (Kirschner, 2002; Sweller, 1994). Many ELLs, especially those from low-income families, also have limited opportunities to use scientific discourse in the classroom because the schools they usually attend face additional pedagogical challenges, such as large class sizes and outdated materials. Teachers in these schools subsequently face obstacles in identifying and implementing appropriate activities (Lee et al.).

Not surprisingly, ELLs have lagged significantly behind their English-proficient counterparts in science, and the achievement gap widens as ELLs progress through school. For example, only 3% of eighth-grade ELLs scored at or above the proficient level in the standardized science assessment, compared with 30% of English-proficient students (National Assessment of Educational Progress [NAEP], 2006). In addition, the largest achievement gaps – on average, 39 points – in science subjects persist between ELLs and EPSs across fourth-, eighth-, and twelfth-grade levels (Figure 1.1). Yet despite the large achievement gaps between ELLs and EPSs, there has been little research on the short- and long-term consequences of these achievement gaps.

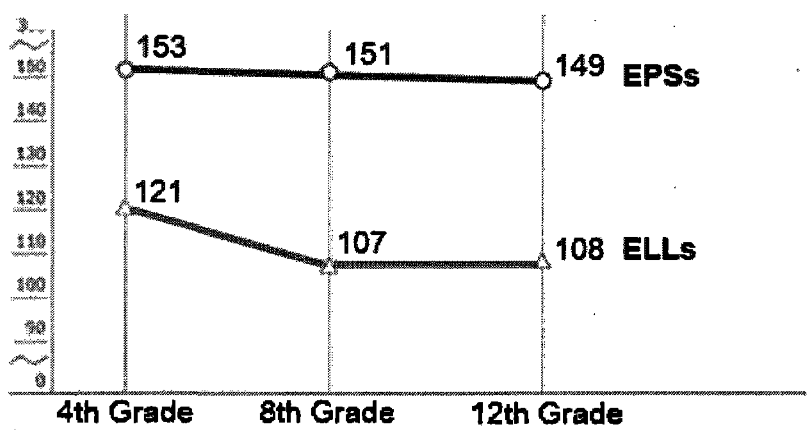


Figure 1.1. Fourth-, Eighth-, and Twelfth-grade Average NAEP Science Scores between ELLs and EPSs.

Although it is critical to provide instructional support to help ELLs successfully develop both the content and the academic language of science, current science instruction does not reflect these students' special needs. For example, there is a lack of qualified bilingual teachers and English as a Second Language (ESL) teachers who can provide linguistic support to ELLs during science instruction (Echevarria, Short, & Powers, 2003). In addition, it is often the case that many highly skilled science teachers have sufficient content knowledge of their subject matter, but nonetheless many of them are not trained to teach ELLs in their classroom (Lee, Luykx, Buxton, & Shaver, 2007; Lee et al., 2007). Another challenge is that, although textbooks are often the dominant method of science instruction, science textbooks introduce complex scientific phenomena in dense, technical vocabulary with complicated sentence structures, both of which are difficult even for EPSs (Kinniburgh & Shaw Jr, 2007).

Given these challenges, it is essential to develop an instructional approach that integrates English language instruction with science subjects in order to improve ELLs' understanding of science content and their use of scientific discourse. Many researchers have suggested a variety of instructional approaches to resolve the challenges ELLs face in the science classroom. For example, inquiry-based science learning has been found to be effective in promoting ELLs' scientific knowledge and language development (Blake & Sickle, 2001; Cuevas, Lee, Hart, & Deaktor, 2005; Kelly & Breton, 2001; Rodriguez & Bethel, 1983; Rosebery, Warren, & Conant, 1992); the potential advantage of computer technology in improving ELLs' science learning has also been examined (Buxton, 1999; Dixon, 1995); and studies examining the effects of language-based science instruction have shown promise for enhancing

ELLs' scientific knowledge and scientific reasoning skills (Duran, Dugan, & Weffer, 1998; Lee & Fradd, 1996; Rivard & Straw, 2000).

Despite the positive outcomes of these instructional approaches on ELLs' science learning, however, several gaps remained in the literature. Although many studies state that the scientific mode of communication used in the classroom is different from the everyday modes of communication used in students' daily lives, these studies have paid little attention to how to solve the discontinuity between everyday English and specialized scientific language. Second, several studies suggest that bringing students' home cultures and home languages into the science curriculum constitutes an effective pedagogical approach to improving ELLs' science learning (Ballenger, 1997; Lee & Fradd, 1996; Lee, Fradd, & Sutman, 1995; Warren et al., 2001). However, given the wide variety of cultures and languages represented by a diverse ELL population, as well as the limited number of multilingual teachers, this approach is often impractical. Other researchers suggest that integrating inquiry-based science instruction into the classroom is particularly beneficial for ELLs' science learning (Hampton & Rodriguez, 2001; Merino & Hammond, 2001; Rosebery, Warren, & Conant, 1992). Yet this approach is equally problematic, given the limited number of highly skilled teachers who are able to implement inquiry-based instruction and the limited resources available at many schools (Buxton, Lee, & Santau, 2008). Another area that has received little attention is the use of instructional technology to enhance ELLs' science learning. Despite numerous studies on technology-enhanced science learning, the effects of computer technology on ELLs' scientific understanding and language development have not been sufficiently evaluated.

Research Questions

This study fills these gaps in the literature by examining the impact of technology-enhanced science instruction on improving ELLs' conceptual understanding of scientific phenomena and their use of scientific discourse, compared to EPSs' performance. More specifically, I explore the effects of two teaching approaches used in technology-enhanced science instruction on ELLs' and EPSs' science learning: teaching science in everyday English prior to introducing scientific language (the Everyday Language approach) and using computer simulation for problem-solving activities (the Simulation approach).

This study was designed to answer three sets of specific questions:

1. Does teaching science in everyday English (Everyday Language approach) and/or using computer simulation (Simulation approach) enhance students' science learning?
    a. Does the Everyday Language approach and/or the Simulation approach increase students' understanding of scientific concepts?
    b. Does the Everyday Language approach and/or the Simulation approach improve students' use of written scientific discourse?
    c. Does the Everyday Language approach and/or the Simulation approach improve students' use of spoken scientific discourse?
2. Does the Everyday Language approach and/or the Simulation approach have different impacts on ELLs' and EPSs' science learning?
    a. Are there any differences between ELLs' and EPSs' understanding of scientific concepts?

   b. Are there any differences between ELLs' and EPSs' use of written scientific discourse?
   c. Are there any differences between ELLs' and EPSs' use of spoken scientific discourse?
3. Does the Everyday Language approach and/or the Simulation approach help close the achievement gaps between ELLs and EPSs?
   a. Are the gaps between ELLs' and EPSs' understanding of scientific concepts smaller after the treatment?
   b. Are the gaps between ELLs' and EPSs' ability to use written scientific discourse smaller after the treatment?
   c. Are the gaps between ELLs' and EPSs' ability to use spoken scientific discourse smaller after the treatment?

Organization of the Dissertation

To answer the above questions, I developed technology-enhanced instruction and conducted a randomized experimental study with 220 fifth-grade students from nine classes from four public elementary schools. The subsequent chapters are organized as follows.

In Chapter 2, I synthesize the relevant literature examining the impact of various instructional approaches on ELLs' science learning and presents the theoretical framework of the study. The literature review examines three types of instructional approaches that emerged from the studies: inquiry-based science instruction, integration of explicit speaking and writing activities, and the use of computer technology. Despite the positive outcomes of these instructional approaches on ELLs' science learning, the current literature on ELLs' science learning has noticeable limitations, such as a lack of identification of what is meant by "scientific language" and small-scale qualitative, descriptive research methodology. The theoretical framework section provides an overview of three aspects of science learning (conceptual, linguistic and social) and then discuss the characteristics of academic scientific language and additional challenges that ELLs face in learning scientific language, based on Cummins' CALP theory. Next, the theoretical framework discusses the role of computer simulation as one approach in increasing ELLs' use of scientific language in social practices.

In Chapter 3, I provide a detailed design process of technology-enhanced instruction and an overview of five pilot studies. For this study, I developed a technology-enhanced curriculum that consists of computer-based science instruction and simulation-based problem-solving activities. I designed and implemented a science instruction program using the Everyday Language approach; in other words, the computer-based instruction teaches concepts of photosynthesis and respiration in everyday English, prior to the introduction of scientific language. I also created a computer simulation program that allows students to manipulate objects and to conduct virtual experiments. I carefully constructed the final versions of both programs based on the actual curriculum design, in consultation with fifth-grade teachers and instructional designers, and findings from several pilot studies and user tests with multiple versions, over the course of four years.

In Chapter 4, I describe the methodology of my study, including the research design, participants, study procedures, and measures. To examine the effects of the Everyday Language approach and the Simulation approach, I conducted a 2 (Language) X 2 (Simulation) X 2 (English proficiency) factorial study with 220 fifth-grade students from nine classes from four public schools. Prior to the study, all students took multiple-choice and open-ended pretests, and three students from each classroom were selected for a pre-interview. Each class was randomly assigned to one of four treatment groups: (1) Everyday-Simulation group (taught in everyday English and used computer simulation for problem-solving activities), (2) Everyday-Website group (taught in everyday English but used a website for the activities), (3) Hybrid-Simulation group (taught simultaneously in everyday and scientific language, and used the simulation program), and (4) Hybrid-Website group (taught in hybrid language and used the website for the activities). All students participated in six hour-long, consecutive science sessions, and after the six sessions, they all took two posttests that were the same as the pretests, and the three same students from each class who initially participated in the pre-interview took a post-interview.

The next three chapters present the results of the study. In Chapter 5, I examined the impact of teaching science in everyday English and using computer simulation on students' conceptual understanding of scientific phenomena, by analyzing students' performance on the multiple-choice tests. The findings revealed that the combination of the Everyday Language approach and the Simulation approach was most effective in improving both ELLs' and EPSs' scientific knowledge. An interesting finding was that the Everyday Language approach significantly enhanced both ELLs' and EPSs' science learning, whereas the Simulation approach was only beneficial for ELLs. Since there were no initial achievement gaps between ELLs and EPSs, the analysis did not reveal whether these teaching approaches could help close the achievement gaps between the two groups. However, the descriptive analyses reveal that the difference between ELLs and EPSs in the Everyday-Website and the Hybrid-Simulation groups became noticeably larger than the gaps between ELLs and EPSs in the Everyday-Simulation and the Hybrid-Website groups on the posttest.

In Chapter 6, I analyze students' performance on the open-ended tests to examine the impact of the two approaches on students' understanding of the scientific concepts and their use of written scientific discourse. Again, the combination of the Everyday Language approach and the Simulation approach was found to be most effective in enhancing both ELLs' and EPSs' understanding of the content and their use of scientific language. This combination was particularly beneficial for ELLs, such that ELLs in the Everyday-Simulation group significantly outperformed ELLs in the other three groups. Similar to the results from the multiple-choice tests, the effect of the Everyday Language approach was significant for both ELLs and EPSs, but the impact of the Simulation was only significant for ELLs. Most notably, the use of computer simulation was found to be helpful in decreasing the learning gaps between ELLs and EPSs. Prior to the study, EPSs showed a significantly better ability to articulate their understanding of the concepts accurately using scientific language than ELLs across the four groups. However, on the posttest, there were no significant gaps between ELLs and EPSs in the Simulation condition, whereas the achievement gaps between the two groups of students became much greater when students used the website.

In Chapter 7, I provide the results of students' interview data. Consistent with previous results from the multiple-choice and open-ended tests, the combination of the Everyday Language approach and the Simulation approach was most effective in improving both ELLs' and EPSs' conceptual understanding of scientific phenomena and their use of scientific language to articulate their understanding correctly. In particular, the combination of these two instructional approaches was significantly more effective in enhancing students' science learning as compared to the combination of teaching science in hybrid language and using the website. On the pre-interview, most students were either unable to provide an answer or showed a serious misunderstanding of photosynthesis and respiration. However, after the treatment, students in the Everyday-Simulation group were able to provide more elaborate, complete responses to the interview questions with necessary detail. They even demonstrated a better ability to accurately use scientific language to explain their scientific ideas, compared to their counterparts.

In Chapter 8, I present a summary of findings and draw conclusions from the study, discuss the implications and potential contributions of my work to the field, and recommend directions for future research. This study calls our attention to the need to develop and use multiple instructional approaches for ELLs' science learning. The results from my sample highlight the potential advantages of the Everyday Language and the Simulation approaches for ELLs' scientific knowledge and their ability to use scientific language accurately. The findings also suggest that computer simulation can be an effective tool in decreasing the achievement gaps between ELLs and EPSs. In terms of academic inquiry into innovative pedagogical approaches, this study helps to fill the gap in the literature by offering a unique perspective on the role of everyday language in science instruction for ELLs, and by examining the potential advantage of educational technology for ELLs' science learning. In the classroom and in students' experiences, the findings of this study ultimately have far-reaching implications for a new technology-enhanced pedagogy that can enhance not only ELLs', but also EPSs' science learning, even eliminating achievement gaps between these two groups of students while fostering improved learning for all students.

CHAPTER 2: LITERATURE REVIEW AND THEORETICAL FRAMEWORK

This study explores how to improve science learning for ELLs who are in the process of developing English proficiency and help decrease the achievement gaps between these students and English-proficient students (EPSs). This chapter both provides an overview of empirical studies that analyze a variety of instructional approaches designed to enhance ELLs' science learning and discusses the theoretical framework for this study to better understand the relationships between science learning and language development through technology, drawing on Cummins' Cognitive Academic Language Proficiency (CALP) theory and computer simulation literature.

This chapter consists of two parts, the literature review [1] and the conceptual framework of the study. First, the literature review is divided into three sections based on the three types of teaching approaches that emerge from the studies considered here: (1) inquiry-based science instruction, (2) integration of explicit speaking and writing activities, and (3) the use of computer technology. These three emerging approaches are used as sub-categories here. In each section, I present a brief summary

[1] Because the term "English Language Learners (ELLs)" is frequently used interchangeably with other terms, such as *Limited English Proficient (LEP) students*, I included in the literature review all studies that involve participants identified as *English Language Learners (ELLs)*, *Limited English Proficient (LEP) students*, *English as a Second Language (ESL) students*, *English Learners (ELs)*, *language minority students*, *bilingual students*, and *English for Speakers of Other Languages (ESOL) students*. I included only studies that use English as the main language of science instruction because this literature review is concerned primarily with examining how to teach science more effectively to ELLs who are comfortable using everyday English in the American mainstream classroom.

of the work, followed by an analysis of the research conducted. I conclude with an examination of the contributions and limitations of the literature.

Second, the conceptual framework starts with an overview of three aspects of science learning (conceptual, linguistic and social). I then discuss the linguistic aspect of science learning for ELLs by analyzing the characteristics of academic scientific language and discussing additional challenges that ELLs face in learning scientific language, based on Cummins' CALP theory. Next, I review the literature of computer simulation as one approach to increase students' use of scientific language in social practices. Finally, I discuss how these theories were applied to the design of my study.

Literature Review

Instructional Approach 1: Inquiry-based Science Instruction

Science education reform documents, such as *Science for All Americans* and *National Science Education Standards*, recommend inquiry as a way of improving scientific literacy for all. They argue that the inquiry-based science approach can provide an authentic science learning environment that engages students in investigating scientific phenomena, using scientific discourse, such as describing or analyzing, and participating in hands-on experimentation. A great number of studies have also found that the use of inquiry-based instruction can be a powerful instructional approach that can enhance both ELLs' understanding of scientific ideas and promote their use of scientific discourse, as well as their English language skills (Amaral, Garrison & Klentschy, 2002; Cuevas, Lee, Hart & Deaktor, 2005; Fradd & Lee, 1999; Hampton & Rodriguez, 2001; Kelly & Breton, 2001; Lee, 2002; Lee, Hart, Cuevas & Enders, 2004; Rodriguez & Bethel, 1983; Stoddart, Pinal, Latzke & Canaday, 2002). These authors posit that, through inquiry learning, ELLs can more actively engage in hands-on science activities and experience the process of scientific inquiry than they would through a traditional textbook approach. The studies argue that participation in inquiry-based instruction not only helps ELLs conceptualize scientific ideas more effectively, but also allows them to articulate their understanding of scientific phenomena in a variety of representations, such as spoken, written and graphic forms.

Hampton and Rodriguez (2001) examine how a hands-on, inquiry-based science curriculum improved K-5 ELLs' science learning and their first (Spanish) and second (English) language skills. Collaborating with elementary school teachers, trained bilingual university interns taught K-5 students the Full Options Science Series (FOSS) curriculum, a hands-on, inquiry-based curriculum, once a week for six weeks. Findings reveal that the inquiry instruction is effective in enhancing ELLs' conceptual understanding of scientific ideas and improving their language skills in both English and Spanish, such as scientific vocabulary development in both languages. However, the study acknowledges the reality that ELLs' limited English proficiency can be a barrier to the inquiry teaching delivered solely in English without assistance from bilingual teachers (in their case, bilingual interns).

Rosebery, Warren, and Conant (1992) also examine the effects of a collaborative inquiry-based science program, called *Cheche Konnen*, on ELLs' development of content knowledge and scientific reasoning. In this project, ELLs participated in a collaborative investigation of scientific phenomena occurring in nature, such as differences in water quality, with guidance from bilingual teachers. The results demonstrate that after participating in the inquiry project, ELLs not only demonstrated improved understanding of scientific phenomena, but they also used scientific discourse more often during problem-solving tests, such as generating more hypotheses to explain their reasoning and providing appropriate experimental designs as a method to test their hypotheses. The authors conclude that a collaborative inquiry-based approach "creates powerful contexts for constructing scientific meanings" because, in such environments, ELLs have more opportunities to use different types of scientific discourse to share their understanding with peers and to negotiate any conflicts during the problem-solving tasks.

Another study that shows positive results from inquiry-based instruction is Kelley and Breton (2001), but they specifically focus on scientific discourse. Kelly and Breton investigated how two Spanish-speaking teachers framed science instruction as scientific inquiry to help Hispanic bilingual students and ELLs learn about the inquiry process and develop scientific discourse. From classroom videotapes, interviews with teachers and students, and students' classroom products (such as their writing samples), Kelly and Breton find that teaching science as inquiry, particularly incorporating explicit discussion and writing activities into the inquiry, can be effective in improving ELLs' science learning because teachers can provide students with models for scientific discourse (such as discussing and critiquing) and with learning opportunities to engage in different modes of scientific discourse in multiple contexts.

The impact of inquiry-based instruction on ELLs' scientific discourse is also examined by Moje, Collazo, Carrillo, and Marx (2001), who specifically focus on how teaching science through inquiry can create "instructional congruence" where students' everyday discourse can intersect with scientific discourse. They observed how seventh-grade Hispanic bilingual students and their bilingual teacher were engaged in scientific discourse during inquiry-based instruction. Observations of the classroom reveal that students were struggling to use scientific discourse and to construct new scientific knowledge while engaging with scientific tasks. However, the teacher was unable to draw upon students' everyday knowledge and discourse, nor could he help them make connections between their everyday discourse with scientific discourse. The authors suggest that it is important for teachers to create "a third space" which integrates students' lives and their primary discourse into the science discourse in the classroom (p. 492).

As a part of a large-scale instructional intervention research project on improving students' scientific literacy, Cuevas, Lee, Hart, and Deaktor (2005) examine the effects of an inquiry-based instructional intervention on non-mainstream third- and fourth-grade students' ability to conduct scientific inquiry. The study involves 28 students from diverse linguistic and cultural groups from six schools. Results from the study demonstrate that the inquiry-based instruction effectively enhanced all students' ability to conduct inquiry, particularly former ELLs and low-achieving students. Students overall demonstrated a significant increase in asking appropriate questions to start scientific investigation and in developing procedures for solving scientific problems, but particularly significant gains were found in the performance of low-achieving and former English for Speakers of Other Languages (ESOL) students. Findings indicate that inquiry-based science instruction can promote science learning for students who are linguistically and culturally different from mainstream students, but for successful inquiry-based science instruction, it is important to integrate explicit instruction of both the science content and inquiry procedures into the lessons.

Amaral, Garrison, and Klentschy (2002) also report positive results from a four-year science intervention with ELLs and EPSs. They conducted a large-scale study with 615 fourth graders and 635 sixth graders for four years to investigate how the inquiry-based science intervention, the Valle Imperial Project in Science (VIPS), enhanced ELLs' and EPSs' science performance and writing proficiency over time. The results indicate that both ELLs and EPSs who participated in the program longer performed better on the science assessment and demonstrated a higher pass rate on the writing exam. Similar to other researchers, Amaral, Garrison, and Klentschy also view inquiry-based science instruction as particularly beneficial for ELLs, because it creates multiple opportunities for ELLs to develop linguistic skills and to use scientific language to articulate their understanding of scientific content and share their experiences with others.

The six studies analyzed above provide strong evidence that inquiry-based science instruction can be an effective approach not only to enhance ELLs' understanding of scientific concepts, but also to help them develop scientific language and an ability to conduct inquiry. All six studies highlight that inquiry-based instruction can provide ELLs with multiple learning opportunities to use scientific language in different contexts and to engage in various types of scientific discourse. Collaboration with other students and/or with teachers can also help ELLs develop language skills and reconstruct their understanding of scientific phenomena.

Although the inquiry-based instruction has been one of the most effective approaches for ELLs' science learning, the feasibility of successful scientific inquiry in the classroom is not guaranteed because it is difficult to identify what components have a positive impact on ELLs' science learning. All of the inquiry-based instruction described in the studies above consisted of multiple layers of valuable resources, such as hands-on activities, professional development, bilingual teachers, peer discussions, and explicit writing activities. However, most studies do not provide details regarding the types of inquiry-projects students were involved with, the duration of the projects, or the procedures of inquiry-based instruction.

An interesting finding that emerges from the six studies is the important role of bilingual teachers in the inquiry-based instruction. The inquiry-based instruction examined in all six studies was partially or solely delivered by bilingual teachers. The six studies find that it is important to provide appropriate assistance from bilingual teachers to ELLs who might struggle with new types of discourses with which they are not familiar. Although it is an ideal solution to have a bilingual teacher who can provide ELLs with some transitional steps from their everyday discourse to scientific discourse, this is challenging in practice because there is a wide range of languages spoken by ELLs, and limited bilingual or multilingual teachers available.

Instructional Approach 2: Integration of Explicit Speaking and Writing Activities

Language is an integral part of science learning because learning science involves multiple uses of the spoken and written language of science, such as using new scientific vocabulary to describe scientific phenomena and to formulate hypotheses (Lemke, 1990). Students need to be able to use both scientific language and discourse patterns accurately to "understand" science and also to "do" science in an appropriate way. The three studies discussed here examine how explicit integration of speaking and writing activities into a science curriculum can help ELLs better develop their understanding of both scientific concepts and scientific language.

Rivard and Straw (2000) examine how a combination of peer discussion and a writing activity can enhance ELLs' scientific knowledge and their use of scientific discourse. They conducted a quasi-experimental study with 43 eighth graders whose first language was French, but who spoke English in schools in Canada. Students were randomly assigned to one of four groups stratified for gender and achievement level: (1) a "talk-only" group, (2) a "writing-only" group, (3) a "combined talk and writing", and 4) a control group. The results revealed that students in the "combined talking and writing" group not only demonstrated a significantly better understanding of scientific phenomena, but they were also able to provide more organized thoughts and more coherent content in written form. The results also provided evidence that either peer discussion or a writing activity alone is not as effective as the combination of the two approaches. Rivard and Straw suggest that writing activities are most effective in enhancing ELLs' science learning when they are preceded by peer discussion which provides an opportunity for ELLs to modify any misunderstanding of scientific concepts and reorganize their scientific ideas.

The effects of writing framed by an initial peer discussion are also addressed in Lee and Fradd's study (1996). The groups of fourth-grade monolingual English-speaking, bilingual Hispanic, and bilingual Haitian students were divided into dyads based on the same "language, culture, and gender as the teachers" (p. 657). For example, a dyad of male Hispanic boys was assigned to a male Hispanic teacher. Each dyad was asked to organize three sets of pictorial task cards illustrating procedures of scientific phenomena, such as hurricanes, in order, and to provide narrative explanations. Then, students were asked to summarize individually their explanations in either written or visual form. Students' written and visual representations were analyzed based on length (or a number of drawings) and content. The results reveal that 64% of the students successfully organized task cards in a correct sequence and showed a clear understanding of the scientific concepts in their explanations. Specifically, Hispanic bilingual students particularly outperformed native English speakers in both science card tasks and writing assessment.

Merino and Hammond (2001) explore the impact of writing activities on developing bilingual students' scientific knowledge and their use of scientific language through an ethnographic study. As part of a larger study that investigated the effectiveness of the Bilingual Integrated Curriculum Project (BICOMP), bilingual teachers implemented inquiry-based science instruction. The findings of the study show that three writing assignments – the scientific method lab sheet, the learning journal, and the narrative journal – helped bilingual students develop a better ability to provide scientific writing over time. Findings also indicate that integration of explicit writing activities into science instruction can be a productive way of improving bilingual students' language development, as well as the content of science subjects.

Duran, Dugan, and Weffer (1998) investigate how Mexican American language minority students with limited English proficiency could develop a conceptual understanding of scientific phenomena using semiotic tools, such as language and diagrams. Duran, Dugan, and Weffer observed a tenth-grade biology classroom where students engaged with a variety of instructional activities designed to help them practice both written and spoken scientific discourse. The results reveal that the use of multiple semiotic tools helped language minority students better construct understanding of scientific topics, in this case biology, and engaged them in using scientific language in different contexts. For example, from the teacher's lessons, students learned how to use scientific language accurately and appropriately, and from the discussions with the teacher, they practiced the newly acquired scientific language in multiple forms, such as questions and argumentation. The use of diagrams also played an important role as a scaffolding to help these language minority students learn how to talk science; through diagram-related activities, students practiced explaining scientific relationships and developed the linguistic skills to express their understanding with diagrams without the teachers' assistance, gradually increasing "their voice in biology talk" (p.338).

Given the fact that acquiring scientific language does not necessarily translate into using that language accurately for different purposes, one of the biggest challenges that ELLs face in learning science is the scarcity of opportunities they have to engage in scientific discourse. The most important contribution of the three studies analyzed above is that each demonstrates that explicit use of speaking and writing activities can provide multiple learning opportunities for ELLs to practice newly acquired scientific language and develop an ability to engage in scientific discourse.

The four studies also describe the different roles of peer discussion and writing activities in ELLs' science learning and suggest that writing activities followed by peer discussion are most effective in helping ELLs develop both the content knowledge and a better ability to use scientific language accurately. In particular, all four studies identify peer discussion as an important learning opportunity that allows for sharing knowledge with other students and for reconstructing students' understanding of scientific ideas, while writing activities function as a mechanism for organizing and consolidating scientific ideas.

Instructional Approach 3: Use of Computer Technology

The effects of various types of educational technology in science education have been widely studied across science fields; using computers to promote students' scientific thinking skills (Fisher, 1997), the role of computers in encouraging students to reflect on the meaning of data and choosing appropriate representation forms (Rogers, 1997), developing positive attitudes toward science learning (Hounshell & Hill), and correcting students' misconceptions in scientific phenomena (Hewson & Thorley; Windschitl). There are, however, only two studies that investigate the impact of computer technology on ELLs' science learning.

Buxton (1999) examines how the use of a computer-based model helps Hispanic bilingual students construct an understanding of scientific ideas and provide more accurate explanations for their explanations. The study was conducted with 26 second- and third-grade students in a two-way bilingual classroom (Spanish/English) at a small elementary school. Students were asked to build animation to describe scientific concepts by using computer-based models, and then to tell their own story to explain the concepts. The findings of the study indicate that the use of computer-based models played a role as a storytelling tool which enabled students to engage actively in scientific discourse. Students actively participated in the discussions about their computer models and the scientific phenomena they were trying to explain using the model. During this process, students had a great number of opportunities to demonstrate their ability to use different forms of representations – written, oral, and pictorial – in order to explain their conceptual understanding of scientific phenomena. Findings of the study suggest that the use of student-generated computer models could be beneficial to bilingual students who have been marginalized in traditional science classrooms, by helping them develop the ability to "think, act, and talk in ways that are compatible with the culture of school science" (p. 25).

Dixon (1995) also explores the potential advantages of computer technology for improving ELLs' science learning, particularly their conceptual understanding of reflection and rotation, as well as their ability to visualize scientific concepts. The study employed a quasi experimental research design with nine classes of eighth-grade students. Students in the experimental group studied reflection and rotation in pairs using the *Geometer's Sketchpad*, a computer program that provides the visual and dynamic representation of rotation and reflection. By contrast, students in the control group studied the identical concepts using textbooks under traditional teacher direction. The results of the study demonstrate that students who received the dynamic instruction from the *Geometer's Sketchpad* significantly outperformed their counterparts taught by the traditional textbook method. In addition, students who had higher visualization levels performed significantly better than students who had medium or lower levels of visualization. However, there is no significant difference between ELLs and EPSs, regardless of treatment and visualization levels. Dixon concludes that dynamic visual representation could improve both ELLs' and EPSs' understandings of reflection and rotation and their visualization levels in the English-dominated classroom.

As addressed earlier, despite the large number of studies in technology-enhanced science learning, the question how the distinctive advantages of educational technology can benefit ELLs in learning science has been significantly underexplored in science education. In that sense, the primary contribution of these two studies is that they provide useful insights into how the use of educational technology in the classroom can enhance ELLs' science learning. Consistent with the literature on the effects of technology-enhanced science learning, both Dixon and Buxton report positive outcomes of interactive computer technology in promoting ELLs' conceptual understanding of scientific phenomena and developing their proficiency in scientific language and discourse. The successful use of computer technology for ELLs' science learning described in these studies indicates that integrating technology into science instruction has the potential advantage for creating a meaningful learning environment that enhances science learning for this special group of students. Future research should examine the impact of various types of technology on ELLs' science learning, such as animation, simulation, and games.

Summary

This review synthesizes research studies that explore how different instructional approaches can enhance ELLs' conceptual understanding of scientific phenomena and their use of scientific discourse. The twelve empirical publications are categorized into three main areas, based on types of instructional approaches: inquiry-based instruction, the use of explicit speaking and writing activities, and the use of computer technology. Under each category, the review provides summaries of the studies examining similar instructional approaches and provides strengths and weaknesses of each instructional approach.

In consulting the findings from these twelve studies, two important themes emerge. First, while there is no agreed-upon definition of scientific language, all the studies reviewed here highlight the relationship between scientific language and science content, and emphasize how important it is to acquire the specialized language of science when learning science. They explain that scientific language and scientific discourse used in the classroom are different from the everyday language and everyday discourse with which ELLs are familiar, which can be a barrier to ELLs' science learning.

Second, all twelve studies analyzed in this review emphasize the importance of collaborative learning in ELLs' science learning. They argue that knowledge construction and scientific language learning are most effective in socially-shared interactions with peers because collaborative learning provides ELLs with multiple opportunities to use scientific language in different contexts and engage in different types of scientific discourse. In addition, ELLs can improve their language skills and reconstruct any misconceptions they initially had by interacting with more advanced peers.

Although the studies reviewed here also highlight the importance of scientific language and the potential for collaborative learning to enhance ELLs' science learning, the current literature on ELLs' science learning has three noticeable limitations that I mention in an effort to identify how they might begin to productively answered.

First, most of these studies do not provide any identification of, or details about, what is meant by "scientific language," and how it is different from everyday language with which ELLs are familiar. Although each study acknowledges the existing differences between everyday and scientific language, with the exception of Durant et al. (1998) and Moje et al. (2001), none of the other studies go into any depth about the definition of scientific language, or more central for the questions of this study, why ELLs have difficulties learning this specialized language.

Second, most of these studies were conducted with bilingual teachers who were able to speak a language in common with their students, and provide appropriate support for ELLs when needed. The advantage of having bilingual teachers might have significantly contributed to the positive outcomes of several instructional approaches analyzed in these studies. Although providing ELLs with appropriate linguistic support from bilingual teachers can be truly effective in improving ELLs' science learning, there is a limited number of qualified teachers who are truly bilingual in both English and the primary language of various students. Additionally, given the wide range of languages spoken by ELLs, it is impractical to find a bilingual teacher for each group of ELLs.

A third limitation in the current literature is the limited methodology. Most studies conduct small-scale qualitative, descriptive research, whose findings can be difficult to generalize. Only two studies that investigate the impact of instructional intervention are large-scale studies with more than 1,500 participants. In addition, many of the studies do not have any comparisons that would strengthen the design considerably, particularly English-proficient counterparts. Only three studies conducted an experimental study with a control group, but two of them failed to control variables in the comparisons.

This study fills these existing gap in the current literature on how to improve science learning for ELLs, by conducting an experimental study with 220 ELLs and English-proficient students (EPSs) in order to examine the impact of new technology-enhanced approaches on ELLs' science learning, compared to that of EPSs'. In this study, instead of teaching science with bilingual teachers, I explore new instructional approaches focusing on how to use ELLs' existing strength in everyday English as a kind of bridge, drawing on their preexisting linguistic strengths to help them efficiently master scientific language, and how to use computer technology for improving ELLs' science learning. I then examine the effects of these two approaches on enhancing ELLs' scientific knowledge and their use of scientific language, as compared to EPSs'. The following section discusses the theoretical framework for the study.

Theoretical Framework of the Study

The findings of the literature review clearly show the three dimensions of science learning, which all students need to master in order to succeed in school science: conceptual, linguistic, and social (Figure 2.1). As proposed in the national standards, students need to build a *conceptual understanding* of scientific phenomena, which includes remembering new facts and principles of scientific concepts, developing knowledge of the nature of science, and modifying any prior misconceptions. Students also need to acquire an appropriate level of *linguistic proficiency* in science, such as gaining technical vocabulary and developing an ability to talk like scientists. Furthermore, they need to participate in the *social practices* of scientists, by conducting scientific inquiry, developing the ability to reason about their explanations and the process of scientific experiments, and constructing arguments.

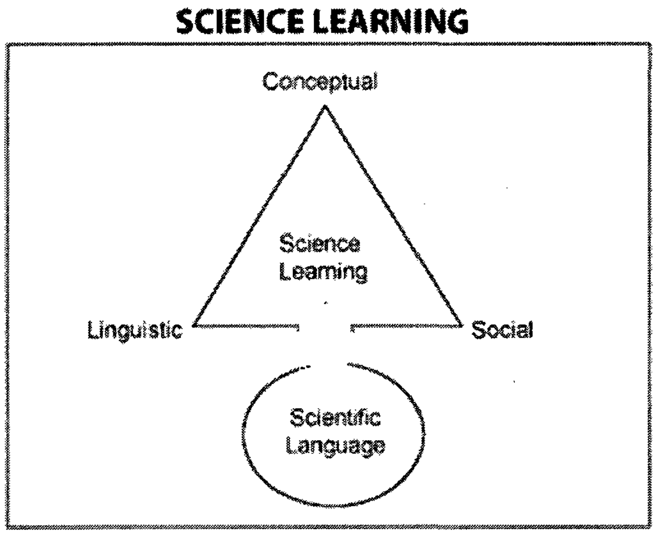


Figure 2.1. Three Dimensions of Science Learning.

These three dimensions of science learning are not only dynamically intertwined with each other, but they are also centered around and deeply connected with everyday language and scientific language. In other words, science learning means learning to use appropriate language associated with science in understanding, talking, writing, and doing science (Lemke, 1990). For example, when students read a science textbook, they should be able to decode scientific language to comprehend the meaning of the text using their everyday language. When they are writing a lab report, they should be able to use both everyday and scientific language to explain the procedure of their experiment. When they solve a scientific problem in a group, they should be able to speak using appropriate language to precisely communicate their understanding of scientific concepts. As many researchers have emphasized, scientific language is indeed an integral part of learning science.

Despite its importance in science learning, scientific language often hinders ELLs' science learning and, in particular, keeps ELLs from understanding scientific phenomena and participating in scientific discourse because scientific language is fundamentally different from the everyday language that ELLs use in more general contexts (Cummins, 1981, 2000, 2003; Fang, 2006; Gee, 1995, 2000, Hamayan & Perlman, 1990; Lee, 2005; Lemke, 1990). The following section explores the definition of scientific language, differences between everyday language and scientific language, and the particular challenges that ELLs face in learning scientific language. In order to define what scientific language is, we should first examine academic language in general because academic language, of which scientific language is a subset, can provide a useful entry point into the quest for a definition of scientific language.

Academic Language

The distinct type of language used in schools or in other academic settings is often called "academic language." Although what constitutes academic language has not yet been definitively agreed upon, the most prevalent view of academic language is Cummins' Cognitive Academic Language Proficiency theory (Cummins, 1979, 1981, 2000, 2003), a theoretical model for Second Language Acquisition (SLA) that distinguishes between everyday language proficiency and academic language proficiency for second language learners.

Cummins separates academic language, the specialized language used to understand academic content in school, which he calls *Cognitive Academic Language*

Proficiency (CALP), from conversational language, the social language used in everyday life, which he labels *Basic Interpersonal Communicative Skills* (BICS).[2] In other words, BICS is the fluency of social language that ELLs use to interact with other people in social situations, such as on the playground, whereas CALP is the ability both to understand the concepts of academic subjects and to use the specialized language in oral and written form, such as classroom discussion.

Cummins argues that CALP is more challenging to develop than BICS because it is more cognitively demanding and there is less contextual support for CALP than for BICS. According to Cummins, BICS is cognitively less demanding because it is easy to understand, uses everyday language, and primarily includes less complicated language structures. By contrast, CALP requires not only the ability to understand and use more specialized vocabulary and complex grammar structures, but also the ability to understand academic subjects simultaneously — both of which demand heavy cognitive process of students.

Another factor making CALP more difficult to acquire is its typical usage in contexts with limited non-verbal cues, which would otherwise help students understand the language and facilitate communication. For example, when students use academic language in the classroom, they frequently need to rely on the language itself to communicate rather than using contextual support, such as facial expressions. By contrast, BICS is more "context-embedded" because when students engage in everyday social conversation, they can use non-verbal clues, such as facial expressions or any surrounding objects, to better deliver the meaning.

[2] The terms "academic language" and "everyday language" are used interchangeably with CALP and BICS in this chapter.

Not surprisingly, ELLs can acquire BICS within approximately two years, whereas they generally require a minimum of five to seven years to develop the appropriate grade level of academic language and to catch up with their English-proficient counterparts (Cummins, 1981, 2003; Hakuta et al., 2000; Klesmer, 1994). Because it takes longer to develop academic language proficiency, even though ELLs may be able to communicate fluently in everyday English, they are still likely to continue struggling with academic language.

Scientific language, which is a type of academic language, has several distinctive features different from everyday language, such as specialized grammar, unfamiliar discourse patterns, and technical vocabulary (Fang, 2005, 2006; Gee, 2005; Lemke, 1990). For example, specialized grammar of scientific language contains passive verbs, nominalization, and complex sentences, and patterns of scientific discourse include formulating hypotheses, making claims, and drawing conclusions. In particular, the technical vocabulary of scientific language consists of two types of words: (1) non-specialized academic words, used across content areas and (2) specialized content area words, unique to specific content areas, such as science and math (Figure 2.2).

Non-specialized academic language includes formal words that are frequently used in academic settings but are not specific to any one subject area, such as the verbs, "examine" or "analyze." Students encounter this non-specialized language across subject areas in school. Specialized content area words, however, indicate technical terms that are specific to one content area, such as the term "carbon dioxide." It also represents those words that have a variety of meanings when used in different contexts, such as the word "volume." For example, "volume" can mean "a loudness of sound" in most everyday situations, but "volume" in physics-related contexts can also indicate "the amount of space occupied by a three-dimensional object" (Merriam-Webster Dictionary; Fang, 2006).

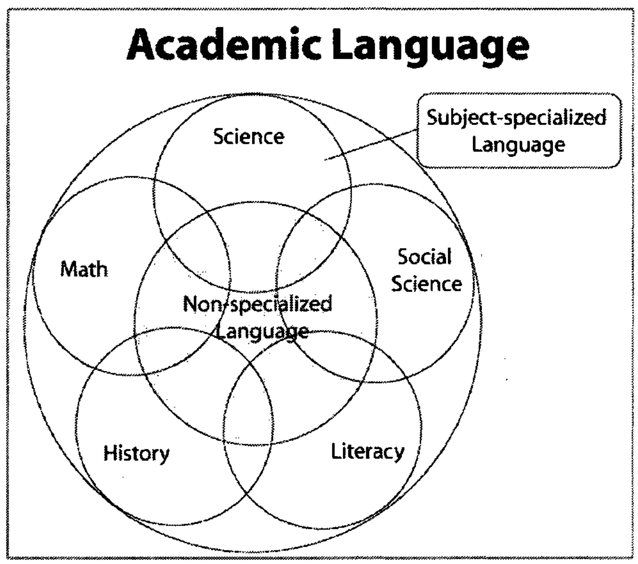


Figure 2.2. Academic Language and Scientific Language.

Among these various features of academic language, the definition of scientific language in this study was limited to the specialized content-area terminology associated with science that is not regularly used in other subject disciplines, such as "photosynthesis" and "oxygen." This study does not include those words that have multiple meanings in various contexts, such as "volume," because the purpose of the study was to explore how to teach science to ELLs through an alternative form of students' everyday language to scientific language.

The term, "everyday language," is commonly used to describe a type of language that students use to communicate with others in their daily lives, such as on the playground, in the market, and in the house. Similar to Cummins' argument regarding the differences between everyday and academic language, many researchers in science education also identify a dichotomy between everyday language of linguistic minority students and scientific language of school, and that it is important to include these students' everyday mode of talking and thinking into science classroom (Lemke; Gee; Lee; Rosebery et al.; Fang). Depending on student populations, everyday language can be students' home language, native language, or a language they are comfortable with. In this study, I expanded the view of everyday language by defining it as a type of English that linguistic minority students actually use to engage in academic subjects in school. For this study, I recorded how language minority students used everyday English to articulate their understanding of photosynthesis and respiration in the school and based on their own everyday words, I created "everyday language," an alternative form to scientific language (see Chapter 4).

While there are various types of academic language used in school, scientific language can be extremely cognitively demanding because the proportion of subject-specialized language in science is significantly higher than that used in many other subjects, such as social science. Additionally, scientific language often deals with abstract scientific concepts that can be difficult to observe in our daily lives, such as photosynthesis.

The following example highlights the noticeable differences between everyday language and scientific language when they are used to describe the same content:

1. Green plants make a type of sugar as their food by taking in light, water, and gas that humans breathe out.
2. Green plants *produce* **glucose,** by taking in **photons**, water, and **carbon dioxide.**

As shown in this example, the two sentences convey the same meaning, but each uses a different type of language to explain the concept. The first sentence is relatively easy for ELLs to comprehend because it is written in everyday English with which ELLs are more familiar, whereas the second sentence is cognitively more demanding for ELLs because it includes a number of specialized scientific terms. Many ELLs are likely to know fewer of these technical terms than EPSs (or they may know none at all). ELLs may even be unfamiliar with a non-colloquial term, such as "produce."

Although this distinctive gap between everyday language and scientific language causes additional challenges for ELLs' science learning, many ELLs do not receive appropriate support to develop their understanding of both the content and the language of science. For example, science textbooks, which are often the main instructional method for teachers, introduce new scientific concepts simultaneously in both everyday language and scientific language. When a new scientific term is introduced, it is presented in bold with a definition in everyday language, but once the term has been introduced, the textbook only uses the scientific term without the definition, such as

> green plants produce their own food, **glucose**. In order to make **glucose**, plants take in light energy called **photons**. They also need water and **carbon dioxide**, gas that humans breathe out.

Similarly, some teachers introduce the list of new scientific vocabulary at the beginning of their lessons by providing definitions of the terms in everyday English. However, once the terms are introduced, teachers often expect ELLs to make connections between the new scientific language and scientific phenomena independently in the course of the lesson and therefore frequently do not provide appropriate support.

As shown in the examples above, learning new scientific phenomena using unfamiliar scientific language is already challenging even for EPSs because of multiple layers of new tasks. In other words, when students learn science, they need to 1) comprehend new concepts, 2) decode the definitions of new scientific terms, and 3) find out and link meanings between the concepts and the language—all of which are already cognitively demanding for EPSs. Not surprisingly, this task increases ELLs' cognitive load more than EPSs' because ELLs often do not have the same literacy skills and the same level of proficiency in academic English as do native English-speaking students when they enter school.

In order to help ELLs master both the content and the language of science more effectively, it is important to reduce the amount of cognitive loads generated by multiple layers of new tasks in science learning. One possible approach is to teach new scientific concepts by using everyday language with which ELLs are already familiar, prior to introducing new scientific language. Through this approach, ELLs can reduced the amount of cognitive loads produced by understanding new information of scientific phenomena, decoding new scientific language, and making connections between the concepts and the language simultaneously. This approach can eventually help ELLs build a stronger conceptual understanding of scientific phenomena in everyday language and use this understanding as a scaffolding to develop fluency in scientific language. In this study, I examine how teaching science in everyday English prior to teaching scientific language can increase ELLs' scientific knowledge and can help them develop the ability to use scientific language accurately.

Social Practices of Science

Although developing proficiency in scientific language is necessary for science learning, it does not automatically improve ELLs' ability to use scientific language appropriately in a variety of academic contexts. In this study, the use of scientific language indicates a student's ability to use accurate scientific terms to communicate his/her ideas when working on science-related tasks, such as articulating scientific knowledge, posing questions, and formulating hypotheses.

In order to develop such skills, ELLs must have multiple opportunities to use scientific language while working on scientific tasks. As noted earlier in the literature review, many researchers have suggested that ELLs can better understand scientific concepts and develop language proficiency when they engage in social practices of science, such as scientific inquiry, because those activities enable ELLs to use scientific language for different purposes, such as arguments and questions, and provide them with opportunities to reconstruct their misconceptions. For example, while ELLs participate in a scientific inquiry project in a group, they need to make their ideas explicit in order to communicate with their partner(s) and to defend their arguments when there is a disagreement. Through this process, ELLs have multiple opportunities to use scientific language to communicate their ideas and develop shared understandings by building on each other's ideas.

Despite the positive outcomes and the potential advantages of various social practices associated with science on ELLs' science learning, it is important to note that social practice itself will not automatically guarantee ELLs' active engagement with using scientific language. The quality of scientific discourse occurring during social practices can differ based on types of tools or materials used, the work assigned, students' prior knowledge, group formation, types of activities, or the interaction among group members (Barron, 2000; Hogan, Natasi, & Pressley, 2000). Among the many possible factors, I chose to examine how different types of tools, particularly computer simulation, can foster ELLs' use of scientific discourse during social practices in this study.

Computer Simulation

Computer simulation has been chosen as a medium for increasing ELLs' scientific discourse because it has distinctive advantages over other types of technology, yet the effect of computer simulation has not been examined for ELLs' science learning. Currently, there is no consensus about the definition of computer simulation, but in this study, "computer simulation" or "simulation" will refer to a computer program in which a user can manipulate virtual objects to conduct scientific experiments, and the program will visually and textually presents the results of the user's actions. For example, a computer program that allows users to conduct science experiments instead of going to a laboratory, or computer software that provides dynamic visual representations of chemical reactions according to a user's input, are both types of computer simulation.

Like other computer-based applications, such as online tutorials and interactive animation, computer simulation has numerous educational advantages for science learning. For example, it can make more visible scientific phenomena, such as photosynthesis, that may be hard to observe in real life (Coleman, 1997; Dwyer & Lopez, 2001; Jonassen, 2000; Leutner, 1993; Schnotz, Boeckheler, & Grzondziel, 1999; Roth, 1995; Zietsman & Hewson, 1986). It can also provide multiple visual representations of the same scientific phenomena, such as animation and graphs, which can assist students in building a more concrete understanding of these events. However, what distinguishes computer simulation from other computer-based applications is *manipulation*. Unlike other computer education technologies, computer simulation not only provides a visual representation of scientific concepts, but it also allows students to actively explore the system by manipulating input variables and based on the user's actions, computer simulation shows different dynamic outputs.

These unique features of computer can provide ELLs with a variety of opportunities to use scientific language for different purpose and engage in scientific discourse. For example, when interacting with computer simulations, students need to decide what to do by themselves, instead of merely following instructions. They need to manipulate materials or variables based on their own hypotheses, interpret visual outcomes, reflect on their decisions, and rerun the program again with revised hypotheses. During this process, students in a group need to explain their ideas, refine their hypotheses, make predictions, share their interpretations, and negotiate meaning. Through this experience, ELLs can develop the ability to properly use scientific language in various academic contexts and strengthen their understanding of scientific concepts. In this study, I examine how the use of computer simulation can increase ELLs' scientific knowledge and improve their use of scientific discourse, compared to the use of a simple website. In the following section, I describe how I implemented these two approaches into designing a technology-enhanced curriculum and discuss the design process of two technology programs used in this study.

CHAPTER 3: DESIGN OF A TECHNOLOGY-ENHANCED CURRICULUM

This dissertation examines whether teaching science in everyday English (the Everyday Language approach) and using computer simulation to solve scientific problems (the Simulation approach) can enhance ELLs' science learning and help close the achievement gaps between ELLs and their English-proficient counterparts. To explore the effects of the Everyday Language and the Simulation approaches, I developed and implemented a technology-enhanced curriculum which consists of two parts: (1) interactive science instruction that teaches scientific concepts in everyday English prior to introducing scientific language and (2) interactive problem-solving activities using computer simulation. Employing a design-based research methodology (Brown, 1992; Cobb, diSessa, Lehrer, & Schauble, 2003; Collins, 1992; Dede, 2004), I designed, implemented, and reiterated both interactive science instruction and a computer simulation program multiple times based on the actual curriculum design, consultation with fifth-grade teachers and instructional designers, and findings from several pilot studies and user tests. In this chapter, I provide an overview of both the computer-based science instruction and the computer simulation programs and describe the design process of these two technologies, including details about the technology and findings from a series of pilot studies that guided the development of the programs.

Description of the Two Science Instruction Programs

To examine the impact of teaching science in everyday English prior to introducing scientific language, I developed the computer-based instruction focusing on concepts of photosynthesis and respiration, which are included in California Science Standards for fifth-grade students. The computer-based instruction was designed to help students build a conceptual understanding of scientific phenomena, in this case photosynthesis and respiration, and acquire specialized language of science. The instruction contained four lessons about photosynthesis and respiration, language activities, and a series of scientific experiments with guidance, all of which required three one-hour sessions for students to complete. The science instruction taught the scientific concepts through multiple representation forms, such as text, animation, narration, and visualization.

I developed two computer-based science instruction programs: the Everyday-Language program and the Hybrid Language program. The two programs were developed based on similar programs used in earlier research and on findings from prior research studies I took part in (Brown & Ryoo, 2008; Ryoo, 2008). The design process of the programs and findings from the previous studies are presented in a later section. The Everyday Language program taught the concepts of photosynthesis and respiration in everyday English, prior to the introduction of the more difficult scientific language, whereas the Hybrid Language program taught the same scientific concepts *simultaneously* in both everyday and scientific language; this is the approach used in most science textbooks. Except for the language used in the instruction, both programs were identical in terms of the content and visualization (Figure 3.1).

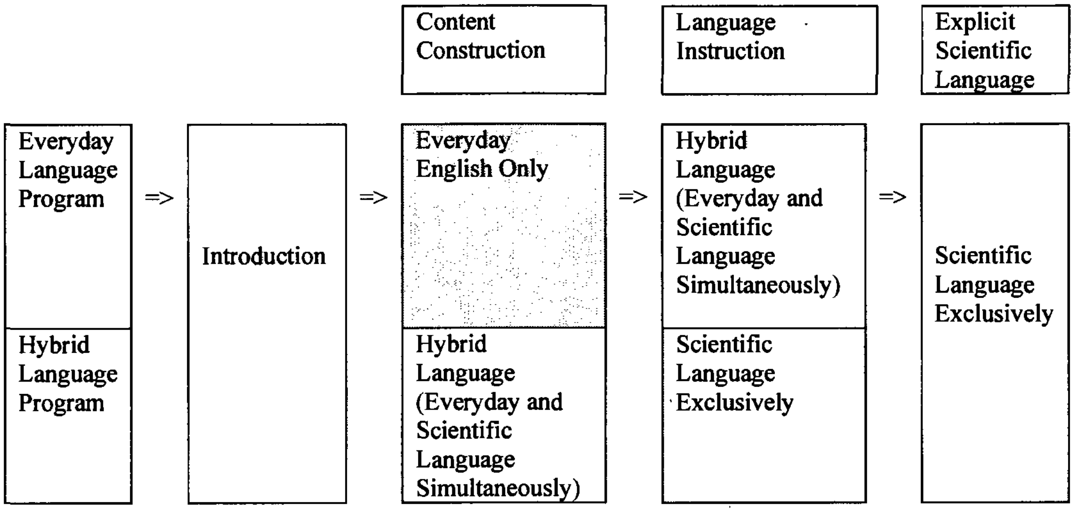


Figure 3.1. Description of the Everyday Language and the Hybrid Language Programs.

Both programs consisted of four distinctive steps: (1) Introduction, (2) Content Construction, (3) Language Instruction, and (4) Explicit Scientific Discourse. The Introduction Step of both programs used animation to introduce both the mission and the interface of the program. A computer avatar called Mandrake explained that she needed to grow a special flower to save her friend Wendy, who had been poisoned by a wicked witch, but the seed of the special flower was locked in a chest. In order to open the chest, Mandrake needed four plant pieces that only could be obtained if the student passed the four lessons of the program. Mandrake then asked students to help her collect these four plant pieces by learning about how plants grow (Figure 3.2). The Introduction also explained the interface of the program, such as the "next" button, the sound option, and the text box (Figure 3.3).

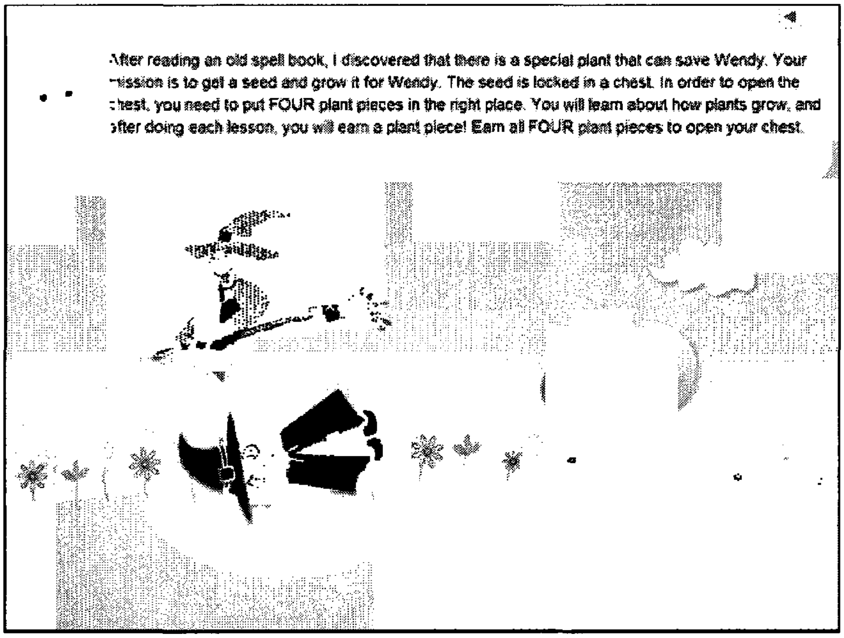


Figure 3.2. Introduction Page.

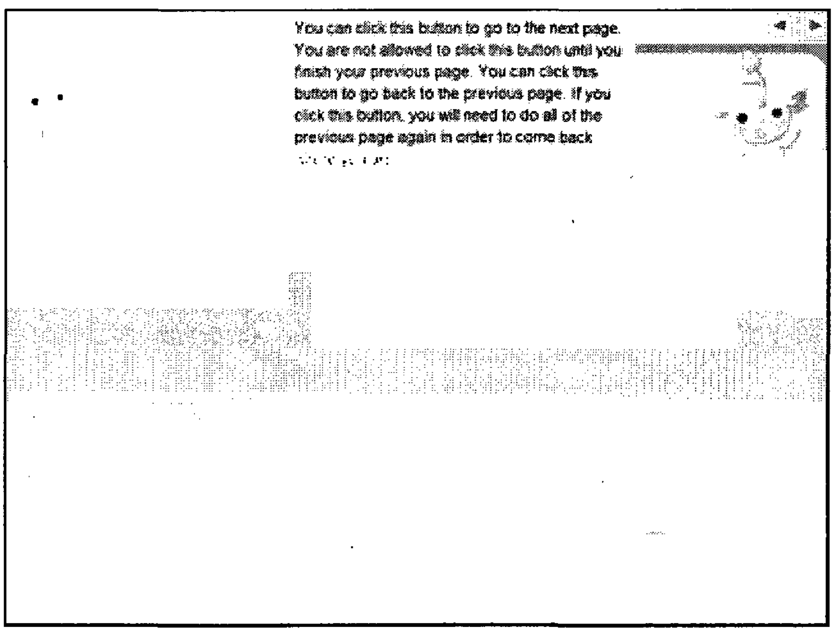


Figure 3.3. Introduction of Interface.

The Content Construction Step was designed to help students build a conceptual understanding of photosynthesis and respiration. This step consisted of four lessons taught by the computer avatar, Mandrake. The Content Construction Step of the Everyday Language program taught the scientific concepts *only* in everyday English[3], without introducing any scientific language until all the concepts had been introduced. For example, the program taught students the concept of "chloroplast" by presenting the picture of a chloroplast and explaining "These are energy pouches. Plants make their own food inside of each energy pouch," without yet introducing the term "chloroplast." Although the Content Construction Step of the Hybrid Language program taught the identical concepts, the content was taught *simultaneously* in both everyday English and scientific language, similar to the way that science textbooks introduce scientific concepts. Once the concept was introduced *simultaneously* in both everyday English and scientific language, the program explained the same concept *exclusively* in scientific language. For example, the program introduced the concept of "chloroplast" by explaining, "These are energy pouches. Scientists call this energy pouch, a chloroplast. Plants make glucose inside of each chloroplast." However once the term "chloroplast" had been introduced, the instruction did not explain it in both everyday and scientific language, but rather used *only* the scientific term "chloroplast."

The Language Instruction step was designed to help students master scientific language used to describe photosynthesis and respiration phenomena. This step

[3] Here "everyday English" defines everyday language that fifth-grade students used to explain the concepts of photosynthesis and respiration in their own way. The everyday English was collected from fifth-grade students in prior studies. Details are presented in the design process section.

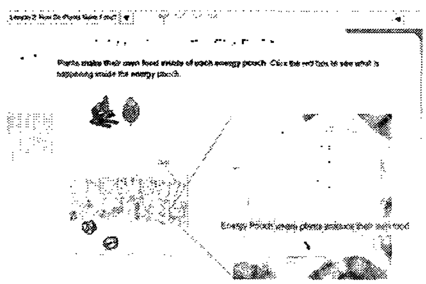
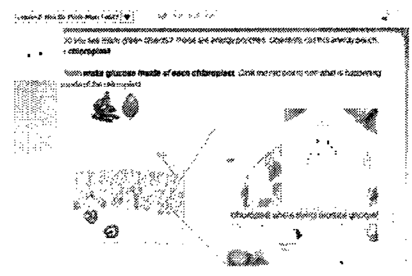
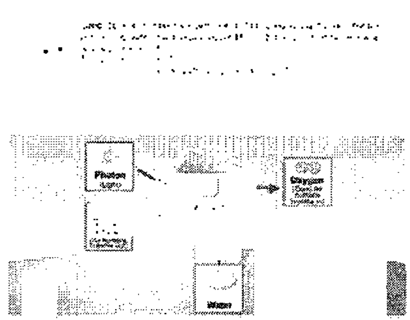
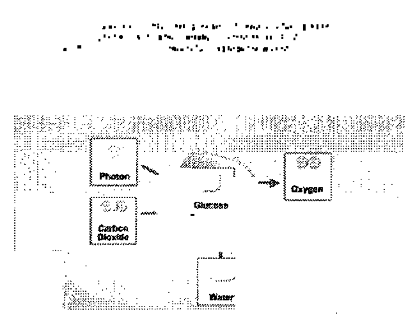
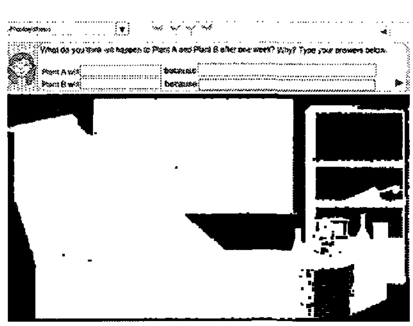
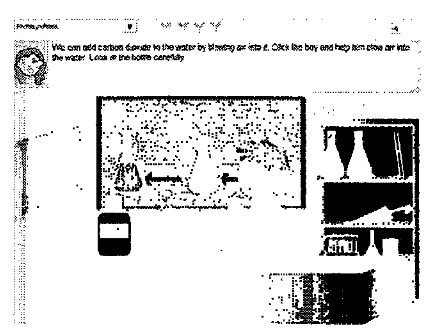
consisted of drag-and-drop quizzes, language activities, and animated instruction. The Language Instruction Step of the Everyday Language program explained the concepts of photosynthesis and respiration in both everyday and scientific language, similar to the Content Construction Step of the Hybrid-Language program. For example, the program introduced the term "glucose" by saying, "During photosynthesis, green plants make their own food, a type of sugar. Scientists call this sugar 'glucose.'" The Language Instruction Step of the Hybrid Language program reintroduced the concepts of photosynthesis and respiration exclusively in scientific language, which had already been introduced in the Content Construction Step. For example, the program reintroduced the concept of glucose by saying, "During photosynthesis, green plants make *glucose*."

The Explicit Scientific Discourse Step was designed to provide students with opportunities to apply their understanding of the concepts to new problems and to practice scientific language in different contexts. This step consisted of six science experiments presented exclusively in scientific language. There was no difference between the Everyday Language program and the Hybrid Language program at this step. In this step, students were asked to solve scientific problems related to photosynthesis and respiration and their applications by conducting virtual experiments. A series of experiments required students to provide multiple explanations of their solutions. For example, one of the experiments asked students to conduct a virtual experiment to figure out whether plants need carbon dioxide for photosynthesis. With some guidance from the computers, students designed an experiment, formulated hypotheses, tested their experiment, observed results, and provided a conclusion.

All four steps included visual representation, animation, written text, and audio narration. With the exception of the language used in the Content Construction and the Language Instruction Steps, the two programs had identical content and presentation. Examples of the two programs are presented in Table 3.1.

Table 3.1

Examples of the Everyday Language and the Hybrid Language Programs

Content Construction Step	
Everyday Language Program	Hybrid Language Program
"Do you see many green objects? These are *energy pouches*. Plants make their own food inside of each *energy pouch*."	"Do you see many green objects? These are *energy pouches*. Scientists call this energy pouch, a *chloroplast*. Plants make glucose inside of each *chloroplast*."
	
Language Instruction Step	
Everyday Language Program	Hybrid Language Program
"During photosynthesis, green plants make their own food, a type of sugar. Scientists call this *sugar* '*glucose*.' Glucose is used by both plants and animals as a source of energy."	"During photosynthesis, green plants make *glucose*. *Glucose* is used by both plants and animals as a source of energy."
	
Explicit Scientific Discourse Step	
	

Description of the Computer Simulation Program and Web Program

After students individually studied the concepts of photosynthesis and respiration using one of the computer programs (either the Everyday Language program or the Hybrid Language program), students in each treatment condition were randomly assigned to heterogeneous groups of three members for problem-solving activities for three sessions. In other words, each triad consisted of three diverse students with different gender and English proficiency. If the teacher observed that they would likely not work together well, s/he switched a student with one in another triad. Each triad was asked to solve five scientific problems by designing virtual experiments using a computer program or a simple website and then to provide written answers to a series of questions in their group workbook (Appendix A).

In order to examine the effect of computer simulation, I designed and implemented a computer simulation program that allowed students to design their own experiments and see the project results immediately. The computer simulation program provided a highly interactive learning environment that allowed students to explore scientific concepts by manipulating virtual objects and testing different hypotheses. The program also presented different results in the form of animation, graphs, and numbers. The simulation program was carefully designed based on findings from several pilot studies with fifth-grade students and fifth-grade teachers.

As an alternative to the simulation program, I also designed a simple website that introduced the identical content through video clips, static images, and text; these media were regularly used for students' science projects. The website was chosen as an alternative because this was a type of technology that the participating students were most familiar with and with which they regularly interacted. Triads in the Everyday-Simulation and the Hybrid-Simulation groups used the computer simulation program, whereas triads in the Everyday-Website and the Hybrid-Website groups used the website for their problem-solving activities.

Both the simulation program and the website consisted of introductory animation and four problem-solving activities about photosynthesis and respiration. Before the problem-solving activities began, both programs introduced an avatar (Dr. Science) who explained that he needed the students' help to conduct scientific experiments. The avatar then provided a brief description of how to work in a group and asked students to choose a role to play for each activity, such as a mouse-controller or a writer. The program also taught students about the process of scientific inquiry, such as making a hypothesis.[4] After the introduction, four problem-solving activities were presented sequentially by the avatar. In each activity, the avatar provided a brief description about the problem and question prompts that would help students design the experiments and solve scientific problems.

Before using the computer program, each triad was asked to discuss and formulate hypotheses. Then, triads in the Everyday-Simulation and the Hybrid-Simulation groups were asked to solve a series of problems in their workbook using the computer simulation program, whereas triads in the Everyday-Website and the Hybrid-Website groups were asked to solve the same problems using the website. In

[4] This introduction was designed based on findings from pilot studies, during which I observed students fighting over a mouse to control the computer, and arguing over who should type the answers. Students who were more outspoken and assertive were observed to take control of using the computer, including manipulating the mouse and doing the typing. Therefore, to give each student a fair opportunity to engage with the computer simulation, I designed the introduction about how to work together.

addition to solving a problem, each triad was asked to provide written answers for a series of questions in their workbook.

The purpose of problem-solving activities was to provide students with multiple opportunities to explore the concepts of photosynthesis and respiration and to engage in using scientific discourse while working on scientific tasks. The first problem asked each triad to find out how to keep both a mouse and a plant alive when they put them in a glass box and closed it. The second problem asked students to find out what kinds of gases candles produce when they burn, and what kinds of gases they need when they burn. In the simulation environment, triads were asked to manipulate different objects, such as candles, water, a mouse, or a glass box, and explore how to save both the mouse and the plant. After each manipulation, the computer asked students to provide their prediction, observation, evidence, and conclusion, either orally or in writing.

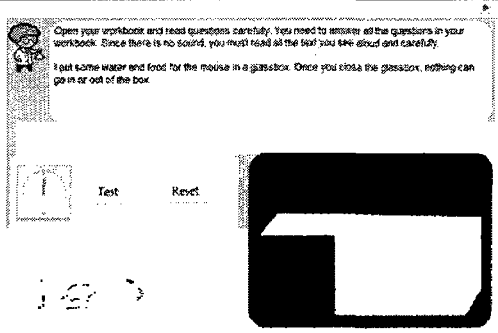
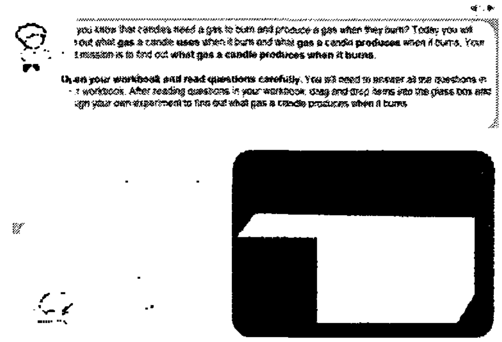
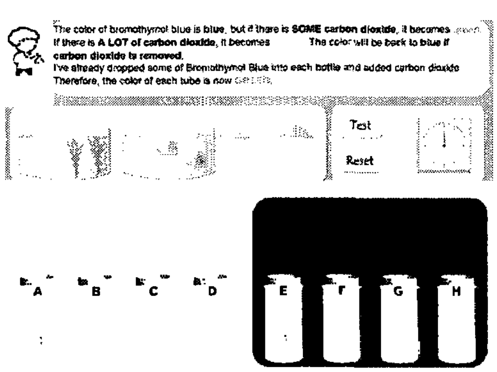
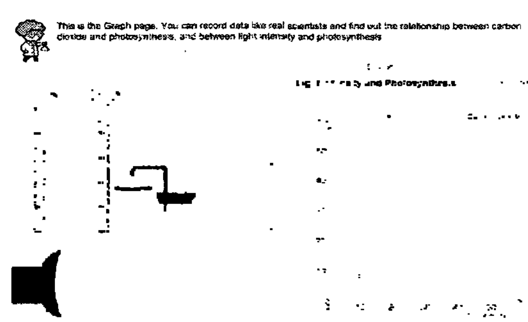
The third problem asked students to work with Bromothymol Blue, a special dye that changes from its original color, dark blue, to green and then to yellow, based on the amount of carbon dioxide. If carbon dioxide is removed from the dye, Bromothymol Blue changes back to blue. Each triad was asked to find out how to turn Bromothymol Blue from green to blue and how to keep Bromothymol Blue green by using water snails and plants. The problem students were asked to solve was to find how to make the Bromothymol Blue change from blue to yellow and from yellow to blue by manipulating light, pond snails, and plants. The computer provided guiding questions to help students test their hypotheses and effectively engage in a discussion.

In all three of these problem-solving activities, both the simulation and the alternative website provided a brief description of the setting in written form. In the computer simulation environment, students were provided with virtual controllers, such as the "test" button and the "reset" button, to control their experiments, and virtual materials, such as a mouse, a plant, and light, to design their experiments. Students were able to construct their own experiments and to test their hypotheses by manipulating virtual materials and controllers. For example, students were able to drag different virtual materials into a desired position. Once they clicked the "test" button, the program showed the results of their experiments by animating the phenomenon in the position. Once the results were presented, students were allowed to click the "reset" button and start their experiments over. No written feedback on the performance or the results of the experiments was provided. In the website environment, students were provided with either video clips that showed all the results of possible hypotheses or static images of the result, both of which were directly captured from the simulation program.

The fourth problem was more complicated than previous problems: it asked students to find the relationships among light intensity, the amount of carbon dioxide, and the amount of oxygen produced during photosynthesis. In the computer simulation environment, students were provided with 1) a virtual laboratory where they manipulated variables and watched the animated results, 2) two input variables (light intensity and the amount of carbon dioxide), 3) two record controllers ("record" and "clear data" buttons), and 4) multiple forms of displays (text graph, bar graph, and data charts). Students were able to control different input variables, such as light intensity and the amount of carbon dioxide, and observe the amount of oxygen produced based on their actions. The results were presented in multiple representations, such as graphs, animation, and tables. They were also allowed to record their observations and design a graph or a table to find a pattern between these two variables. Examples of these problem-solving activities are presented in Table 3.2. Students in the Everyday-Website and the Hybrid-Website groups used the website that presented the complete graphs and tables captured from the simulation program.

Table 3.2

Examples of the Problem-Solving Activities and the Computer Simulation Program

Problem-Solving Activity 1	Problem-Solving Activity 2
	
Problem-Solving Activity 3	**Problem-Solving Activity 4**
	

Design Process of the Science Instruction Programs

The two science instruction programs, the Everyday Language and the Hybrid Language programs, were carefully constructed based on findings from previous research study (Brown & Ryoo, 2008) and two pilot studies, the design of a photosynthesis curriculum, and my own classroom observations. Three different versions of the programs, all known as the Science of Wizardry, were created over the course of four years. Each of them was evaluated with different groups of people and revised based on the findings of the pilot studies and several learner studies, as well as observations of students' interaction with the programs. Table 3.3 below provides an overview of the three versions of the programs, including the topic, narration, length, and the sequence comprising each version.

Table 3.3

Overview of the Three Versions of the Science of Wizardry and the Final Version

	Science of Wizardry			Dissertation Technology
	First Version	Second Version	Third Version	Final Version
Topic	• Process of Photosynthesis	• Process of Photosynthesis • Function of Plant Parts related to Photosynthesis	• Process of Photosynthesis • Function of Plant Parts related to Photosynthesis	• Process of Photosynthesis • Process of Respiration • Function of Plant Parts related to Photosynthesis and Respiration
Narration	• Adult Voice only	• Adult Voice (Mandrake) • Children's Voice	• Adult Voice (Mandrake) • Children's Voice	• Adult Voice only
Length	• 30 min	• 120-150 min	• 120-150 min	• 180 min
Introduction	• Mission of the Program	• Mission of the Program	• Mission of the Program	• Mission of the Program • Interface of the Program
Step 1: Content Construction	• Quiz Format • 6 Questions and Answers	• Quiz Format • 14 Questions and Answers • 3 Virtual Experiments	• Game Format • Logging Function • 14 Questions and Answers • 3 Virtual Experiments	• Lecture Format • 4 Lessons
Step 2: Language Instruction	• Drag and Drop Quiz	• Drag and Drop Quiz • 6 Language Activities	• Drag and Drop Quiz • Logging Function • 8 Language Activities	• 2 Drag and Drop Quizzes • 10 Language Activities
Step 3: Explicit Discourse	• 5 Language Activities	• 7 Virtual Experiments with Guidance	• 7 Virtual Experiments with Guidance • Logging Function	• 7 Virtual Experiments with Guidance

Cycle 1: The Science of Wizardry I (September 2003 – June 2004)

1.1 Implementing a design

Initial design. The first version of the science instruction programs (both the Everyday Language and the Hybrid Language programs) was created between September 2003 and June 2004 in fulfillment of my Master's project. The first version was designed to teach the concepts of photosynthesis to fifth-grade language minority students whose first language was not English and who spoke a language other than English at home. Photosynthesis was chosen as a curriculum unit because it is a very complicated scientific phenomenon and involves a number of scientific terms. The content of the program was developed based on the following materials: the California Science Standards, a review of lesson plans and chapters of science textbooks about photosynthesis that were available online at the time and in the Stanford's Teacher Education library, and a review of the existing educational technology, such as online tutorials, games, and simulation programs.

During the character design process, I showed different versions of the possible characters to help teach the scientific concepts to twenty fifth- and sixth-grade students in an afterschool program in Redwood City and asked them to rank them for their preference. Based on the types of characters students were most fond of, I created all the characters used in the program. For the development of "everyday language," I interviewed the same twenty students about their understanding of photosynthesis in order to explore how they described the concepts in everyday language. The interview consisted of three main questions about the overall process of photosynthesis, the three elements plants need for photosynthesis, and the byproducts of photosynthesis. Then, I asked each student to explain the definitions of scientific terms related to photosynthesis, such as oxygen, and how each term was important to plants. I recorded each student's use of everyday and scientific language to describe photosynthesis and found several everyday terms that many students used to articulate their understanding of photosynthesis. For example, most students described "carbon dioxide" as "air that we breathe out" and "a type of gas we breathe," and "oxygen" as "air that we breathe" and "clean air." Based on these everyday terms, I created the list of "everyday language" as an alternative to scientific language and created the program. The following table presents the list of everyday and scientific terms used in this study

Table 3.4

Everyday Terms and Scientific Terms Used in the Study

Scientific Term	Everyday Term
Photosynthesis	The process which plants make their own food
Carbon dioxide	Gas that humans and animals breathe out Gas that plants breathe in
Photons	Energy from light Light energy Small particles of light that have energy
Oxygen	Good gas that humans and animals breathe in Gas that plants breathe out
Glucose	A type of sugar Plants' food
Chlorophyll	Green objects that capture light energy Green pigment that take in light energy
Chloroplast	Energy pouch where plants make their own food
Stomata	Small holes on the leaf that take in and out gasses
Respiration	Breathing process The process which plants use energy and breathe
Water vapor	Water that plants make during the breathing process
Phloem	A thin tube that carries sugar (or plants' food) from the leaves to other parts of the plant
Xylem	A thick tube that carries water from the roots to the leaves

Before implementing the design, a number of storyboard and user scenarios were created and evaluated by graduate students at Stanford, science educators, elementary school teachers, fourth- and fifth graders, and instructional designers. Based on feedback from a variety of user groups, I modified the storyboard and implemented the design.

Design of the program. The first version was created based on a teaching approach called the *Directed Discourse Approach to Science Instruction* (Brown, 2004). This instructional methodology was designed to provide students with both conceptual and linguistic support for science learning though four instructional stages. The first stage of this methodology, the "Pre-Assessment Instruction" which measured students' prior knowledge of scientific concepts, was not included in the Science of Wizardry. Both the Everyday Language and the Hybrid Language programs consisted of four steps: (1) Introduction, (2) Content Construction, (3) Introduction of Explicit Discourse, and (4) Scaffolding Opportunities for Discourse. Except for the language used, the Everyday Language and the Hybrid Language programs were identical in terms of content and visualization.

The Introduction Step of both programs used animation to introduce the mission of the program.[5] However, the first version of the program did not provide any instruction on how to navigate the program interface. The Content Construction Step taught the process of photosynthesis in a quiz format. In other words, the program asked students six questions regarding how plants grow, and based on a student's answer, the program provided detailed instruction about the concepts being asked (Figure 3.4). In this step, the Everyday Language program only used everyday language to teach photosynthesis, while the Hybrid Language program simultaneously used both everyday and scientific language (hybrid language). The first version of the programs did not teach the function of plant parts, such as stomata and chloroplast, but only focused on the overall process of photosynthesis.

[5] The mission of the three versions was the same as the one in the final version.

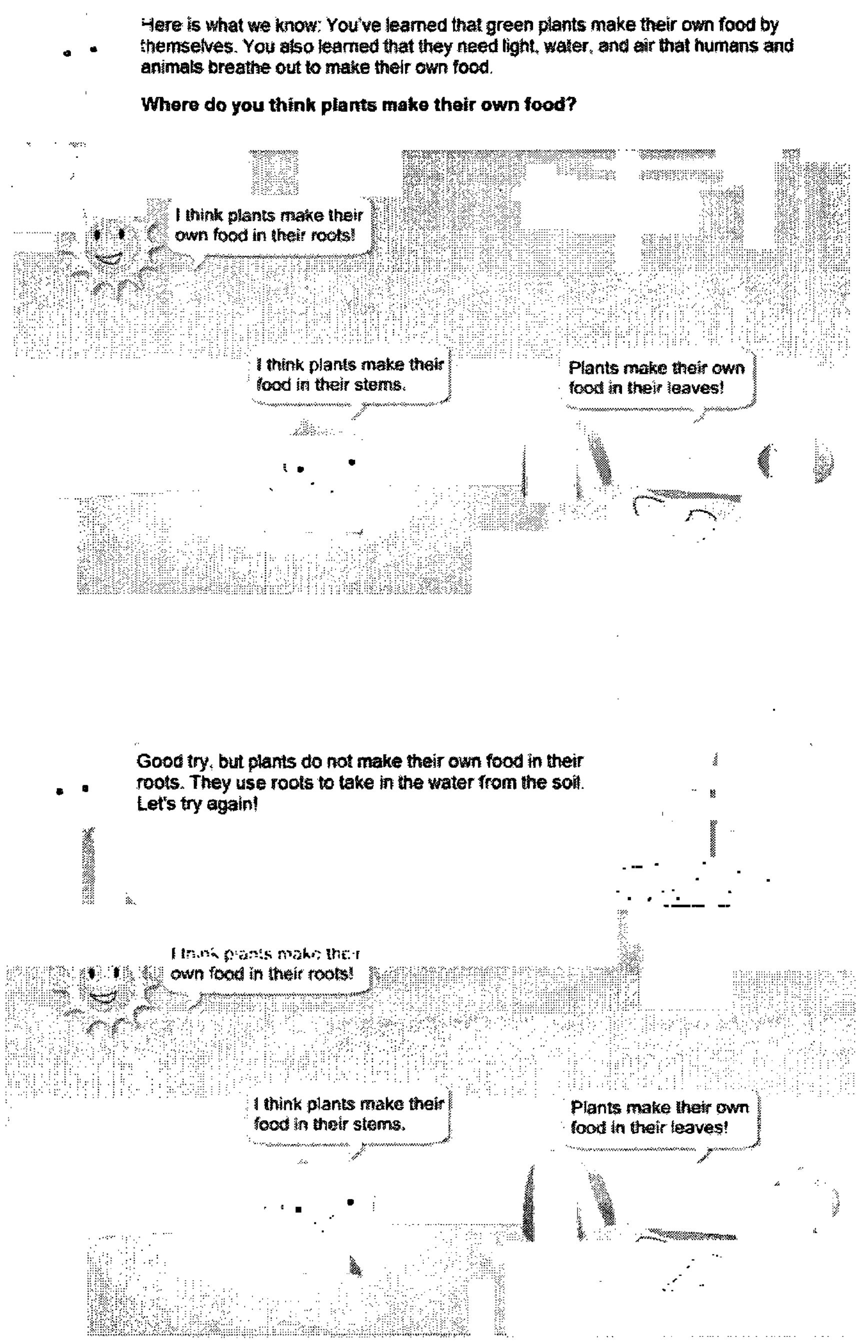
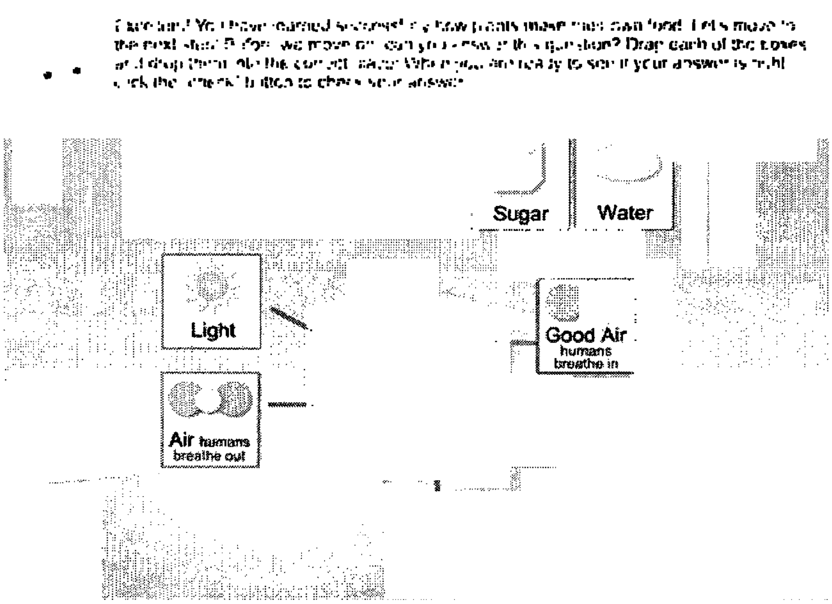


Figure 3.4. Content Construction Step of the First Version.

The third step, Introduction of Explicit Discourse, was designed to help students build connections between everyday language and scientific language. In this step, students were asked to drag and drop words related to photosynthesis in the right positions. Once all the words were put in the correct place, the program introduced how the same concepts can be explained using scientific language (Figure 3.5). For the Hybrid Language program, the program only used scientific language. The Explicit Scientific Discourse Step consisted of five language activities which helped students acquire new scientific language through multiple activities. For example, one of the language activities asked a student to create a sentence about photosynthesis by dragging and dropping the given words (Figure 3.6).



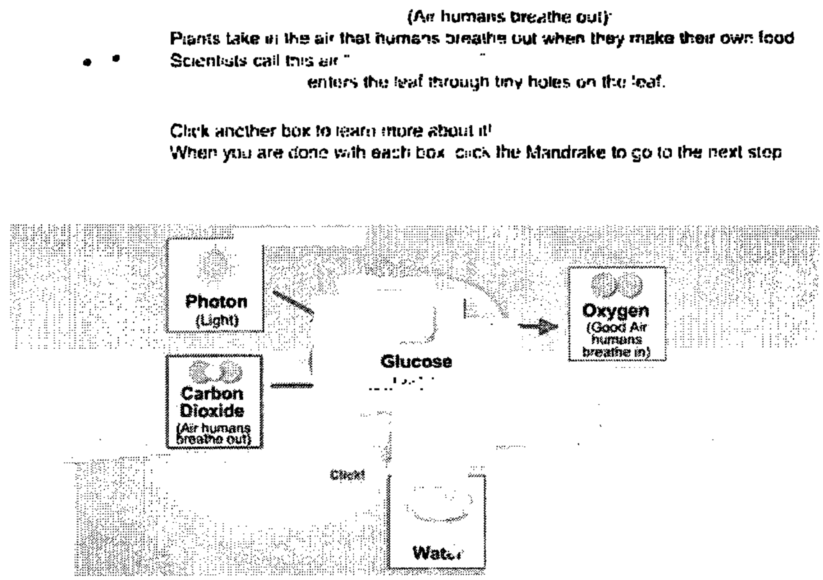


Figure 3.5. Introduction of Explicit Discourse Step of the First Version.

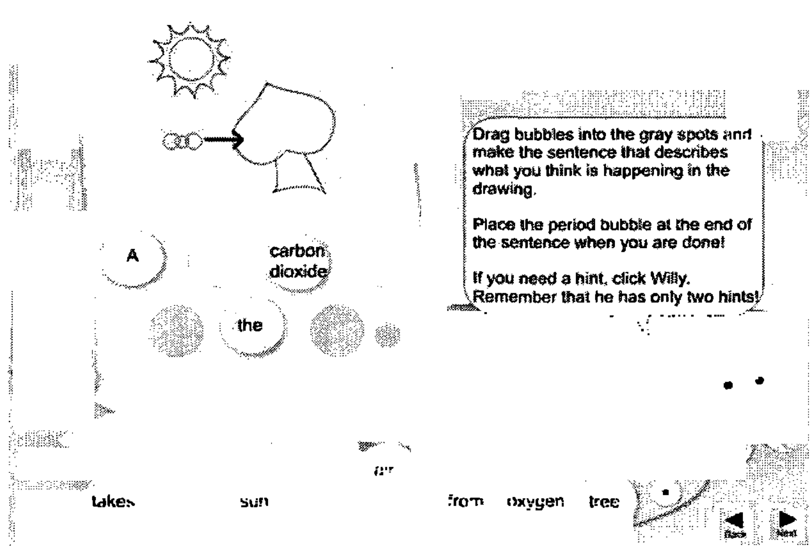


Figure 3.6. Explicit Scientific Discourse Step of the First Version.

1.2 Evaluating the Design

In order to examine the impact of teaching science in everyday English on language minority students' science learning, I conducted a pilot study with ten third- and fourth-grade language minority students whose first language was not English and who spoke a language other than English at home.[6] The participants were equally divided into an experimental group (taught in everyday English prior to the introduction of scientific language) and a control group (taught simultaneously in both everyday and scientific language) by gender, grade, and race. According to two reading teachers who worked with the students, all participants had a low fourth-grade reading level.

The study employed a pre-posttest design with four dependent measures: 1) conceptual understanding of photosynthesis described in everyday English, 2) conceptual understanding of photosynthesis described in scientific language, 3) ability to explain concepts of photosynthesis in everyday English, and 4) ability to explain concepts of photosynthesis in scientific language. All participants took a pretest that consisted of six multiple-choice questions about photosynthesis: three in everyday English and three in scientific language. They were also asked to explain five everyday English words and five scientific terms related to photosynthesis. Students were asked to explain how each word was pertinent to plants and to give the reason for their answers.

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[6] Third and fourth graders were chosen as participants of the study instead of fifth graders since at the time of study, most schools I had access to had already taught the concepts of photosynthesis to their fifth graders.

Upon completing the pretest, students in the experimental group received individual, interactive science instruction using the Everyday Language program, which taught the concepts of photosynthesis in everyday English prior to introducing scientific language. By contrast, students in the control group received the science instruction using the Hybrid Language program, which taught the same scientific concepts simultaneously in both everyday and scientific language. The software itself required approximately 30 minutes for completion. After the science instruction, all participants completed their posttest on the same day.

Results revealed that teaching science in everyday English prior to introducing scientific language improved language minority students' understanding of scientific phenomena and their development of scientific language more than teaching science in hybrid language. Students in the experimental group demonstrated a more complete understanding of the concept on the posttest in both everyday English and scientific language than those in the control group. They also showed a superior ability to articulate their scientific knowledge using both everyday English and scientific language when compared to students in the control group.

1.3 Implications

The findings of the pilot study showed the potential of teaching science in everyday English and encouraged further development of the program in order to help ELLs develop their understanding of both the content and the language of science. By observing student interactions with the computer programs and examining student performance, I found several ways to strengthen the content and the design of the

Science of Wizardry. First, I determined that the future program should implement a longer version of the curriculum that teaches the concepts of photosynthesis in more depth, including the function of plant parts and details of how each plant part related to photosynthesis. Second, the future program should provide more activities to help students bridge the divide between scientific concepts in everyday language and scientific language, and should also provide multiple opportunities to use scientific language in different contexts. The first version of the program provided a limited number of activities to improve students' understanding and use of scientific language. For example, the second step of the program (the Introduction of Explicit Discourse) provided only one activity to make the transition from everyday English to scientific language. Similarly, the language activities in the last step of the program (the Explicit Scientific Discourse) helped students remember scientific terms, but this step did not allow them to articulate their understanding of photosynthesis using scientific language. Third, the future program should give students limited control in navigating the program. In the first version, students were able to move to the next page without listening to or reading the necessary narration. I observed that several students were interested in clicking buttons on the page and finishing the program as soon as possible, without reading the text and listening to the narration.

Cycle 2: The Science of Wizardry II (September 2004 – September 2006)

2.1 Implementing a Design

The second version of the Science of Wizardry was constructed based on the findings of the first pilot study, the design of a photosynthesis curriculum, and classroom teaching with Dr. Bryan Brown. More specifically, collaborating with a fifth-grade teacher, we developed a science curriculum on the concepts of photosynthesis and taught that curriculum to one fifth-grade classroom. During this process, we included more concepts of photosynthesis, including the function of plant parts in photosynthesis, and designed more activities to help students use scientific language in different contexts, such as a related lab activity. We used our lesson plan as a model to create the computer program and developed interactive activities that paralleled the photosynthesis curriculum that we introduced to the same fifth-grade class. For example, when we taught the students in the classroom the function of a leaf in photosynthesis, we showed how different parts of a leaf looked in a microscope. In order to provide the same experience in our computer program, we designed animation that provided magnified images of a leaf, which resembled the experience students had in a classroom. Table 3.5 illustrates the relationship between the activities used in the lesson and the parallel website.

Table 3.5

Relationship Between Website and Lesson Plan

Table 2
Relationship between website and lesson plan

Lesson Plan Activity	Description of Lesson Plan Activity	Website Alternative	Description of Website Activity
"Which one will grow best?" lab activity	Students worked in groups to complete the lab activity testing the optimal conditions for plant growth	Web-based experiments	Audio responses were documented from the students' classroom experiences. The students' most common answers in the class were set up as answer choices that students could choose from in the web version
Reading activity	Students read excerpts from a common 5th grade science textbook	Mandrake narrative	The character that leads the website learning environment (The Mandrake) provides a narrative that parallels the information reviewed in the text. This audio feature also parallels the classroom reading activities
Plant drawing	Students drew pictures of the parts of the plant to familiarize themselves with plant physiology	"Drag and drop" of plant parts	The website included a drag and drop activity where students matched the names of plant parts with the appropriate location
Micro viewer activity	The students used faux microscopes to view detailed images of the parts of the plant (chloroplasts, stomata, and roots)	The microscope magnification	The website included a series of pages that placed plant parts on a microscope and used animation to zoom into the plant to review specific plant parts
Quick writes	Students wrote about their understanding of the ideas involved in the unit. These writings were used for discussion	Bubble writing activities	Students had the opportunity to engage in sentence writing that required them to drag bubbles that included words used to construct sentences about their understanding of the ideas involved in the unit
Group assessment of experiments	The students engaged in classroom discussions that evaluated the experiments that were underway	Selection of best answer	In the treatment pages, the students were able to choose a "Best Answers" from a series of possible answers regarding the outcome of the experiments. These comments were derived from answers produced in the classroom version
Assessment	Students wrote a letter to a fictitious doctor explaining how plants grow	Mandrake leaf growth	As students answered questions correctly and moved through each topic, they added leaves to the Mandrake. After completing the entire lesson, they were able to free the character, "Wendy", from her captives

Note. From "Teaching Science as a Language: A 'Content-First' Approach to Science Teaching," by Bryan Brown and Kihyun Ryoo, 2008, *The Journal of Research in Science Teaching*, 45(5), p.537. Copyright 2008 by Wiley Periodicals, Inc. Reprinted with permission.

During the classroom teaching, we also collected students' responses and their ways of explaining photosynthesis, and used their own responses to create the narration of the program. In addition to using students' own responses, we also recorded students' voices for character narration to create a more engaging learning environment. For Mandrake's narration, we continued to use an adult voice because Mandrake was a character designed to teach students the concepts of photosynthesis.

Another change we made was to develop more language activities for the second step in order to help students make connections between everyday and scientific language. We moved the language activities from the third step to the second step. And for the third step, we created virtual experiments which allowed students to conduct a variety of scientific experiments with guidance from the computer and to use scientific language to explain their understanding of the concepts and provide reasoning behind their answers (Figure 3.7). For the second version of the program, we also limited students' control of the program. In order to stop students from moving to the next page before the narration was complete, we designed each page to show a button to go to the next page after the narration was played out.

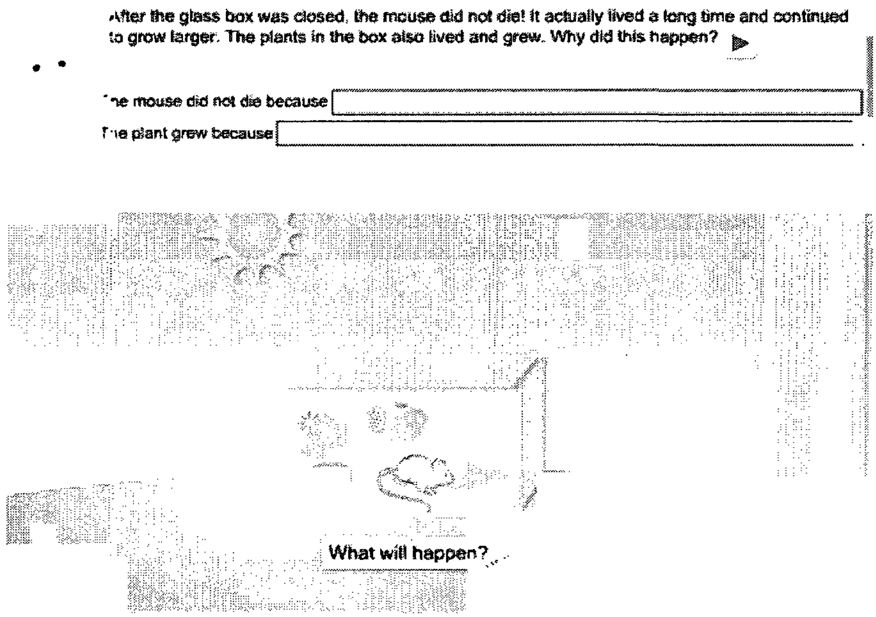


Figure 3.7. An Example of Virtual Experiments in Step 3.

2.2 Evaluating the Design

The second study was an experimental study with 49 fifth-grade students from two classes. Nineteen students spoke English at home, while 30 students spoke Spanish as their primary language at home. Using an intact-group comparison design, students were randomly assigned to an experimental group (taught in everyday English prior to being introduced to scientific language) or a control group (taught simultaneously in everyday and scientific language) within each class. Prior to the study, all students took a pretest which consisted of 18 multiple-choice and six open-ended questions. After completing the pretest, students in the experimental group received interactive science instruction from the Everyday Language program that taught photosynthesis in everyday language prior to introducing scientific language.

By contrast, students in the control group studied the same concepts using the Hybrid Language program which taught the scientific concepts simultaneously in everyday and scientific language (hybrid language). After the instruction was completed, all participants took a posttest and participated in an individual interview.

The results revealed that students taught in everyday English prior to the introduction of scientific language demonstrated a significantly greater improvement in both their understanding of photosynthesis ($p=.046$) and their use of scientific language ($p=.001$) when compared to students taught in hybrid language. In particular, the effect of teaching science in everyday English was even more apparent in students' written responses. Students in the experimental group provided more concrete, elaborate answers using both everyday and scientific language than those in the control group ($p=.012$). The analysis of students' use of different discourse (everyday, scientific, and hybrid) during the interviews also revealed consistent findings, such as that students in the experimental group used not only everyday and hybrid discourses more correctly than those in the control group, but they also showed a greater ability to use scientific discourse to articulate their understanding of photosynthesis. The quantitative results of this study have been published in the *Journal of Research in Science Teaching* (Brown & Ryoo) and the qualitative results will be available in the *International Journal of Science Education.*

2.3 Implications

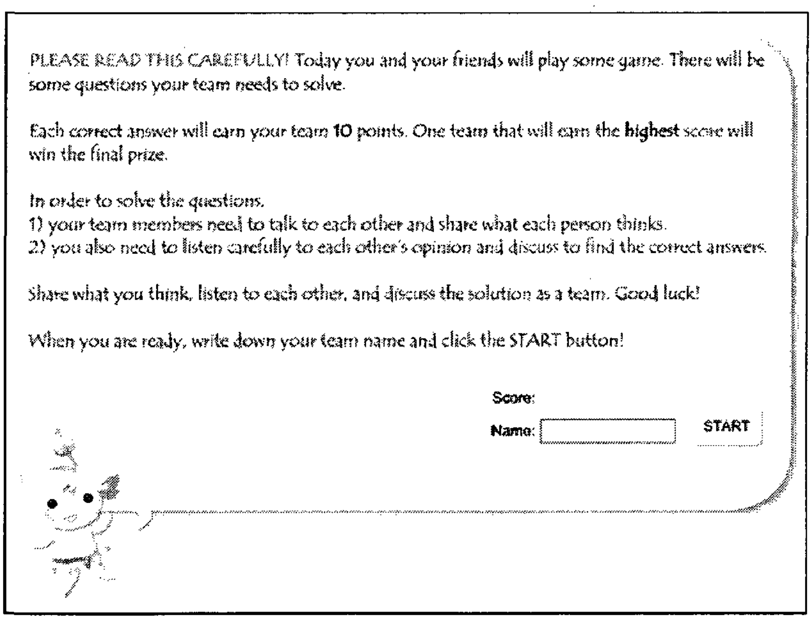
The results of the second study suggested that teaching science in everyday English can be an effective approach to improving students' conceptual understanding of complex scientific concepts and their use of scientific language. From the observation of students interacting with the program, we noticed that students were very engaged with the program because they thought it was a game rather than science instruction. Every time a student answered a question correctly, s/he was able not only to move to the next topic, but also to make Mandrake grow a leaf, which would eventually help save Mandrake's friend, Wendy, from the wicked witch. Students showed a great deal of interest in growing Mandrake's leaves and compared the number of leaves in their Mandrake to that of their friends. This observation indicated that designing educational science games may increase students' motivation to learn science and improve their science learning, ultimately making it more effective.

Another interesting finding was that a number of students were sharing their thoughts and asking questions of students next to them, although the students were not supposed to talk to others during the study. This observation raised a question about whether collaborative science learning would enhance ELLs' science learning more than individual learning. In addition, during the interview, some students still demonstrated confusion about certain scientific terms, such as chlorophyll, and they were unable to use scientific language accurately to elaborate their understanding. Since one of the goals of the study was to improve students' use of scientific discourse, I became interested in whether collaborative science learning would help ELLs engage in scientific discourse.

Cycle 3: The Science of Wizardry III (September 2006 – March 2007)

3.1 Implementing a design

The purpose of the third pilot study was twofold: to examine whether collaborative learning would enhance students' science learning more effectively than individual learning and to explore how we could increase students' use of scientific discourse. Based on the findings of the second study I conducted during cycle II and my observations of students interacting with the program, I created the third version of the Science of Wizardry in a game format. When students started the program, they were asked to create their group name and a password, and the program showed each group's score at the top of each page. Whenever students answered a question correctly, they received 10 points. If their first attempt was incorrect, they would still have a chance to find the correct answer but did not receive any points (Figure 3.8).



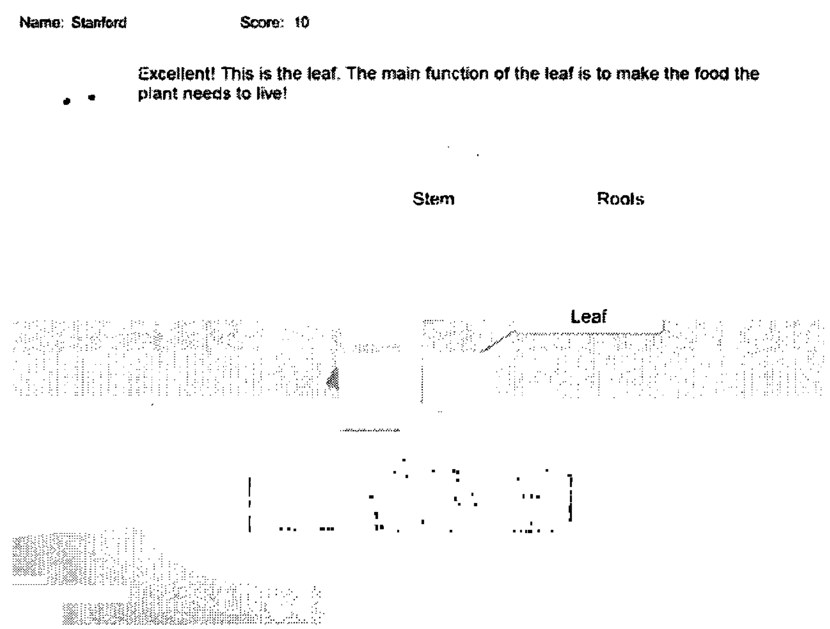


Figure 3.8. Game Format.

Collaborating with a fifth-grade teacher at a local elementary school, I conducted four interface designs of the scientific experiments in the third step in order to increase students' discussion about scientific phenomena and to provide students with multiple opportunities to use scientific language. First, some experiments asked students to make a prediction by choosing one of the hypotheses provided, which was similar to a multiple-choice test (Figure 3.9). Second, some experiments asked students to type their predictions and findings. Students were not allowed to move to the next page until they typed their answers (Figure 3.10). Third, another experiment asked students to record verbally their predictions and findings by clicking the record button (Figure 3.11).[7] Finally, other experiments asked students to write down their answer on a worksheet that they shared.

[7] Although the program did not actually record students' answers, students believed that the program was recording their answer.

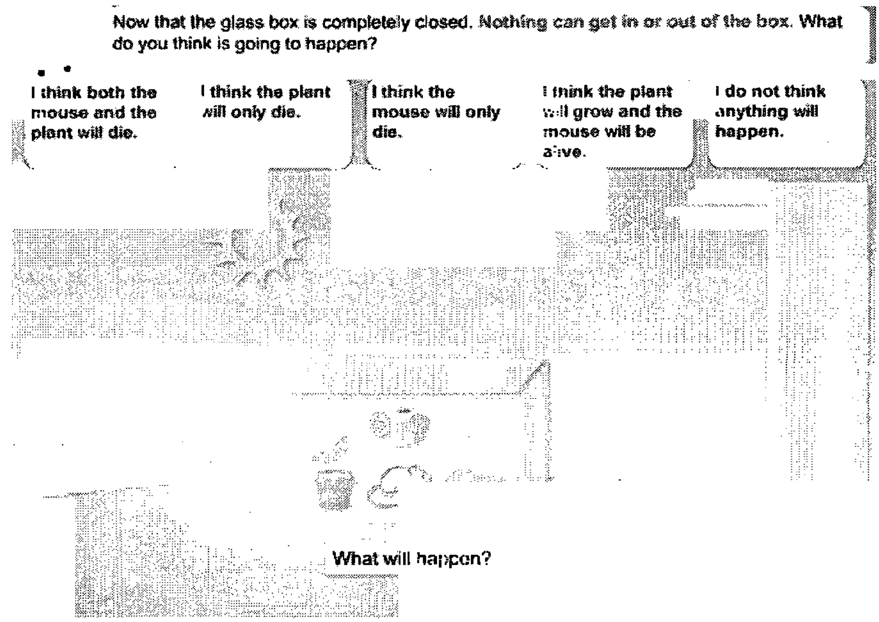


Figure 3.9. Multiple-Choice Format.

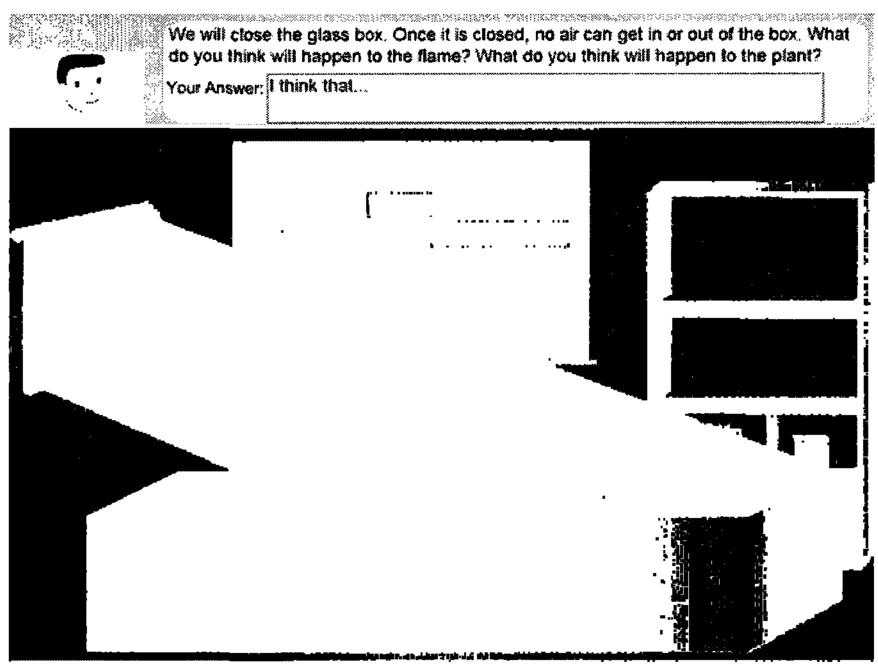


Figure 3.10. Typing Format.

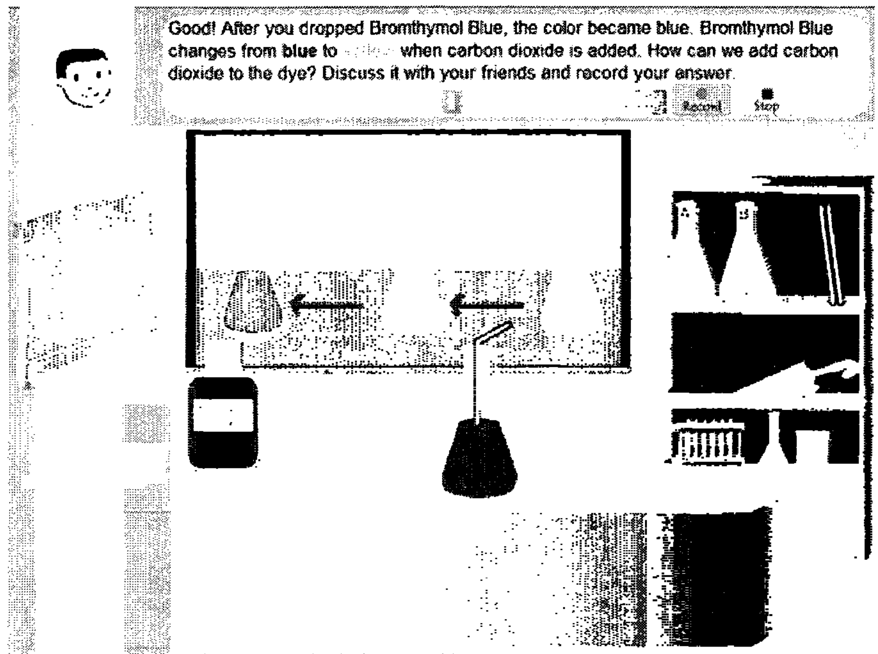


Figure 3.11. Recording Format.

The last design change was a logging function; in order to understand students' thinking patterns and explore their understanding more deeply, I created the third version of the program which automatically logged students' data as they interacted with the program, such as clicking or typing, and sent the information to my database.

3.2 Evaluating the Design

In order to examine the impact of collaboration on students' science learning and to explore the best design approach to enhance students' use of scientific discourse, I conducted a pilot study with 12 fifth-grade students at a local elementary school. Six were ELLs, while six were EPSs. Half of the students were male and half were female. Students were randomly assigned to a heterogeneous triad stratified by gender and English proficiency. Before the study began, each student took a multiple-choice pretest. After the pretest, each triad participated in five consecutive science sessions about photosynthesis (an hour per day) and received interactive science instruction from the Everyday Language program. During the sessions, each triad's interaction and discussions were videotaped. After all six sessions were completed, each student took a posttest that was identical to the pretest.

The observation of each triad revealed several interesting findings. First, collaborative learning did not appear to be as effective as expected in terms of enhancing students' scientific knowledge. Although students in each triad were supposed to discuss their ideas before selecting a correct answer, there was always a student who was left out. For example, fast readers often chose the answer they thought correct without consulting the other members. Outspoken students dominated the conversation and controlled the program, while quiet students were often ignored. If a triad consisted of one EPS and two ELLs who spoke the same language, those two ELLs often used their native language and did not include the EPS in the conversation. Those students who were either slow readers or less active participants did not have enough time to digest the lessons and were forced to move forward before they fully understood the concepts.

A related finding was that the game environment appeared to cause a huge tension between the group members. Because students received 10 points when they answered a question correctly, there were many arguments about who should decide which answer would be correct. Without providing any evidence to support their claim, students were often arguing that their answer was correct, and outspoken ones always ended up deciding the answer. This point system also created a competitive learning environment rather than a collaborative one. Because of the point system, students in each triad were very sensitive about their scores and blamed each other when they did not answer a question correctly and received 0 points.

The four different design approaches to enhance students' use of scientific discourse also revealed interesting results. The multiple-choice design approach, which asked students to choose a prediction from the given choices, was the least effective approach because students just selected one of the options without sharing ideas with each other. By contrast, the typing approach increased students' conversation not only about the content of their answer, but also about its linguistic aspect. For example, students discussed what their answer should be and how to spell certain words, such as carbon dioxide. Students were helping each other develop the best answer to each question. However, students were often distracted by the typing itself and fighting over who should be typing answers. Another problem of the typing approach was that most of the fifth graders were extremely slow at typing words using the keyboard. Typing a long sentence was a challenging task for every triad, and it therefore took longer for the instruction. Although the recording approach encouraged students to speak about scientific ideas using scientific language more often, students frequently took turns to record their answers instead of discussing them before recording them. An interesting observation was that EPSs often corrected ELLs' pronunciation and grammar. The most effective approach was to ask students to write down their answers on the worksheet. Similar to the typing approach, students more actively engaged in discussions about both the content and the language of their answers. Although students did not enjoy writing down their answers on the paper, it was certainly easier than typing their answers using the keyboard.

3.3 Implications

Findings of the third pilot study suggested that a collaborative learning approach would not be best to help students build a conceptual understanding of scientific phenomena in this technology-enhanced environment because of the different learning pace of each student. In particular, ELLs needed more time to read the text on the screen than EPSs, and their ideas were often ignored during the discussions. Another interesting finding is that the game format of the program did not enhance students' learning in a collaborative environment because it created tension between group members and irrelevant arguments about who should be controlling the computer.

However, working on scientific experiments in groups was found to be more effective than working individually because it provided students with more opportunities to talk about science and to use scientific language in different forms, such as a question and an argument. Students also built their scientific knowledge on each other's ideas and often corrected each other's English skills, such as spelling and grammar. Among several design approaches, writing answers on the worksheet was found to be most effective and practical, given the typing level of fifth graders.

These findings indicated several suggestions to strengthen the program. First, I determined that the future program should adopt a new format for science instruction because the game format or the quiz format of the instruction made students think that they were playing a game rather than studying science, which made them more interested in finishing the "game" to see the ending by clicking any object on the page. Second, the individual learning approach can be more effective when students first study new concepts of scientific phenomena, while collaborative learning can create a more effective environment when students work on a scientific task which requires them to apply their scientific ideas to new problems.

Based on the findings of the third study, I developed the new version of the Content Construction step, which is now in a lecture format rather than a quiz or a game format, and also included one more science unit, respiration.

Design Process of the Computer Simulation Program

The computer simulation program was carefully designed based on findings from two pilot studies and several user tests I previously conducted between 2007 and 2008, the design of a workbook for problem-solving activities, and classroom observations. Two different versions of the simulation program were created, and each of them was evaluated by fifth-grade students, graduate students at Stanford, and a fifth-grade teacher at a local elementary school. Table 3.6 below provides an overview of the topic, narration, length, and the content of each version of the simulation program.

Table 3.6

Overview of the Three Versions of the Simulation Program

	First Version	Second Version	Final Version
Number of Simulations	• 4	• 5	• 5
Number of Problem-Solving Activities	• 4	• 5	• 5
Instruction about How To Work Together	• N/A	• N/A	• Animation
Instruction about How To Conduct Scientific Experiments	• N/A	• Animation	• Animation
Instruction about How To Use Simulation Program	• N/A	• Instructional Video	• Instructional Video
Narration	• Adult Voice	• No Narration	• No Narration
Workbook	• No Workbook	• Partial Workbook	• Full Workbook

Cycle 4: Computer Simulation I (August 2006-August 2007)

4.1 Implementing a design

Initial design. The first version of the computer simulation program for problem-solving activities was created based on a review of lesson plans, problem-solving activities, and hands-on lab materials on the topics of photosynthesis and respiration in both English and Korean, all of which were available online. Because of the limited number of existing simulation programs regarding photosynthesis and respiration, I reviewed all existing computer simulation programs across science topics, such as biology, chemistry, and physics. Based on these reviews, I designed five activities whose procedure steps were not overly complicated for fifth-grade students. Because most elementary school students do not have much experience with scientific experiments, it was important to design the simulation program and problem-solving activities in ways that my target students would be able to understand without any detailed guidance from a teacher or a computer. The first version of the simulation program consisted of four problem-solving activities with small simulation programs.

Before conducting a pilot study, the first version of the simulation program was evaluated by a different group of people, including Stanford graduate students, computer programmers, teacher educators, and pre-service teachers. Based on feedback from a variety of these user groups, the interface of the simulation program was modified.

Design of the program. The first version of the simulation program consisted of four problem-solving activities and small simulation programs described in the earlier section (pg. x). The last problem-solving activity regarding the relationships among the amount of carbon dioxide, light intensity, and photosynthesis was not part of the first version. The only difference between the first version and the final version of the program was the fourth simulation used in the Bromothymol Blue experiment. The first version of the fourth simulation presented a lab-note page next to the simulation program, which included a series of prompting questions and asked students to record verbally their answers (
Figure *3.12*). Other than the fourth simulation, the first and the final versions were identical.

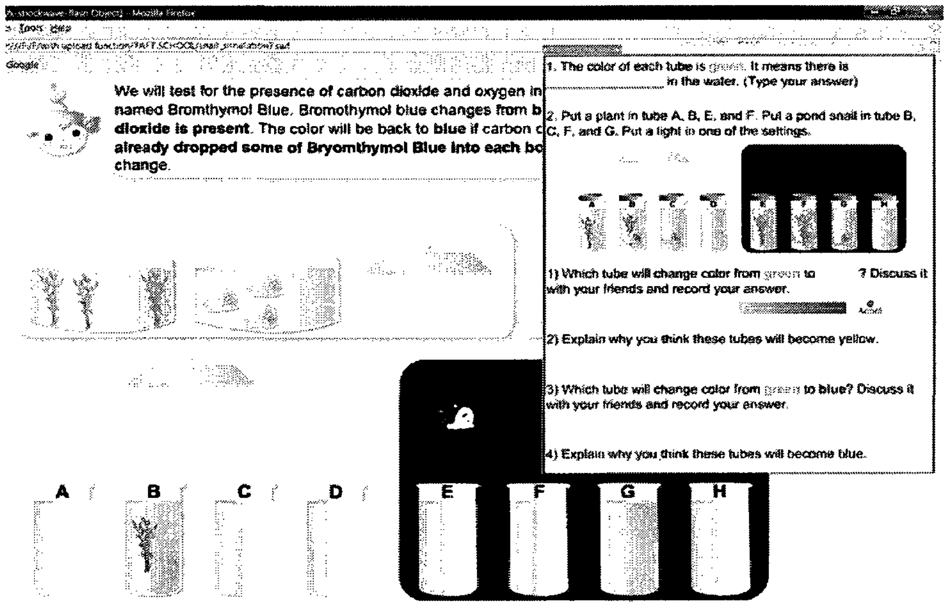


Figure 3.12. The Fist Version of the Fourth Simulation.

4.2 Evaluating the Design

The purpose of the first pilot study was twofold: to examine whether the use of computer simulation can engage students in the use of scientific discourse and to explore how triads work together with the simulation program. The study involved nine fifth-grade students whose parents provided consent for their children's participation. Five of the participants were intermediate ELLs, and four were EPSs. Students participated in five hour-long, consecutive science sessions in the library after school for five days.

Students received individual science instruction from the Everyday Language program and studied the concepts of photosynthesis for three sessions. For the last two sessions, students were assigned to a heterogeneous triad based on their English proficiency and gender. Each triad was asked to solve two problem-solving tasks (the third and the fourth experiments) using the computer simulation program. Each triad's interactions and discussions were videotaped.

Findings of the study demonstrate that conducting virtual experiments without step-by-step guidance was a challenging task for fifth-grade students. All three triads had difficulties with designing experiments and testing their hypotheses. According to their teacher, the participants did not have much experience in scientific inquiry in the classroom. The simulation program allowed students to manipulate virtual objects and show different results based on their design, but students did not draw conclusions from their scientific results. By contrast, students performed better on the fourth problem which provided prompting questions. Students used the prompting questions as guidance to design their experiments. However, similar to findings from the previous study, students took turns recording their answers without sharing thoughts and did not engage in much discussion. Another interesting finding was that all three triads spent a lot of their time discussing who should control the mouse but none of them wanted to write down their answers on the worksheet.

4.3 Implications

The results of this study indicated that in order to help students solve scientific problems with the simulation program, the program needed to teach students how to work collaboratively, as well as how to conduct scientific inquiry. Observation of student interactions clearly showed that students were not comfortable taking turns while working on their task and were not familiar with designing scientific experiments. Similar to previous findings with triads, students in every triad spent a large amount of their time arguing about who should control the mouse and who should type an answer. When they were supposed to discuss their ideas for problem-solving activities, outspoken students often dominated the conversation and made decisions without input from the other members. Also there was always one student who was quiet and often ignored by the triad's members. This observation indicated that the future program should teach students how to work together as a team and suggested some strategies for successful collaboration, such as taking turns. The results also suggested that problem-solving activities should be presented with a clear objective and some prompting questions, which can help students design their scientific experiments. In terms of the design of the program, it was important to turn off the narration during the problem-solving activities because it became very loud and distracted the other groups from their own work.

Cycle 5: Computer Simulation II (December 2007 – May 2008)

5.1 Implementing a design

Based on the findings from the first pilot study, I created a workbook which introduced the goal of each problem-solving activity and a series of small questions that students needed to answer as a group. Each group was asked to write down their answers in the workbook. The second version also removed all the recording functions from the simulation program since the previous study showed that it did not encourage students to share their ideas; it instead prompted students to record answers individually. Another design change I implemented was an introduction page about collaboration. In this introduction, the avatar emphasized the importance of working together and taking turns to control the mouse, type answers, and write down answers in the workbook (Figure 3.13). Additionally, the second version of the simulation program did not provide any narration, but only written text. The second version of the simulation program consisted of all five problem-solving activities and simulations described on page x.

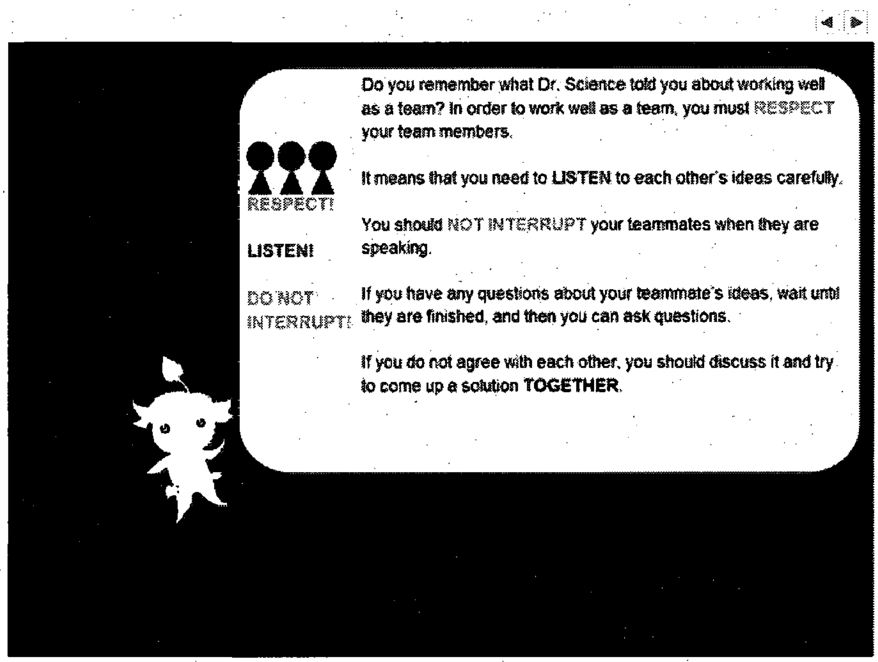


Figure 3.13. Instruction About How To Work Together.

5. 2 Evaluating the Design

The second pilot study was designed to explore how pairs with different English proficiency develop their use of scientific discourse using computer simulation. The study involved 12 fifth-grade ELLs; half of them were advanced ELLs students (CELDT 4 or 5) and half were intermediate ELLs (CELDT 3). Prior to the study, all students took a pretest. Then, all students participated in six hour-long, consecutive science sessions. They first received individual science instruction from the Everyday Language program and studied the concepts of photosynthesis. After the science instruction, students were randomly paired based on their English proficiency level and their degree of social interaction (i.e., students who were already friends with one another were permitted to work together). Each pair was then assigned into three different groups: 1) the Advanced-Advanced Group, 2) the Intermediate-Intermediate Group, and 3) the Advanced-Intermediate Group. Each pair participated in a series of computer-based problem-solving activities that involved both group discussion and writing. Each pair's collaborative dialogue was videotaped. After completing all six sessions, the students individually took a posttest and were interviewed.

The analysis of students' discussions during the problem-solving activities revealed mixed results. Some pairs actively engaged in discussion and worked successfully as a team by exchanging their ideas and criticizing each other's ideas with reasonable evidence. By contrast, some pairs showed passive interaction patterns throughout the sessions: they did not actively engage in conversations to discuss solutions to their problems or challenge each other's ideas. Overall, however, pairs produced less scientific discourse than triads in the first pilot study. In terms of the design of the simulation program, all six pairs had difficulties with the last simulation for the fifth problem-solving activity because not only was the problem itself very challenging for fifth graders, but the simulation program also presented very complicated interface without any guidance.

5.3 Implications

Findings of the final pilot study indicated that it was important to introduce students to the interface of the last simulation program and to teach them how to use it because the last simulation program had a very complicated interface with multiple variables that students could manipulate. Based on this finding, I created a five-minute instructional video to teach students how to navigate the simulation program. The video introduced the interface of the simulation program step-by-step through narration and text (Figure 3.14).

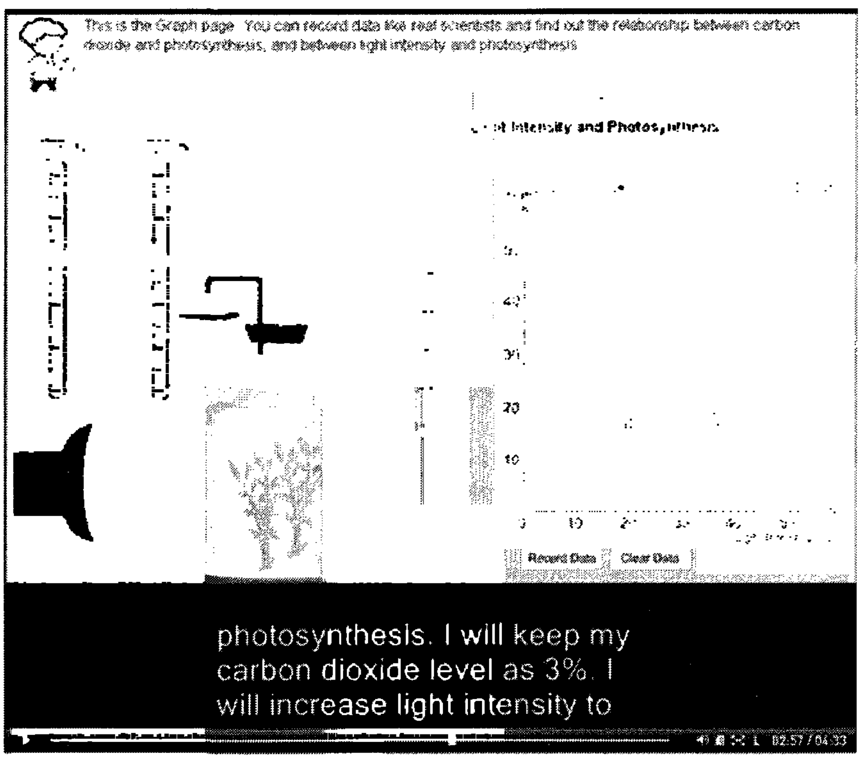


Figure 3.14. Instruction Video for the Simulation Program.

This chapter has described the development and studies of the science instruction programs and the simulation programs that led to this dissertation study, both of which were carefully constructed based on findings from several pilot studies conducted between 2004 and 2008. The chapter has also explained the design process of the two technology programs— implementing a design, evaluating a design, and implications from the pilot studies.

One of the major findings from the three studies with the computer-based science instruction revealed that a quiz format of the instruction made students think that they were playing a game rather than studying science, which made them more interested in finishing the "quiz" to see the ending by clicking any object on the page. Therefore, I redesigned the Content Construction step as a lecture format to engage students in learning science itself, rather than advancing to the next page.

Another interesting finding from the studies is that students always wanted to have more control over the program. For example, they wanted to play the narration multiple times and wished to go back to the previous pages whenever needed. Based on these findings, I modified the program to allow students to play the narration whenever needed by just clicking the speaker icon (Figure 3.15). I also designed a menu which allows students to go back to the lesson they have completed and a back button which takes students to a previous page within the same lesson (Figure 3.16).

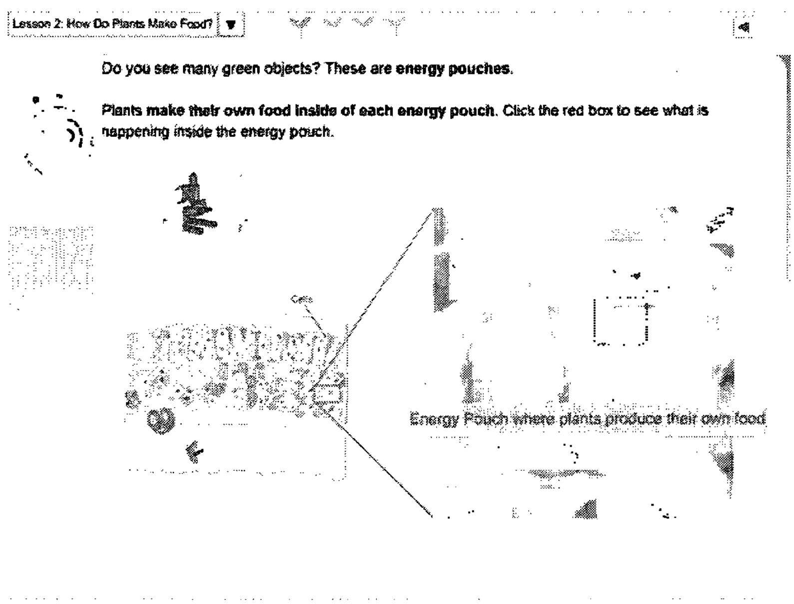


Figure 3.15. Narration Playback Function.

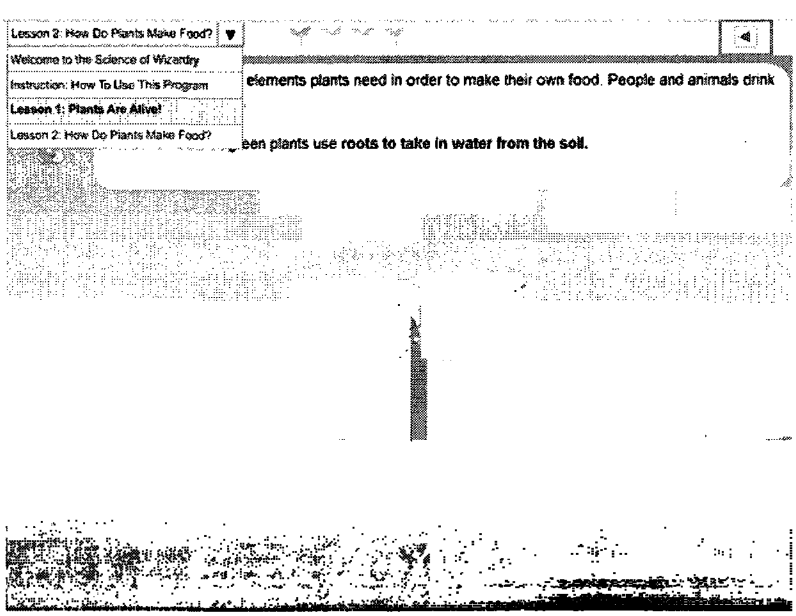


Figure 3.16. New Menu Function.

The results of the two pilot studies with the computer simulation program revealed that, although students were supposed to read questions on their workbook for each experiment, students often directly interacted with the simulation program. In order to remind students of the workbook, I designed a main page of each experiment which reminded students that they should read all questions on the workbook before conducting experiments (Figure 3.17).

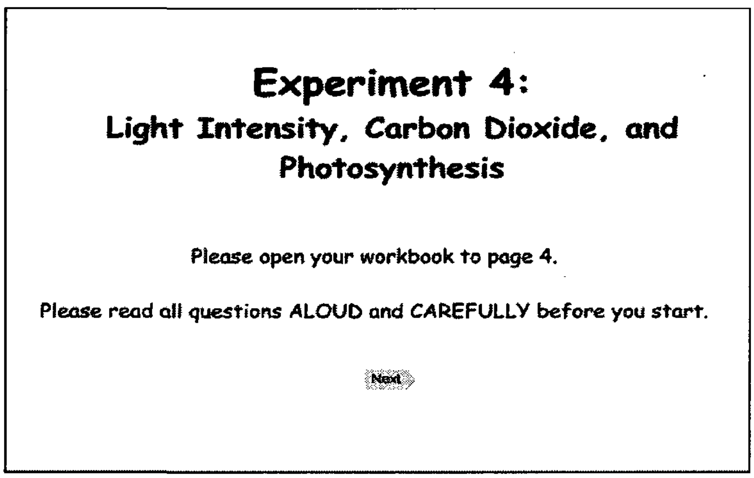


Figure 3.17. Main Page of Experiment.

My observation from students' interactions with the simulation program indicates that many triads struggled with the last experiment regarding the relationships between the amount of carbon dioxide, light intensity, and photosynthesis. In addition to the complex problem they were supposed to solve, the interface of the simulation program was very complicated and overwhelming. Therefore, as explained on page 95, I also created a five-minute instructional video to teach students different functions of the simulation program and how to manipulate each function in order to help them understand

The next chapter presents the details of the study methodology, including the description of participants, the study procedure, and instrument items.

CHAPTER 4: METHODOLOGY

This study investigated the impact of technology-enhanced instruction on students' science learning. Specifically, this study examined whether teaching science in everyday language (the Everyday Language approach) and using computer simulation to solve problems (the Simulation approach) enhanced ELLs' understanding of scientific phenomena and their use of scientific language, compared to EPSs'. The study also examined whether this teaching approach could help close the achievement gaps between ELLs and EPSs. Based on the literature review and previous research studies (see Chapter 3), I hypothesized that

1. the combination of the Everyday Language and the Simulation approach would be most effective in enhancing both ELLs' and EPSs' science learning
2. the combination of the Everyday Language and the Simulation approach would decrease the achievement gaps between ELLs and EPSs
3. the Everyday Language approach would improve both ELLs' and EPSs' science learning
4. the Simulation approach would increase ELLs' and EPSs' performance

In this chapter, I describe the design of the study, participants and settings, and the methods of data collection and data analysis.

Design

As described in Chapter 3, this study was carefully design-based on the findings from a series of design-based research studies conducted in the past (Brown, 1992; Cobb, diSessa, Lehrer, & Schauble, 2003; Collins, 1992; Dede, 2004). Although the nature of this study was still design-based research, in order to test the specific hypotheses described above, I conducted a 2 (Language) X 2 (Simulation) X 2 (English Proficiency) factorial study with two dependent measures: scores from multiple-choice and open-ended tests. The first factor, Language, was whether students were taught in "Everyday English approach" which means that students were taught the concepts of scientific phenomena in everyday English prior to the introduction of scientific language, or whether students was taught in "Hybrid Language approach" which indicates that students were taught simultaneously in both everyday and scientific language. The second factor, Simulation, was whether students used computer simulation during the problem-solving activities, or whether they used a simple website. The third factor was whether students were EPSs, or whether they were ELLs. In order to prevent treatment erosion[8], each class was randomly assigned to one of the four conditions described in Table 4.1 and participated in six one-hour long consecutive science sessions for six days (one hour per day).

During the first three sessions, students received individual, interactive science instruction on the concepts of photosynthesis and respiration, which is aligned with California science standards for fifth-grade students. For the last three sessions,

[8] Assigning students in the same classroom to one of the four treatments could have affected the results of the study because students in different treatment groups could have shared information they received between the sessions.

students participated in a series of problem-solving activities in a group of three. During the problem-solving activities, two triads were randomly selected and videotaped. Before and after the study, all students took multiple-choice and open-ended tests, and three students randomly selected from each class participated in pre- and post-interviews. The pre- and post-interviews were used to track students' understanding of these scientific concepts and their use of scientific discourse. By comparing the four groups' pre- and posttest scores and interview scores, this study examined the effects of teaching science in everyday English and using computer simulation on ELLs' and EPS' conceptual understanding of scientific phenomena and their use of scientific discourse.

Table 4.1

Study Design

Everyday-Simulation (N=56)		Everyday-Website (N=54)		Hybrid-Simulation (N=54)		Hybrid-Website (N=56)	
ELLs (n=17)	EPSs (n=39)	ELLs (n=18)	EPSs (n=36)	ELLs (n=17)	EPSs (n=37)	ELLs (n=16)	EPSs (n=40)
Pre-Multiple-choice Test Pre-Open-Ended Test Pre-Interview							
Science Instruction in *Everyday* Language: Taught in Everyday English Prior to Introducing Scientific Language		Science Instruction in *Everyday* Language: Taught in Everyday English Prior to Introducing Scientific Language		Science Instruction in *Hybrid* Language: Taught *Simultaneously* in Everyday and Scientific Language (Hybrid Language)		Science Instruction in *Hybrid* Language: Taught *Simultaneously* in Everyday and Scientific Language (Hybrid Language)	
Problem-Solving Activities Using *Computer Simulation*: Solved a Series of Scientific Problems Using a Simulation Program		Problem-Solving Activities Using a Simple *Website*: Solved a Series of Scientific Problems Using a Simple Website		Problem-Solving Activities Using *Computer Simulation*: Solved a Series of Scientific Problems Using a Simulation Program		Problem-Solving Activities Using a Simple *Website*: Solved a Series of Scientific Problems Using a Simple Website	
Post-Multiple-choice Test Post-Open-Ended Test Post-Interview							

School Sites and Participants

The participants in the study were 220 fifth-grade students from four public elementary schools. Based upon insight gleaned from previous pilot studies (see Chapter 3), I carefully selected four schools using the following criteria: (1) diverse ethnic and linguistic population, (2) the number of English Language Learners, (3) bilingual programs, (4) Academic Performance Index (API)[9], (5) socioeconomic status, and (6) openness to my research. First, I selected schools that had a similar ethnically and linguistically diverse population because I did not want my results to appear to represent science learning for a specific population. For example, if Latino/a students made up the dominant demographic of a school, the school was excluded from the selection. Second, among the schools that met the first criterion, I selected schools that had a higher number of ELLs because I wanted to compare ELLs' science learning to EPSs. Third, I did not include schools with bilingual programs which provide students lessons in both Spanish and English because the purpose of the study was to explore instructional approaches for those who are dealing with a variety of ELLs with different primary languages. Fourth, I also looked at each school's API score and selected schools whose API scores were similar. Fifth, I chose schools that had a similar number of students who were eligible for free or reduced lunch. Sixth, I selected schools whose principal and teachers were willing to participate in the study and committed to the study during the entire study period.

At the time of my study, all four participating schools, located in northern California, served ethnically and linguistically diverse communities and taught first- to fifth grades. The student population at these schools was composed of Hispanic, White, Asian, and African American students. Within each school's population, approximately 34% of the students participated in free or reduced-price lunch programs, and 33% of the students were identified as English Language Learners

[9] "The API is a single number, ranging from a low of 200 to a high of 1000, that reflects a school's, an LEA's, or a subgroup's performance level, based on the results of statewide testing. Its purpose is to measure the academic performance and growth of schools" (p.5, California Department of Education, 2008).

(ELLs) who had limited English proficiency. All four schools had an API score lower than 800 points (ranging from a low of 740 to a high of 780), which is below the statewide goal of 800. All four schools also had a broad linguistic diversity that included speakers of English, Spanish, Tagalog, Samoan, as well as other languages from Asia, India, and Europe.

All fifth-grade students at these four schools were invited to participate in the study, and the total number of participants was 226. Students who missed any of the pre- or posttests or who were absent during the science lessons were excluded, and the total number was six. Among 220 students, 68 were ELLs who were still developing English, whereas 152 were proficient English-speaking students. ELLs' English proficiency was determined based on their performance level on the California English Language Development Test (CELDT), ranging from "Beginning" (level 1) to "Advanced" (level 5). Most ELLs in this study had CELDT level 2 (Early Intermediate) to level 4 (Early Advanced). 105 were female and 115 were male. Table 4.2 below describes the demographic information of the study participants. All the participating schools provided their students' achievement level, ethnic composition, English proficiency information, and students' home language. The percentage of students who qualified for free or reduced lunch in each school was collected from school websites. Before the study began, I met with the participating teachers and principals to discuss logistics and the schedule of the study. Each teacher was given samples of multiple-choice and open-ended tests and presented with a demo of computer programs. Each teacher was also informed not to answer students' questions directly during the study but rather to direct students' questions to me or reply to them, "what do you think?" I limited teachers' direct interactions with students in order to ensure the same procedure for all four schools and to protect any influence this might affect the results of the study.

Table 4.2

Demographic Information for the Study Participants Given in Numbers

		Gender		English Proficiency	
	n	Female	Male	ELLs	EPSs
Everyday-Simulation	56	25	31	17	39
Everyday-Website	54	25	29	18	36
Hybrid-Simulation	54	25	29	17	37
Hybrid-Website	56	26	30	16	40

Procedures

A week before the study began, all students were administered in their classrooms multiple-choice and open-ended pretests on all the required concepts of photosynthesis and respiration and their applications. The multiple-choice test consisted of 18 items with a maximum score of 18 (Appendix B), and an open-ended test included six items with a maximum score of 24 (Appendix C). Students were given 50-55 minutes to complete both tests, and even if they could not finish their tests within the time limit, they still had to submit their tests.

Both tests included equal numbers of three types of questions: retention questions, inference concept questions, and transfer questions (see the Instrumentation section for more details). Additionally, three students from each classroom – one ELL and two EPSs or one EPS and two ELLs – were randomly selected and participated in a pre-interview about their understanding of the scientific concepts and their applications of concepts. Each interview took approximately 15 minutes and was videotaped (see Appendix D for interview protocols).

A week after the pretests and pre-interviews, all students participated in six consecutive, hour-long, computer-lab sessions on the concepts of photosynthesis and respiration. For the first three sessions, students received individual science instruction about the scientific concepts using one of two computer programs: the Everyday-Language program and the Hybrid-Language program. Students in the Everyday-Simulation and the Everyday-Website groups used the Everyday-Language program, which taught scientific concepts in everyday English prior to introducing scientific language. Students in the Hybrid-Simulation and the Hybrid-Website groups used the traditional program that taught the same concepts simultaneously in both everyday and scientific language (hybrid language). Both programs provided the scientific concepts through multiple representation forms, such as narration, text, images, and animation. Each student used an individual computer and wore a headphone to listen to the narration (Figure 4.1).

Figure 4.1. Computer-Based Science Lessons.

For the last three sessions, students in each treatment group were randomly assigned to a heterogeneous group of three students with different gender and English proficiency. Each triad completed a series of problem-solving activities using either a computer simulation program or a simple website. A group of three students shared one computer and was given a workbook which consisted of a series of questions they had to answer as a group (see Figure 4.2 for a photo of triads and see Appendix A for a workbook). Triads in the Everyday-Simulation and the Hybrid-Simulation groups used a computer simulation program that allowed students to design their own experiments by manipulating virtual objects. Triads in the Everyday-Website and the Hybrid-Website groups used an alternative website consisting of video clips, animation, static images, and text. The website presented the identical content and visual representations directly captured from the simulation program. Two triads from each classroom were randomly selected and videotaped during the problem-solving activities. As described in Chapter 3, these computer programs were carefully constructed and redesigned several times to meet the needs of fifth-grade students based on the findings from a series of design-based research studies.

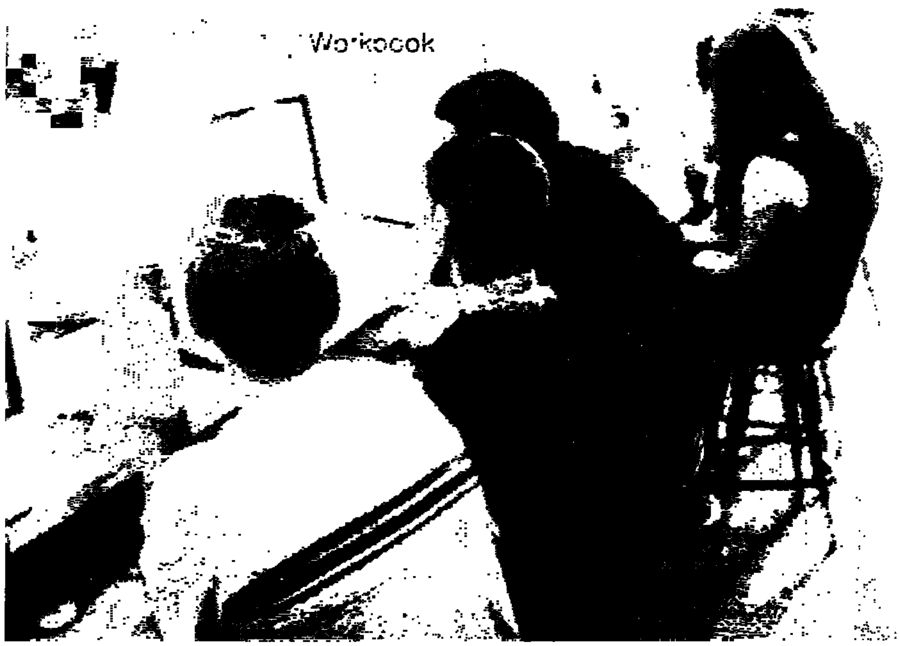


Figure 4.2. Problem-Solving Activities.

The day after the six sessions were completed all students took multiple-choice and open-ended posttests, which were exactly the same as the pretests. The same three students initially selected for the pre-interview participated in the post-interview, which took approximately 15 minutes and was videotaped. Students were interviewed in a separate, quiet room, such as a library, an empty classroom, or a computer lab. To prevent teacher bias, each session was taught by a computer program, and teachers served only as facilitators with limited interaction with students.

Instrumentation

Multiple-Choice Test

The multiple-choice pre- and posttests were designed to measure students' broad understanding of photosynthesis and respiration. The multiple-choice test was developed based on questions used in a previous research study and consultation with three fifth-grade teachers at a pilot-test school. The test consisted of 18 multiple-choice items, each of which was scored one point for a correct answer with a maximum score of 18 (see Appendix B). The multiple-choice test contained an equal number of retention, inference, and transfer questions. Retention questions measured students' factual knowledge that could be answered directly from the earlier instruction that students had. Inference questions required students to integrate information across concepts. Transfer questions measured students' ability to apply their understanding of the concepts to solve new problems in unfamiliar contexts. The reliability of the multiple-choice tests was calculated using the Cronbach's alpha coefficients. The reliability of the pretest was 0.70, and the reliability of the posttest was 0.79.

Open-Ended Tests

The open-ended pre- and posttests contained six items with an equal number of retention, inference, and transfer questions (see Appendix C). The open-ended test items were also designed based on questions used in previous research and reviewed by three fifth-grade teachers. The six items on the open-ended test were scored by two raters using a five-point rubric (0-4), with a maximum score of 24. Inter-rater reliability coefficients for the open-ended test was .92.

Student Interviews

Pre- and post-interviews were conducted before and after the study with three students randomly selected from each class (N=24).[10] Each interview was semi-structured with nine questions that consisted of equal numbers of retention, inference, and transfer questions (see Appendix D). Students were interviewed in a separate, quiet room, such as a library, an empty classroom, or a computer lab. Each interview took approximately 15 minutes and was videotaped. Students' interview responses were scored using a five-point (0-4) rubric.

Videos of Group Discussions

Two triads randomly selected from each class were videotaped during all three problem-solving activity sessions. I recorded both students' discussions and interactions and their onscreen activities with either a simulation program or a website. To capture each triad's discussions and interactions, I used a web camera and attached it to the top of the computer the triad used. To clearly record their discussions, I used a desktop microphone and placed it in the middle of three students. To record onscreen activities, I used a Camtasia Studio, a tool designed to record the action and sound from the computer screen. The video data are excluded from the analysis of the study.

[10] Among the 27 students who participated in a pre-interview missed the post-interview. Therefore, these three students were removed from the analysis.

Collection of Data on Students' Group Writing

During problem-solving activities, each triad was given a workbook which consisted of a series of questions they were asked to answer. The triad was asked to provide written answer for each question on the workbook. The collective writing from each triad was collected. The workbook data are also excluded from the analysis of the study.

Analysis Method

Each student's scores on the multiple-choice pre- and posttests were entered into the SPSS program and analyzed using a repeated measures Analysis of Variance (ANOVA). Since each class was randomly assigned to one of the four treatment group and there was no initial difference on the pretests among students across the classrooms, the unit of analysis was the students, not a classroom.

CHAPTER 5: RESULTS OF THE MULTIPLE-CHOICE TESTS

This study examined whether teaching science in everyday English (the Everyday Language approach) and/or using computer simulation to solve problems (the Simulation approach) enhance students' understanding of scientific phenomena and their use of scientific language. The study specifically focused on whether these teaching approaches had different effects on ELLs' and EPSs' science learning, and whether these same teaching approaches helped close the existing achievement gaps between ELLs and EPSs. This chapter discusses the effects of the Everyday Language approach and the Simulation approach on ELLs' conceptual understanding of photosynthesis and respiration compared to that of EPSs by analyzing students' scores from the multiple-choice pre- and posttests.

The results revealed that the combination of the Everyday Language and the Simulation approaches was most effective in increasing not only ELLs' but also EPSs' scientific knowledge. ELLs and EPSs in the Everyday-Simulation group demonstrated the greatest improvement from the pre- to posttests and also outperformed their counterparts in the other three groups. Of particular interest is that the Everyday Language had a significant impact on enhancing both ELLs' and EPSs' understanding of photosynthesis and respiration, whereas the Simulation approach was only beneficial for ELLs.

The multiple-choice test was designed to measure students' understanding of complex scientific phenomena, in this case, photosynthesis and respiration. The test consisted of 18 multiple-choice items, each of which was scored one point for a correct answer with a maximum score of 18 (Appendix B). Each student's overall score was entered into the SPSS program and analyzed across and within the groups.

Results of the multiple-choice tests are presented in the four sections that follow. The first section examines students' pretest scores to ensure that all students had a similar level of scientific knowledge prior to the study. The second section considers overall effects of teaching science in everyday English and using computer simulation on students' science learning by comparing their pre- and posttest scores. The third section discusses whether these two teaching approaches had different influences on ELLs' science learning, compared to that of EPSs. The final section explores whether these teaching approaches helped close the existing achievement gaps between ELLs and EPSs.

Pretest Results

To ensure that groups were equivalent in their understanding of photosynthesis and respiration prior to the study, a week before the study began, all students took a multiple-choice pretest (a paper-and-pencil test) in the classroom. I compared students' pretest scores using a 2 (Language) X 2 (Simulation) X 2 (English Proficiency) univariate ANOVA. The results of the ANOVA revealed that there were no significant main effects of Language, $F(1, 212) = 2.66, p = .11$ or Simulation, $F(1, 212) = 0.15, p = .70$. Although EPSs achieved a slightly higher mean score than ELLs across the four group, there was no statistically significant difference between ELLs and EPSs, $F(1, 212) = 0.63, p = .43$. The ANOVA also did not indicate any interaction effects among these variables (all *F*s <0.43), indicating that there was no initial difference in students' prior knowledge in photosynthesis and respiration. The results indicate that all students, including ELLs and EPSs, had a similar understanding of photosynthesis and respiration before they received the treatment. Table 5.1 presents the mean scores and Standard Deviation (SD) by the treatment condition.

Table 5.1

Means and Standard Deviations for the Pretest

Treatment Group		N	Mean (SD)
Everyday-Simulation	All	56	4.04 (1.68)
	ELLs	17	3.89 (1.58)
	EPSs	39	4.10 (1.74)
Everyday-Website	All	54	4.24 (1.59)
	ELLs	18	4.22 (1.22)
	EPSs	16	4.25 (1.76)
Hybrid-Simulation	All	54	4.67 (1.78)
	ELLs	17	4.29 (1.69)
	EPSs	37	4.84 (1.82)
Hybrid-Website	All	56	4.54 (2.10)
	ELLs	16	4.50 (1.97)
	EPSs	40	4.55 (2.17)

Effects of the Everyday Language Approach and the Simulation Approach

Does teaching science in everyday English (the Everyday Language approach), and/or using computer simulation (the Simulation approach) enhance students' understanding of scientific phenomena?

To answer this question, students' scores from the multiple-choice pre- and posttests were compared using a 2 (Language) X 2 (Simulation) X 2 (English Proficiency) X 2 (Gain) repeated measures ANOVA. The between-subjects variables were Language (taught in Everyday English or in Hybrid Language), Simulation (used the Simulation program or the Website during problem-solving activities), and English Proficiency (EPSs or ELLs) with Learning Gain (difference between pre- and posttests) as a within-subjects factor.

The repeated measures ANOVA revealed a main effect of Learning Gain, $F(1, 212) = 385.263$, $p = .000$, indicating that students overall demonstrated an improved understanding of photosynthesis and respiration over time. The mean score of all the participants on the pretest was 4.37 (SD = 1.80), as compared to 8.44 (SD = 2.69) on the posttest, which means that the mean score improved by 22.61% after the study. More specifically, the results from paired t-tests showed that all students across the four groups achieved significantly higher scores on the posttest than on the pretest at $p < .000$ (Table 5.2). As expected, students in the Everyday-Simulation group demonstrated the largest learning gain of 5.36 (SD = 2.55), whereas students in the Hybrid-Website group showed the least improvement (Gain = 2.61, SD = 3.06) among the four groups. Figure 5.1 illustrates the mean differences between the pre- and the posttests by the treatment condition.

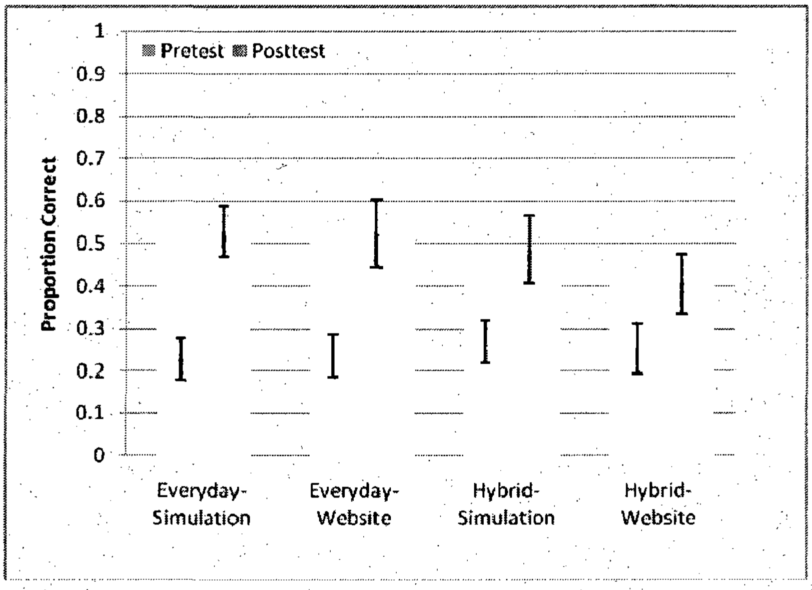


Figure 5.1. Comparison of Pre- and Post Mean Scores by Treatment Group.

Table 5.2

Comparison of Mean Scores and Learning Gains between Pretest and Posttest

Group	n	Pretest (SD)	Posttest (SD)	Gain (SD)	Gain Percentage (%)	t	Effect Size
Everyday-Simulation	56	4.04 (1.68)	9.39 (2.20)	5.36 (2.55)	29.78	15.70***	2.73
Everyday-Website	54	4.24 (1.59)	8.91 (2.87)	4.67 (3.11)	25.94	11.01***	2.01
Hybrid-Simulation	54	4.69 (1.75)	8.31 (2.52)	3.65 (2.16)	20.28	12.39***	1.67
Hybrid-Website	56	4.54 (2.10)	7.14 (2.66)	2.61 (3.06)	14.5	6.37***	1.67

***$p<0.001$.

The results of the ANOVA also showed several significant interaction effects. There was a significant interaction effect between Learning Gain and Language, *F*(1,

212) = 21.68, $p = .000$, such that students taught in everyday English prior to learning scientific language demonstrated significantly more improved understanding of photosynthesis and respiration after the study than those taught simultaneously in everyday and scientific language. It is important to remember that on the pretest, students in the Everyday Language condition (the Everyday-Simulation and the Everyday-Website groups) achieved a *lower* mean score (M = 4.04, SD = 1.68) than those in the Hybrid language condition (the Hybrid-Simulation and the Hybrid-Website groups) (M = 4.67, SD = 1.78); however, students in the Everyday Language condition showed a significantly better understanding of the complex process of photosynthesis and respiration on the posttest, compared to their counterparts in the Hybrid Language condition ($p = .000$). As hypothesized, these findings indicate that introducing complicated scientific phenomena in the language with which students are more familiar can indeed decrease students' cognitive load, thereby enhancing their understanding of the concepts. Figure 5.2 shows a significant interaction effect between Learning Gain and Language.

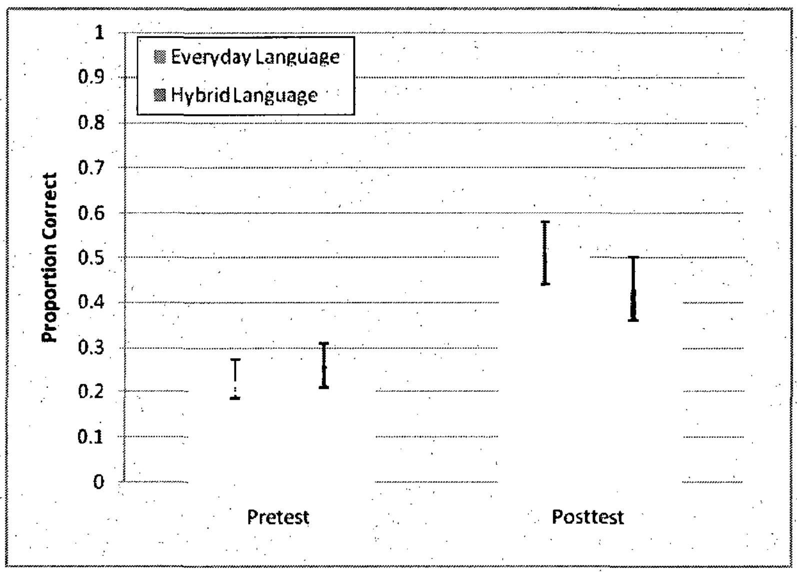


Figure 5.2. Interaction Effect between Learning Gain and Language.

Another significant interaction effect was found between Learning Gain and Simulation; $F(1,212) = 5.68$, $p = .02$, where students who used the simulation program during problem-solving activities demonstrated much improved understanding of the scientific ideas than those who used the simple website on the posttest (Figure 5.3). On the pretest, students in the Simulation and the Website conditions were comparable; students in the Simulation condition (the Everyday-Simulation and the Hybrid-Simulation groups), on average, achieved a mean score of 4.28 (SE=0.19), and students in the Website condition (the Everyday-Website and the Hybrid-Website groups) scored 4.38 (SE=0.19). However, on the posttest, students in the Simulation condition (the Everyday-Simulation and the Hybrid-Simulation groups) performed significantly better than students in the Website condition ($p = .018$), gaining a mean score of 4.4. These results suggest that the use of computer simulation

These results suggest that the use of computer simulation to solve scientific problems may more engage students in discussing their understanding of the concepts.

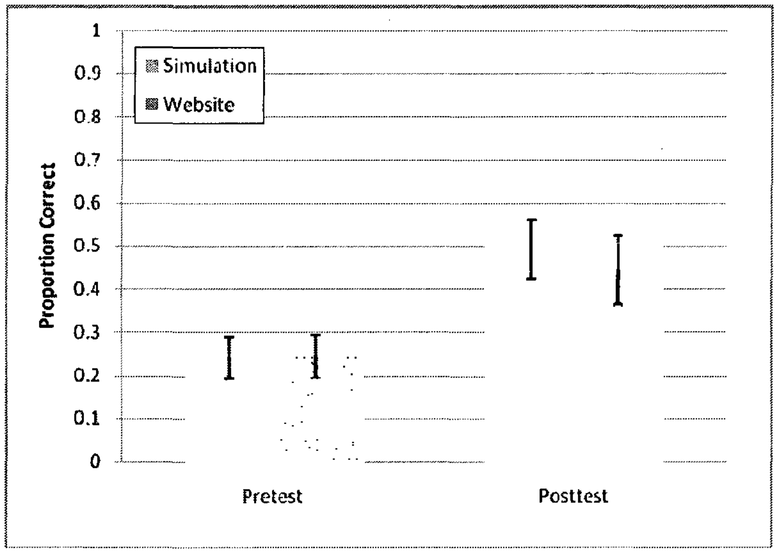


Figure 5.3. Interaction Effect between Learning Gain and Simulation.

Although there was no three-way interaction effect between Learning Gain and Language on Simulation, $F(1, 212) = 0.015, p = .90$, I examined whether any of the combinations of the Everyday Language and the Simulation approaches had more different impacts on students' science learning, The results of a one-way ANOVA on the differences between the pre- and the posttest indicated that there were significant differences among the condition, $F(3, 216) = 10.16, p = .000$. As shown in Figure 5.4, all four groups showed fairly similar mean scores on the pretest, but there were noticeable gaps across the four groups on the posttest. To further examine the difference, I conducted Tukey's HSD tests for post hoc comparisons. Post hoc comparisons revealed that students in the Everyday-Simulation group demonstrated the greatest improvement over time, which was significantly larger than those in the Hybrid-Simulation ($p = .01$) and the Hybrid-Website ($p = .000$) groups In addition, students in the Everyday-Website group also showed a significantly better understanding of the scientific concepts than those in the Hybrid-Website group ($p = .000$). Although students in the Hybrid-Simulation group performed better than those in the Hybrid-Website group, the difference was not significant ($p = .19$).

These findings support my hypothesis that the combination of teaching science in everyday English and using computer simulation approaches help students better develop a deeper understanding of scientific concepts than other approaches. The findings also show that, although both the Everyday Language and the Simulation approaches were found to be beneficial for students' science learning, teaching science in everyday English prior to introducing scientific language (the Everyday Language approach) can be a more effective tool in improving students' understanding of scientific ideas than the use of computer simulation. These results indicate that it is important to make science learning more accessible to students by bridging the difference between students' everyday modes of communication and the scientific mode of communication.

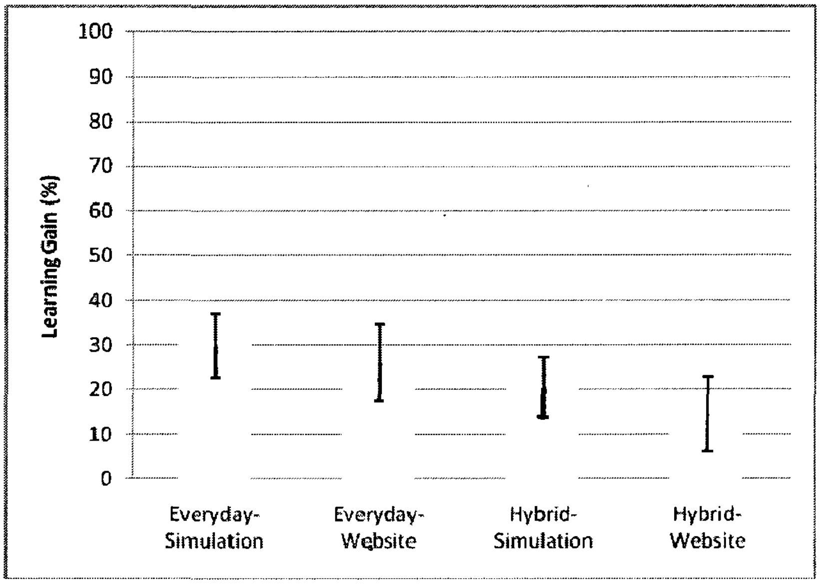


Figure 5.4. Comparison of Learning Gain by Treatment Group.

An unexpected result was an marginal interaction effect between Learning Gain and English Proficiency; $F\,(1{,}212) = 3.38$, $p = .067$. Although the effect was marginally significant, this result was surprising because there was no significant difference between ELLs and EPSs on the pretest, showing that they both had a similar level of prior knowledge before the study began. However, EPSs, overall, significantly outscored ELLs on the posttest ($p = .02$) and showed greater improvement than ELLs over time. The ANOVA did not reveal any other interactions between the variables (all Fs <1.00).

Effects of the Everyday Language Approach and the Simulation Approach on ELLs' Science Learning Compared to EPSs' Science Learning

Does the Everyday Language Approach, and/or the Simulation Approach Improve ELLs' and EPSs' Understanding of Scientific Phenomena Differently?

Previous results revealed that both the Everyday Language approach and the Simulation approach were indeed effective in increasing students' scientific knowledge. In order to examine whether these approaches had a different impact on ELLs' and EPSs' science learning, I examined ELLs' and EPSs' performance on the multiple-choice tests separately, using a 2 (Language) X 2 (Simulation) X 2 (Learning Gain) repeated measures ANOVA.

Similar to the previous results, there was a significant Learning Gain effect for both ELLs, $F(1,64) = 135.57$, $p = .000$, and EPSs, $F(1, 148) = 349.26$, $p = .000$, indicating that both groups demonstrated significant improvement from the pretest to the posttest. More specifically, as shown in Table 5.3, both ELLs and EPSs in the Everyday-Simulation group showed the greatest learning gains (5.24, 5.41 respectively), whereas ELLs and EPSs in the Hybrid-Website group demonstrated the lowest improvement (2.25, 2.75 respectively). Of particular interest is that ELLs in the Everyday-Website and the Hybrid-Simulation groups showed similar learning gains, while EPSs in the Everyday-Simulation and the Everyday-Website groups performed similarly to each other (Figure 5.5). These findings indicate that employing the Everyday Language approach or the Simulation approach alone would have similar positive impacts on ELLs' development of scientific knowledge.

Table 5.3

Comparison of ELLs' and EPSs Mean Scores and Learning Gains between Pretest and Posttest

English Proficiency	Group	n	Pretest (SD)	Posttest (SD)	Gain (SD)	Gain Percentage (%)	t	Effect Size
ELLs	Everyday-Simulation	17	3.88 (1.58)	9.23 (2.37)	5.24 (2.82)	29.11	7.66***	2.66
	Everyday-Website	18	4.22 (1.22)	7.89 (2.27)	3.67 (2.14)	20.39	7.26***	2.01
	Hybrid-Simulation	17	4.29 (1.69)	7.41 (1.62)	3.12 (1.54)	17.33	8.37***	1.88
	Hybrid-Website	16	4.50 (1.97)	6.75 (2.86)	2.25 (3.32)	12.5	2.71*	0.92
EPSs	Everyday-Simulation	39	4.10 (1.74)	9.51 (2.14)	5.41 (2.47)	30.06	13.69***	2.77
	Everyday-Website	36	4.25 (1.76)	9.42 (3.03)	5.17 (3.42)	28.72	9.07***	2.09
	Hybrid-Simulation	37	4.84 (1.82)	8.73 (2.76)	3.89 (2.38)	21.61	9.96***	1.66
	Hybrid-Website	40	4.55 (2.17)	7.30 (2.59)	2.75 (2.99)	15.28	5.83***	1.15

*$p<0.05$.
***$p<0.001$.

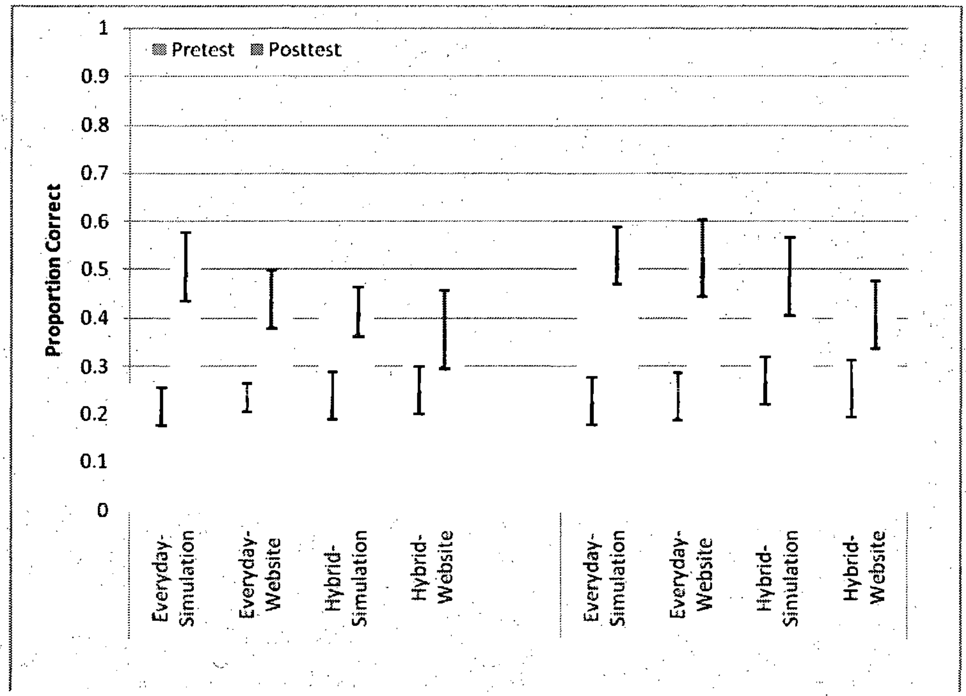


Figure 5.5. Comparison of Mean Scores between Pre- and Posttests across Four Treatment Groups by English Proficiency.

The results of the ANOVA also revealed that for ELLs, there was a significant interaction between Learning Gain and Language, $F(1,64) = 8,32$, $p = .005$, as well as a marginal interaction between Learning Gain and Simulation, $F(1,64) = 3.96$, $p = .051$. As illustrated in Figure 5.6, regardless of the use of computer simulation, ELLs who were taught in everyday English prior to the introduction of scientific language significantly outperformed ELLs taught in hybrid language. Similarly, whether they were taught in everyday or hybrid language, ELLs who used the simulation program during the problem-solving activities achieved a higher mean score on the posttest than those who used the website. These findings indicate that it is important to provide ELLs not only with a transitional step to learn scientific language in order to help them understand the concepts better, but also with multiple opportunities to reconstruct their understanding of scientific topics through social interaction.

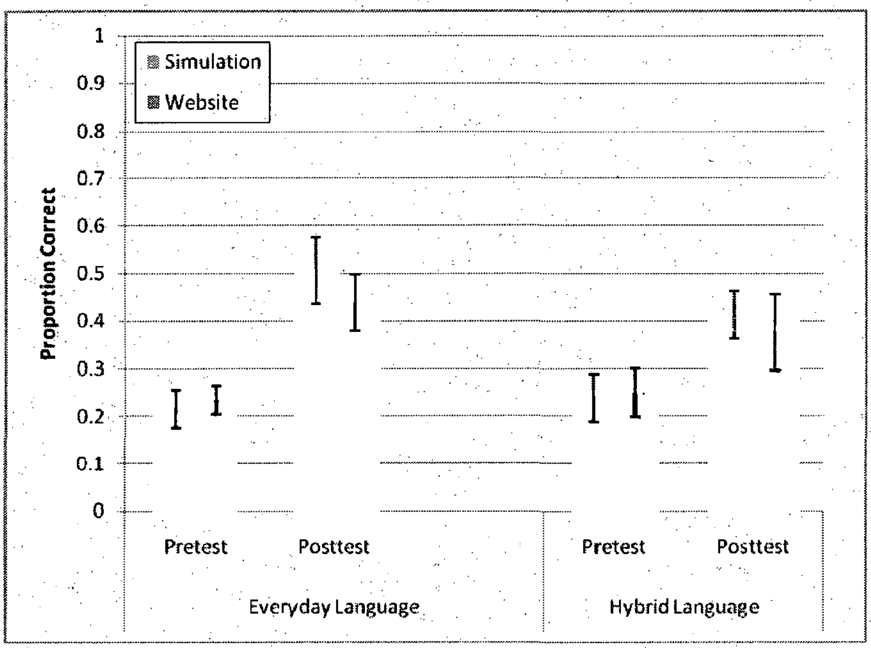


Figure 5.6. Comparison of ELLs' Mean Score by Language and Simulation.

Unlike the results from the ELLs' performance, for EPSs, there was only an interaction effect between Learning Gain and Language, $F(1,148)=18.24$, $p=.000$, indicating that EPSs taught in everyday English prior to learning scientific language showed greater improvement than those taught in hybrid language. Surprisingly, there was no interaction effect between Learning Gain and Simulation for EPSs, $F(1,148) = 2.26$, $p = .14$, suggesting that the use of computer simulation did not have any significant impact on EPSs' understanding of scientific concepts. As shown in Figure

5.7, EPSs taught in everyday English prior to the introduction of scientific language achieved similar scores on the posttest, regardless of the use of the simulation program or the website. In the Hybrid condition, EPSs who used the simulation program during the problem-solving activities performed better than EPSs who used the website, but the difference was not statistically significant ($p = .22$).

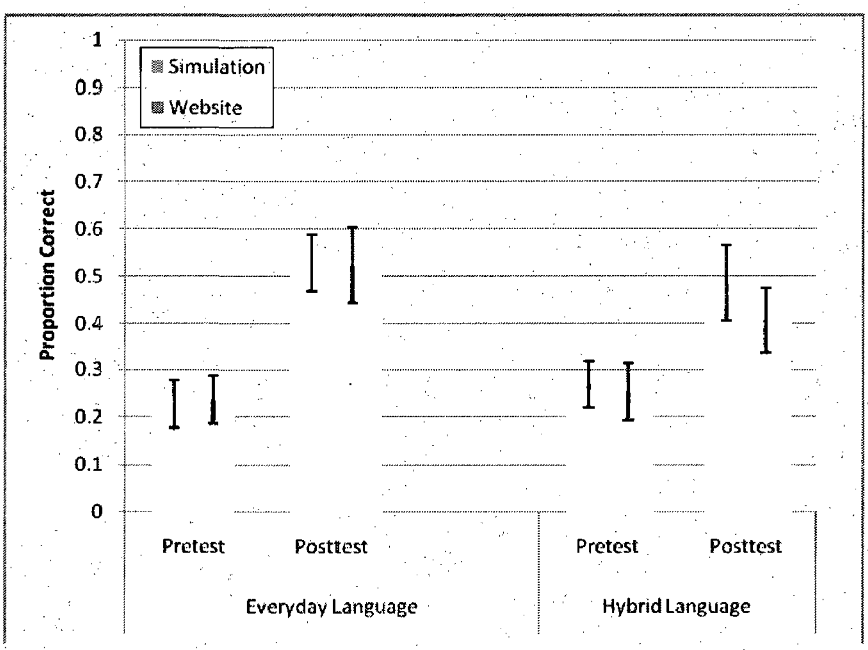


Figure 5.7. Comparison of EPSs' Mean Score by Language and Simulation.

To examine whether there were any significant differences in the mean gain scores among the four groups, I conducted a one-way ANOVA on ELLs' and EPSs' learning gains across the four conditions. The results showed that there were significant differences among the groups for both ELLs ($p = .007$) and EPSs ($p = .000$). Tukey's HSD tests for post hoc comparisons revealed that ELLs in the Everyday-Simulation group improved significantly more than ELLs in both the Hybrid-

Simulation (p = .045) and the Hybrid-Website (p = .006) groups (Figure 5.8). By contrast, EPSs in both the Everyday-Simulation and the Everyday-Website group demonstrated significantly higher learning gains than EPSs in the Hybrid-Website group (p = .000, p = .002 respectively). These results demonstrate that teaching science in everyday English and using computer simulation had different impacts on ELLs' and EPSs' science learning. In other words, teaching science in everyday English can be only valuable for ELLs when it is combined with the use of computer simulation, whereas the everyday language approach can significantly improve EPSs' science learning without the use of computer simulation.

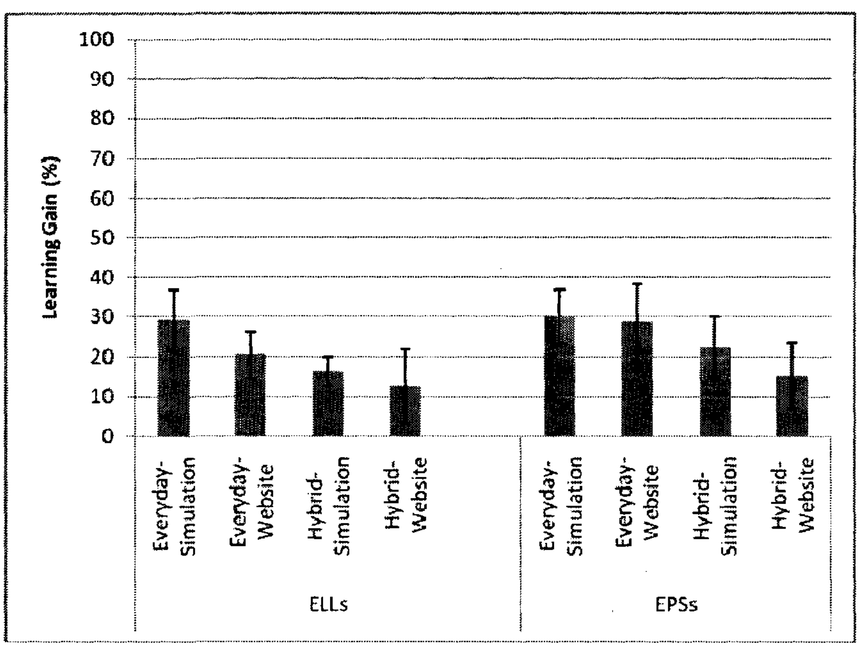


Figure 5.8. Comparison of Learning Gain Between the Treatment Groups by English Proficiency.

Effects of the Everyday Language Approach and the Simulation Approach in Decreasing Achievment Gaps between ELLs and EPSs

Does the Everyday Language Approach, and/or the Simulation Approach Help Decrease learning gaps between ELLs and EPSs?

The analysis of students' pretest scores revealed that there were no significant mean differences between ELLs and EPSs, although EPSs showed a slightly better understanding of photosynthesis and respiration than ELLs prior to the study. On the posttest, EPSs still showed a more complete understanding of the scientific concepts than ELLs across the groups, but the learning gap between ELLs and EPSs was found to be smallest in the Everyday-Simulation group. By contrast, surprisingly, there were statistically marginal achievement gaps between ELLs and EPSs in the Everyday-Website ($p = .07$) and the Hybrid-Simulation ($p = .07$) groups (Table 5.4). This finding indicates that the combination of teaching science in everyday English and using computer simulation was more effective in improving ELLs' science learning than using one of the approaches alone. Figure 5.9 illustrates the mean differences between ELLs and EPSs across the four conditions.

Table 5.4

Comparison of Mean Scores and Learning Gains between ELLs and EPSs

Group	n	Pretest		Difference	t	Posttest		Difference	t
		ELLs	EPSs			ELLs	EPSs		
Everyday-Simulation	17	3.88 (1.58)	4.10 (1.74)	0.22	0.45	9.23 (2.37)	9.51 (2.14)	0.40	0.62
Everyday-Website	18	4.22 (1.22)	4.25 (1.76)	0.03	0.60	7.89 (2.27)	9.42 (3.03)	1.53	1.89
Hybrid-Simulation	17	4.29 (1.69)	4.84 (1.82)	0.54	1.04	7.41 (1.62)	8.73 (2.76)	1.32	1.83
Hybrid-Website	16	4.50 (1.97)	4.55 (2.17)	0.05	0.08	6.75 (2.86)	7.30 (2.59)	0.55	0.80

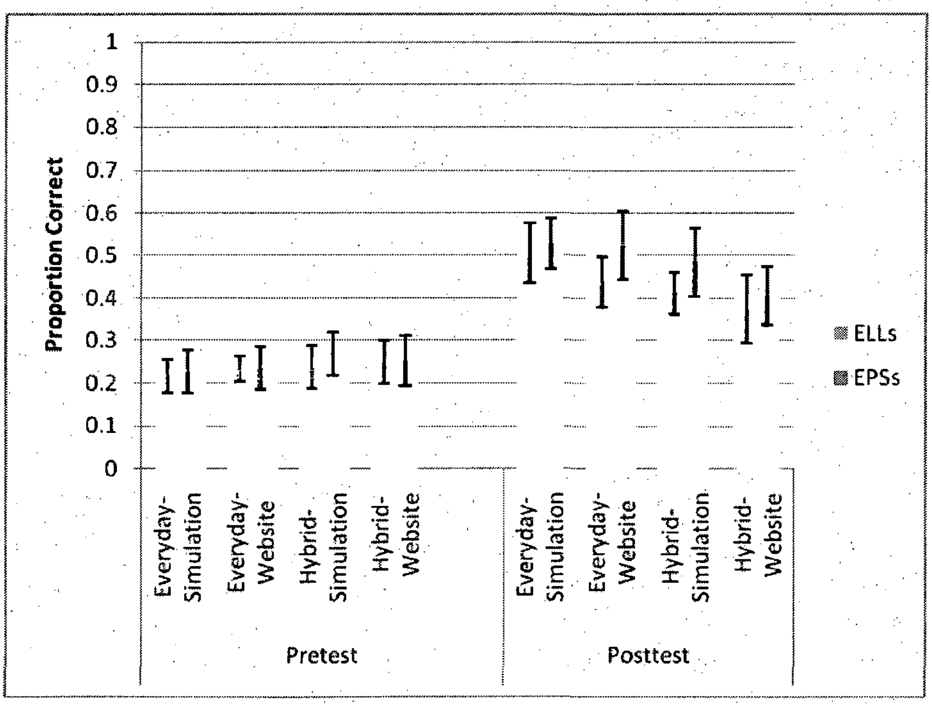


Figure 5.9. Comparison of Mean Scores between ELLs and EPSs by Treatment Group.

Summary and Discussion

This chapter has reviewed the effects of the Everyday Language approach and the Simulation approach on ELLs' and EPSs' understanding of photosynthesis and respiration by analyzing students' performance on the multiple-choice pre- and posttests. The analysis of the pre- and posttests revealed that the combination of the Everyday Language and Simulation approaches was most effective in increasing both ELLs' and EPSs' scientific knowledge. Although ELLs and EPSs in the Everyday-Simulation group achieved the lowest mean scores on the pretest, they both outperformed their counterparts in the other groups on the posttest and also demonstrated the greatest improvement in their understanding of photosynthesis and respiration over time. In particular, ELLs in the Everyday-Simulation group showed almost same learning gain as EPSs in the group, which were also higher than those of EPSs in the other three groups. This finding demonstrates the strong potential advantage of the Everyday Language and the Simulation approaches for promoting high academic achievement for all students.

When examining the individual effect of the Everyday Language and the Simulation approaches, however, I found that the Everyday Language approach significantly increased both ELLs' and EPSs' scientific knowledge, whereas the Simulation approach had a positive impact on only ELLs' science learning. More specifically, regardless of the use of the Everyday Language approach, ELLs who used the simulation program during the problem-solving activities showed a better understanding of photosynthesis and respiration than ELLs who used the website. By contrast, in the Everyday-Language condition, there was no difference between EPSs in the Simulation condition and in the Website condition; the use of computer simulation was only effective for EPSs when they were taught in hybrid language. One possible explanation stems from my argument that ELLs need more language support to catch up with EPSs' scientific language proficiency and their level of scientific knowledge. Teaching science in everyday English can significantly improve ELLs' scientific knowledge than teaching science in hybrid language, but in order to help ELLs achieve the same level of understanding as EPSs, they need additional instructional support. Another possible explanation is that ELLs in the simulation environment might have more opportunities to change their misconceptions about photosynthesis and respiration by interacting with more advanced peers.

These findings suggest that it is important to provide not only ELLs, but also EPSs, with a transitional step between everyday language and scientific language in order to help them build a more concrete understanding of scientific concepts. The findings also indicate that the use of computer simulation during the problem-solving activities can be more effective for those who struggle with scientific language, such as ELLs or EPSs taught in hybrid language, by providing them with more opportunities to articulate their understanding using scientific language in multiple contexts.

The next chapter explores the effects of the Everyday Language approach and the Simulation approach on ELLs' ability to explain scientific ideas using accurate scientific language in written form, compared to that of EPSs.

CHAPTER 6: RESULTS OF THE OPEN-ENDED TESTS

This chapter reports the effects of the Everyday Language and the Simulation approaches on ELLs' understanding of scientific phenomena and their ability to articulate their understanding using appropriate scientific language, compared to those of EPSs. By analyzing ELLs' and EPSs' scores from the open-ended pre- and posttests, this section examines how these two teaching approaches enhance ELLs' science learning and whether these approaches helped close any learning gaps between ELLs and EPSs.

Consistent with the findings of the multiple-choice tests, the results of the open-ended tests revealed that the both ELLs and EPSs in the Everyday-Simulation group not only demonstrated the greatest improvement, but they also performed much better than their counterparts in the other three groups. In particular, the learning gains of ELLs in the Everyday-Simulation group was significantly greater than these of ELLs in the other three groups, which indicates that the combination of Everyday Language and the Simulation approaches can be a powerful pedagogical tool for ELLs' science learning. The significant effects of computer simulation were again only found in the ELLs' performance, whereas the Everyday Language approach was effective for both ELLs' and EPSs' science learning. The most interesting finding of the open-ended tests was that the use of computer simulation appeared to reduce achievement gaps between ELLs and EPSs. Prior to the study, EPSs showed a significantly better ability to articulate their understanding in using appropriate scientific language across all four groups. However, after the treatment, there was no significant achievement gap between ELLs and EPSs in the Simulation condition, whereas EPSs still significantly outperformed ELLs in the Website condition.

The open-ended test was constructed to measure students' conceptual understanding of photosynthesis and respiration, as well as their ability to use to articulate their scientific knowledge in accurate scientific language. The open-ended test consisted of six items, with an equal number of retention, inference, and transfer questions. To establish the reliability of scores, students' written answers were scored blindly and independently by two different raters, using a scoring rubric designed to measure students' conceptual understanding of photosynthesis and respiration in scientific language. One point was given for each correct answer in scientific language. If a response provided a correct understanding but did not use appropriate scientific language, it did not receive any points. The maximum score for each question was four, and the maximum possible score for the open-ended test was 24. The interrater reliability of the open-ended tests was .84.

Pretest Results

To examine whether there were any initial differences in students' ability to explain the concepts of photosynthesis and respiration using scientific language, I compared students' scores from the open-ended pretests using a 2 (Language) X 2 (Simulation) X 2 (English Proficiency) univariate ANOVA. The results of the ANOVA did not reveal a main effect of Language, $F(1,212) = 0.45$, $p = .50$, nor a main effect of Simulation, $F(1,212) = 2.67$, $p = .10$, indicating that students in the four groups had similar prior knowledge and ability to articulate their understanding of the scientific concepts prior to the study.

Students, on average, achieved a mean score of 2.12 (SD = 2.18), which indicates students answered only 8.83% of the questions correctly. This result suggests that all students had a very limited understanding of photosynthesis and respiration; it also demonstrates the students' limited ability to explain scientific phenomena using scientific language. Among the four groups, students in the Hybrid-Simulation group scored highest (M=2.55, SD = 2.26), whereas students in the Hybrid-Website group scored lowest (M=1.51, SD=1.96). Table 6.1 presents the mean scores and standard deviation (SD) across the four groups.

Of particular interest is a significant main effect of English Proficiency, $F(1,212) = 20.86$, $p = .000$, suggesting that EPSs overall achieved a higher score on the pretest than did ELLs (Figure 6.1). This finding is surprising, given that there was no pre-existing difference between the two groups of students on the multiple-choice pretest. A series of t-tests revealed that EPSs showed a superior ability to elaborate on scientific ideas using accurate scientific language compared to ELLs in all four groups (all $ps<.05$). In particular, the Everyday-Simulation and the Hybrid-Simulation group showed the largest achievement gaps between ELLs and EPSs among the four groups.

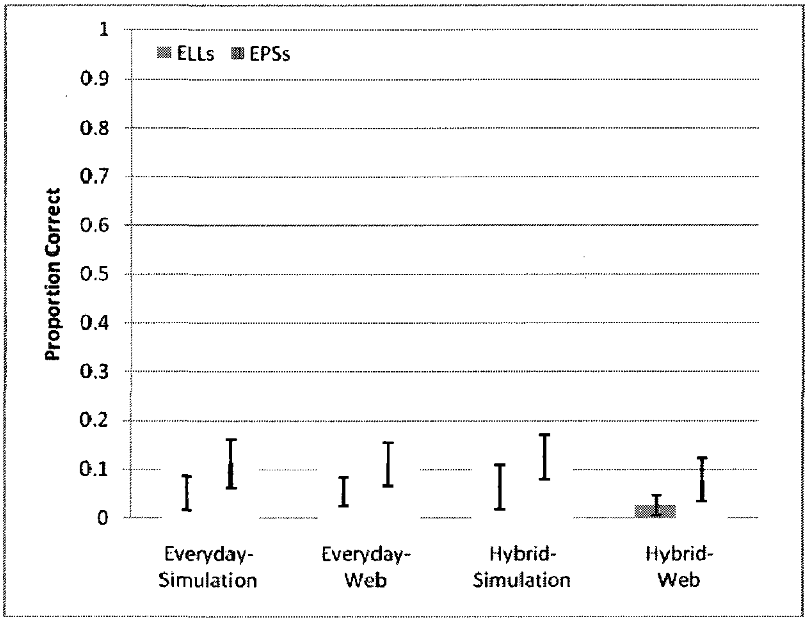


Figure 6.1. Comparison of Mean Scores on the Pretest between ELLs and EPSs.

This result indicates that EPSs showed a better ability to articulate their understanding of photosynthesis and respiration in written form than did ELLs prior to the study, a skill which can provide students with a significant advantage in learning science. These findings support my argument that ELLs usually have less proficiency in scientific language, and that it is more challenging for ELLs to use scientific language to elaborate on their understanding of the scientific concepts than it is for EPSs to do the same. The ANOVA did not reveal any other interaction effects (all *Fs*<.20). The mean scores and standard deviation (SD) across the four groups are shown in Table 6.1.

Table 6.1

Pretest Scores with Sample Means and Standard Deviations

		N	Mean (SD)	Difference	t	Effect Size
Everyday-Simulation	All	56	2.23 (2.36)			
	ELLs	17	1.21 (1.69)	1.47	2.23*	0.69
	EPSs	39	2.68 (2.48)			
Everyday-Website	All	54	2.20 (2.03)			
	ELLs	18	1.31 (1.54)	1.35	2.40*	0.72
	EPSs	36	2.65 (2.12)			
Hybrid-Simulation	All	54	2.55 (2.26)			
	ELLs	17	1.53 (2.15)	1.48	2.34*	0.68
	EPSs	37	3.01 (2.18)			
Hybrid-Website	All	56	1.51 (1.96)			
	ELLs	16	0.63 (1.02)	1.24	2.21*	0.74
	EPSs	40	1.86 (2.13)			

*p<0.05

Effects of the Everyday Language Approach and the Simulation Approach

Does the Everyday Language Approach, and/or the Simulation Approach enhance students' ability to articulate their understanding of scientific phenomena using scientific language?

To examine the effects of teaching science in everyday English and using computer simulation, I compared students' open-ended pre- and posttest scores using a 2 (Language) X 2 (Simulation) X 2 (English Proficiency) X 2 (Learning Gain) repeated measures ANOVA. The between-subjects variables were Language (Everyday Language or Hybrid Language), Simulation (Simulation or Website), and English Proficiency (ELLs or EPSs) with Learning Gain (difference between the pre- and the posttests) as a within-subjects variable.

The results of the ANOVA provided evidence of a Learning Gain effect, $F(1,212) = 589.92, p = .000$, such that all students overall performed significantly better on the posttest than on the pretest. The mean score of all the participants on the pretest was 4.37 (SD = 1.80), as compared to 8.44 (SD = 2.69) on the posttest, indicating that the mean score improved by 22.61%. Paired t-tests demonstrated that all students across the four groups demonstrated a significantly better ability to articulate their understanding of scientific concepts using scientific language after the treatment (all *ps*= .000). Figure 6.2 illustrates the mean difference between the pre- and posttest across the four conditions.

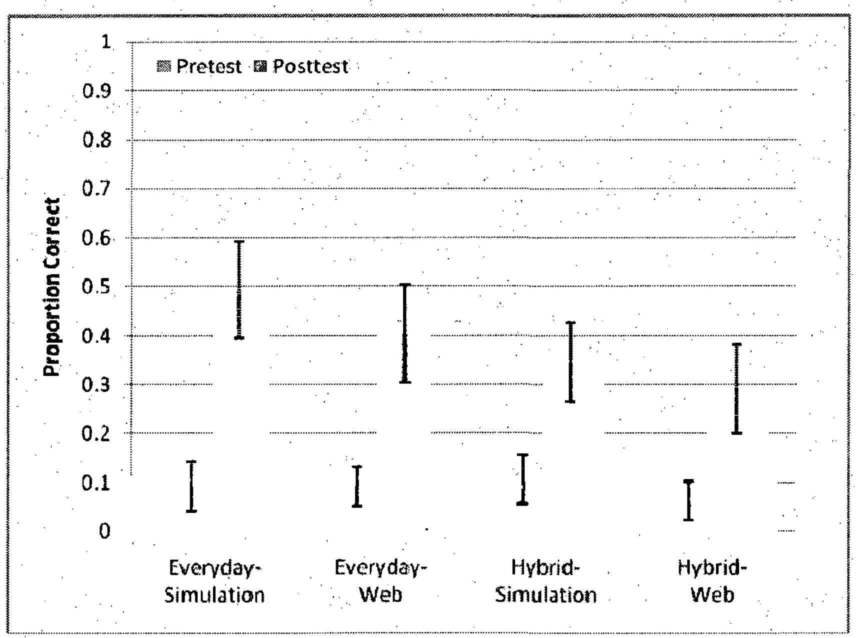


Figure 6.2. Comparison of Mean Scores between Pre- and the Posttests.

Similar to the results from the analyses of the multiple-choice tests, students in the Everyday-Simulation group showed the greatest learning gain by improving 40.04%, whereas students in the Hybrid-Website group demonstrated the least improvement among the four groups by gaining only 17.57%. Table 6.2 presents the mean scores from the pre- and the posttest, learning gain, and the results of paired t-test.

Table 6.2

Comparison of Mean Scores between Pretest and Posttest

Group	n	Pretest (SD)	Posttest (SD)	Gain (SD)	Gain Percentage (%)	t	Effect Size
Everyday-Simulation	56	2.23 (2.36)	11.84 (4.69)	9.61 (3.74)	40.04	19.24***	2.59
Everyday-Website	54	2.20 (2.03)	9.70 (5.24)	7.5 (4.20)	31.25	13.12***	1.89
Hybrid-Simulation	54	2.55 (2.26)	8.28 (4.07)	5.73 (3.45)	23.88	12.19***	1.74
Hybrid-Website	56	1.51 (1.96)	5.75 (4.47)	4.24 (3.53)	17.67	8.98***	1.23

In addition to a main effect of Learning Gain, the results of the ANOVA also revealed several interaction effects, similar to those found in the multiple-choice test. As expected, there was a significant interaction effect between Learning Gain and Language, $F(1,212) = 42.50, p = .000$, such that students taught in everyday English prior to learning scientific language showed a greater improvement than students taught in hybrid language. As illustrated in Figure 6.3, there was no mean difference between the Everyday language condition and the Hybrid language condition prior to the study (Everyday Language $M = 1.96$ and Hybrid Language $M = 1.76$). However, there was a noticeable gap between the two groups on the posttest, proving that students in the Everyday language condition were more able to explain their understanding of photosynthesis and respiration in scientific language than those in the Hybrid language condition ($p = .000$). This finding is consistent with the result from the analysis of the multiple-choice test, indicating that teaching science in everyday English prior to introducing scientific language can be effective in improving both students' conceptual understanding of scientific phenomena and their ability to use scientific language appropriately to articulate scientific knowledge.

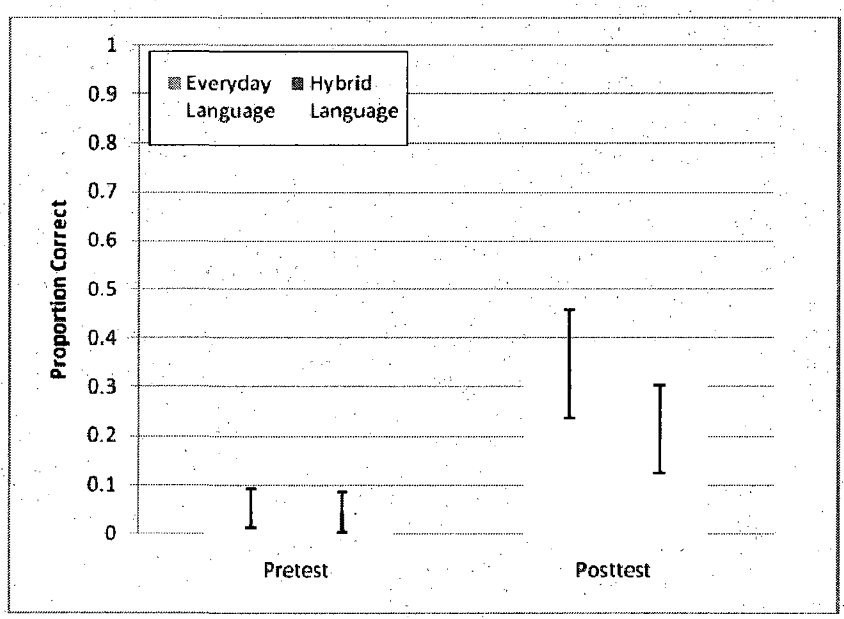


Figure 6.3. Interaction between Learning Gain and Language.

There was also an interaction between Learning Gain and Simulation, $F(1,212) = 17.73$, $p = .000$, suggesting that students who used the simulation program during problem-solving activities showed a better ability to articulate their understanding of the scientific concepts using scientific language than those who used the website (Figure 6.4). As found in the analysis of the pretest, there was again an interaction effect between Learning Gain and English Proficiency, $F(1,212) = 10.64, p = .001$, indicating that EPSs showed greater improvement over time than did ELLs. This last finding will be discussed in a later section where I examine whether teaching science in everyday English and using computer simulation helped close the achievement gaps between ELLs and EPSs.

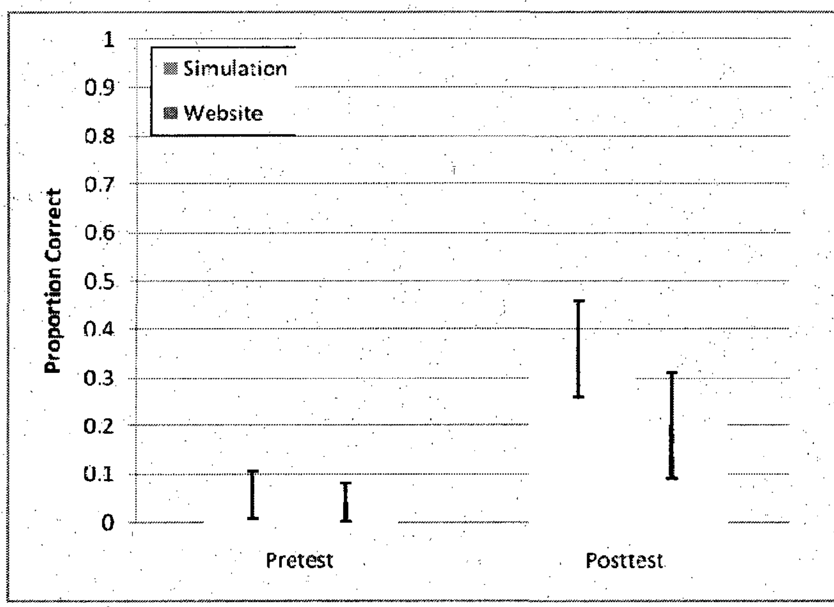


Figure 6.4. Interaction between Learning Gain and Simulation.

Of particular interest is a three-way interaction between Learning Gain and Simulation on English Proficiency, $F(1,212) = 5.03, p = 0.03$. Surprisingly, the use of computer simulation during problem-solving activities was found to be more effective in enhancing ELLs' development of scientific discourse than EPSs. As Figure 6.5 illustrates, there was no significant learning gain difference between EPSs who used the simulation program and who used the website ($p = .22$). By contrast, ELLs in the

Simulation condition showed a significantly greater improvement on the posttest than ELLs in the Website condition ($p = .000$), suggesting that the use of computer simulation can provide multiple opportunities for ELLs to reorganize their understanding of scientific ideas and to use scientific language in different contexts to articulate their ideas. There was no evidence of other interactions with any of the other factors, *ps* >.05.

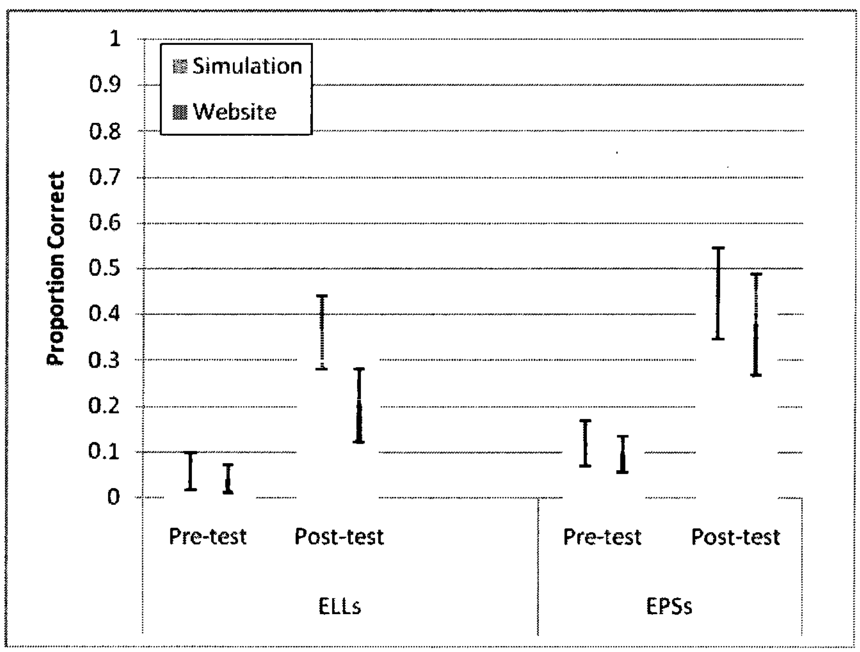


Figure 6.5. Interaction Effect between Learning Gain and Simulation by English Proficiency.

Although there was no three-way interaction effect between Learning Gain and Language on Simulation, I examined whether any of the combinations of the two approaches had significant impacts on students' open-ended test scores through a one-way ANOVA on the differences between the pre- and the posttest. The results of the

ANOVA identified significant mean differences in learning gains across the four conditions, $F(3, 216) = 16.99$, $p = .000$. The results of Tukey's HSD tests for post hoc comparisons revealed that mean gain scores for all four condition groups were significantly different on multiple levels.

The most interesting finding is that students in the Everyday-Simulation group showed a significantly greater ability to explain scientific ideas about photosynthesis and respiration using scientific language accurately, compared to not only those in the Hybrid condition (the Hybrid-Simulation and the Hybrid-Website groups), but also students in the Everyday-Website group ($p = .018$). This is an unexpected outcome because the analyses of the multiple-choice tests did not reveal any differences in learning gain between the Everyday-Simulation and the Everyday-Website groups. This result indicates that the combination of teaching science in everyday English and using computer simulation to solve problems is the most effective teaching approach to improve students' conceptual understanding of scientific phenomena and their use of scientific language.

Another significant difference was found between the Everyday-Website group and the Hybrid-Website group. Students in the Everyday-Website group were better able to elaborate on their understanding of the scientific phenomena in scientific language than were those in the Hybrid-Website group ($p = .000$). This finding is consistent with findings from the analyses of the multiple-choice test, which indicates that in the Website condition, the use of everyday English in science instruction can be more beneficial for improving students' ability to use scientific language more accurately to explain their ideas about scientific concepts. Figure 6.6 compared the learning gain between the pre- and posttests of each treatment group.

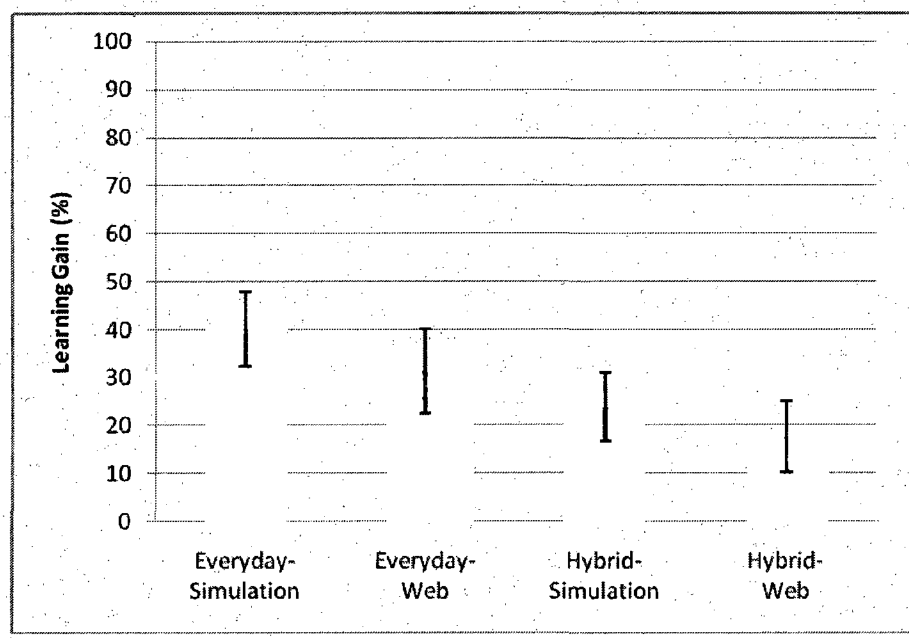


Figure 6.6. Interaction between Learning Gain and Simulation by English Proficiency.

Effects of the Everyday Language Approach and the Simulation Approach on ELLs' Science Learning Compared to EPSs' Science Learning

Does the Everyday Language Approach, and/or the Simulation Approach affect ELLs' and EPSs' ability to elaborate on their understanding of scientific concepts differently?

Given the significant three-way interaction between Learning Gain and Simulation on English Proficiency, $F(1,212) = 5.03$, $p = 0.03$, I examined ELLs' and EPSs' scores from the open-ended pre- and posttests separately in order to explore how teaching science in everyday English and/or using computer simulation impacted ELLs' and EPSs' science learning differently. A 2 (Language) X 2 (Simulation) X 2

(Learning Gain) repeated measures of the ANOVA looked at ELLs' and EPSs' science learning over time.

As expected, the results of the ANOVA revealed a main effect of Learning Gain for both ELLs, $F(1,64) = 196.35, p = .000$, and EPSs, $F(1, 148), p = .000$, suggesting that both ELLs and EPSs significantly improved their scientific knowledge and ability to use scientific language accurately over time. The results of paired t-tests showed that ELLs in the Everyday-Simulation showed the greatest learning gain among the four groups, whereas ELLs in the Hybrid-Website group demonstrated the lowest improvement (Table 6.3). More specifically, ELLs in the Everyday-Simulation group improved 38% from the pretest to the posttest, whereas ELLs in the Hybrid-Web group improved only 11%. Again, ELLs in the Everyday-Website and the Hybrid-Simulation groups showed similar learning gains, but surprisingly, ELLs in the Hybrid-Simulation group demonstrated a slightly higher learning gain than ELLs in the Everyday-Website group on the open-ended tests.

Similar patterns were also found among EPSs. EPSs in the Everyday-Simulation group again showed the greatest improvement by gaining 9.85 points higher on the posttest (41% improvement), while EPSs in the Hybrid-Simulation group gained only 20% more on the posttest. Consistent with findings from the analyses of the multiple-choice tests, EPSs in the Everyday-Website group performed similarly to EPSs in the Everyday-Simulation group and showed a better improvement than EPSs in the Hybrid-Simulation group.

Table 6.3

Comparison of Mean Scores between Pretest and Posttest for ELLs and EPSs

English Proficiency	Group	n	Pretest (SD)	Posttest (SD)	Gain (SD)	Gain Percentage (%)	t	Effect Size
ELLs	Everyday-Simulation	17	1.21 (1.69)	10.26 (3.99)	9.06 (3.37)	37.75	11.09***	2.95
	Everyday-Website	18	1.31 (1.54)	6.42 (3.58)	5.11 (2.93)	21.29	7.41***	1.85
	Hybrid-Simulation	17	1.53 (2.15)	7.06 (3.36)	5.53 (3.15)	23.04	7.24***	1.96
	Hybrid-Website	16	0.63 (1.02)	3.25 (3.66)	2.63 (3.68)	10.96	2.85*	0.98
EPSs	Everyday-Simulation	39	2.68 (2.48)	12.53 (4.86)	9.85 (3.90)	41.04	15.75***	2.55
	Everyday-Website	36	2.65 (2.12)	11.35 (5.19)	8.69 (4.26)	36.21	12.24***	2.19
	Hybrid-Simulation	37	3.01 (2.18)	8.84 (4.29)	5.82 (3.62)	24.25	9.78***	1.71
	Hybrid-Website	40	1.86 (2.13)	6.75 (4.41)	4.89 (3.30)	20.38	9.36***	1.41

The results of the ANOVA also revealed that for ELLs, there was a significant interaction effect between Learning Gain and Language, $F(1,212) = 14.26, p = .000$. There was no difference between ELLs in the Everyday language condition and the Hybrid language condition on the pretest, but ELLs taught in everyday English significantly outperformed their counterparts taught in hybrid language ($p = .000$). Of interest is a significant interaction between Learning Gain and Simulation, $F(1,212) = 18.50, p = .000$, which was not found in the analyses of the multiple-choice tests (Figure 6.7). The use of computer simulation to solve scientific problems was found to be more effecitve in improving ELLs' content knowledge and their use of scientific language than the use of the website.

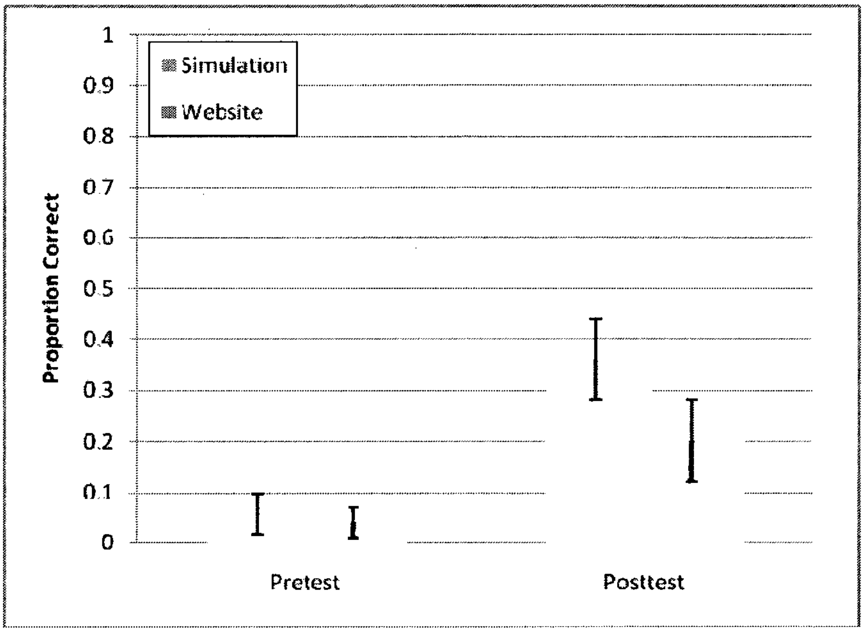


Figure 6.7. Interaction Effect between Learning Gain and Simulation for ELLs.

For EPSs, the ANOVA revealed an interaction between Learning Gain and Language, $F(1,148) = 40.71$, $p = .000$, but there was only a very marginal interaction effect between Learning Gain and Simulation, $F(1,148) = 2.90$, $p = .090$. In other words, EPSs taught in everyday English improved significantly more than those taught in hybrid language (Figure 6.8), but the use of computer simulation had very little impact on EPSs' ability to articulate their scientific ideas using scientific language (Figure 6.11). This finding is consistent with findings from the analyses of the multiple-choice tests.

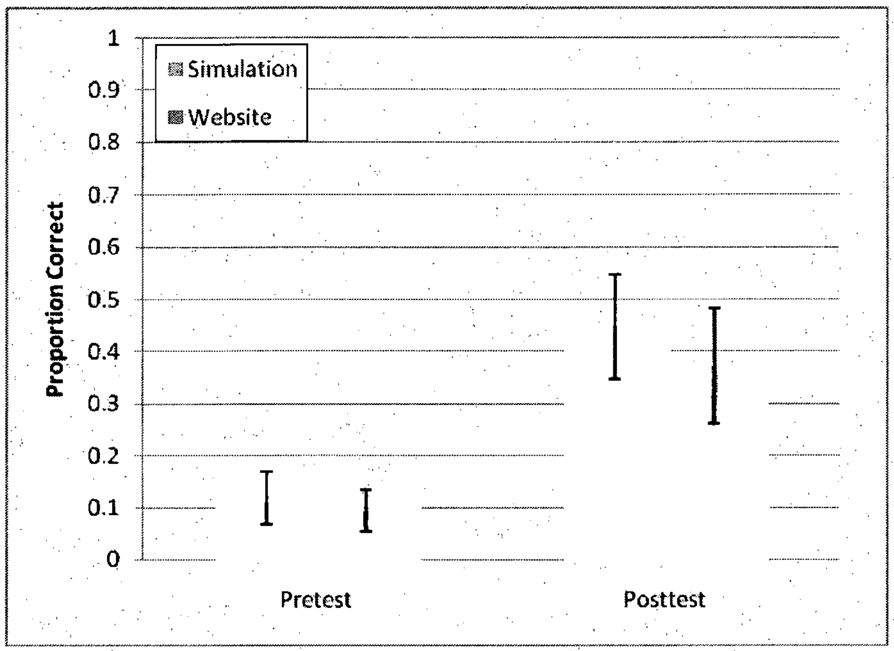


Figure 6.8. Interaction Effect between Learning Gain and Simulation for EPSs.

To examine whether there were any significant differences in the mean gain scores among the four groups, I conducted a one-way ANOVA on ELLs' and EPSs' learning gains across the four conditions. The results showed that there were significant differences among the groups for both ELLs ($p = .000$) and EPSs ($p = .000$).

Tukey's HSD tests for post hoc comparisons revealed different patterns for ELLs and EPSs. The learning gains of ELLs in the Everyday-Simulation group was significantly greater than these of ELLs in the other three groups (all $ps < .05$), which indicates that the combination of the Everyday Language and the Simulation approaches can be a powerful pedagogical tool for improving ELLs' science learning. By contrast, EPSs in the Everyday language conditions, namely the Everyday-Simulation and the Everyday-Website groups, demonstrated a significantly better ability to articulate their scientific ideas using scientific language than EPSs in the Hybrid language (the Hybrid-Simulation and the Hybrid-Website groups). Consistent with findings from the multiple-choice test, the use of everyday English had a stronger impact on EPSs' science learning than the use of computer simulation. Figure 6.9 illustrates ELLs' and EPSs' mean percentage of learning gains between the pre- and posttests across four groups.

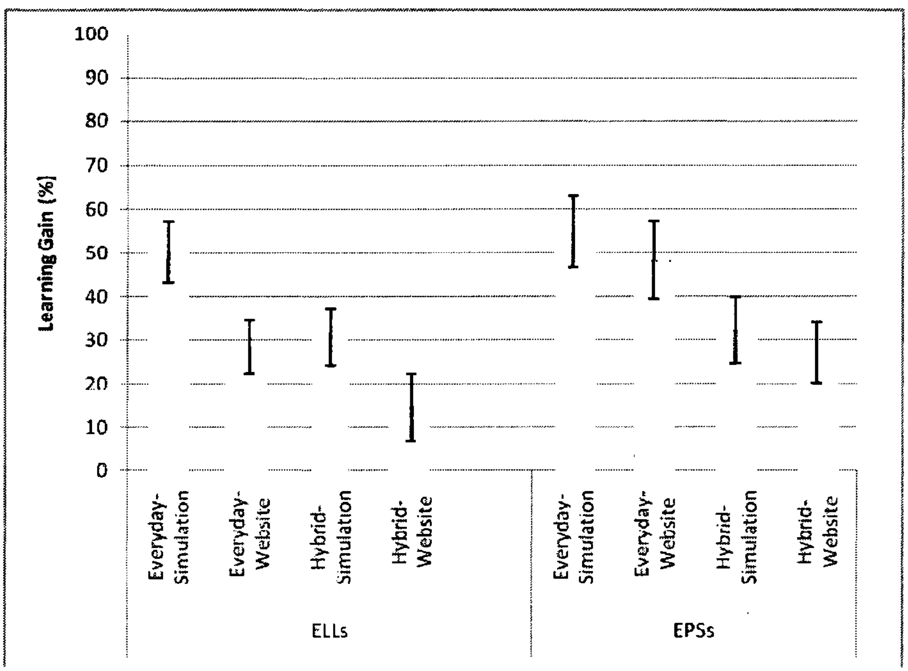


Figure 6.9. Mean Percentage of Learning Gains by English Proficiency.

Effects of the Everyday Language Approach and the Simulation Approach in Decreasing Achievment Gaps between ELLs and EPSs

Does the Everyday Language Approach, and/or the Simulation Approach Help Decrease the Learning Gap Between ELLs and EPSs?

As addressed in the earlier section, there were significant achievement gaps between ELLs and EPSs across all four groups on the pretest (all $ps < .05$), suggesting that, prior to the study, EPSs were more able to explain scientific ideas using accurate scientific language than ELLs. This finding supports my argument that ELLs are likely to have less proficiency in scientific language and to be less able to use scientific language to explain their understanding of the concepts, compared to EPSs.

To examine whether teaching science in everyday English and/or using computer simulation decreased those gaps, I compared ELLs' and EPSs' posttest scores using a series of t-tests. Surprisingly, no mean differences were found on the posttest between ELLs and EPSs in the Everyday-Simulation and the Hybrid-Simulation groups (Figure 6.10). Although EPSs still achieved slightly higher scores than ELLs in these two groups, the mean differences between ELLs and EPSs were not statistically significant ($ps > .05$).

By contrast, much larger achievement gaps were found between ELLs and EPSs who used the website during the problem-solving activities (all $ps < .05$). EPSs in the Everyday-Website and the Hybrid-Website groups significantly outperformed ELLs, demonstrating that EPSs were still much better able to elaborate on their understanding of the scientific concepts in scientific language than ELLs. These results suggest that using computer simulation to solve scientific problems can indeed decrease the existing learning gaps between ELLs and EPSs by helping ELLs more effectively master not only the content, but also the specialized language of science. Figure 8 illustrates the mean differences between ELLs and EPSs across the four groups. Table 6.4 presents the mean scores and the mean differences between ELLs and EPSs across the four groups.

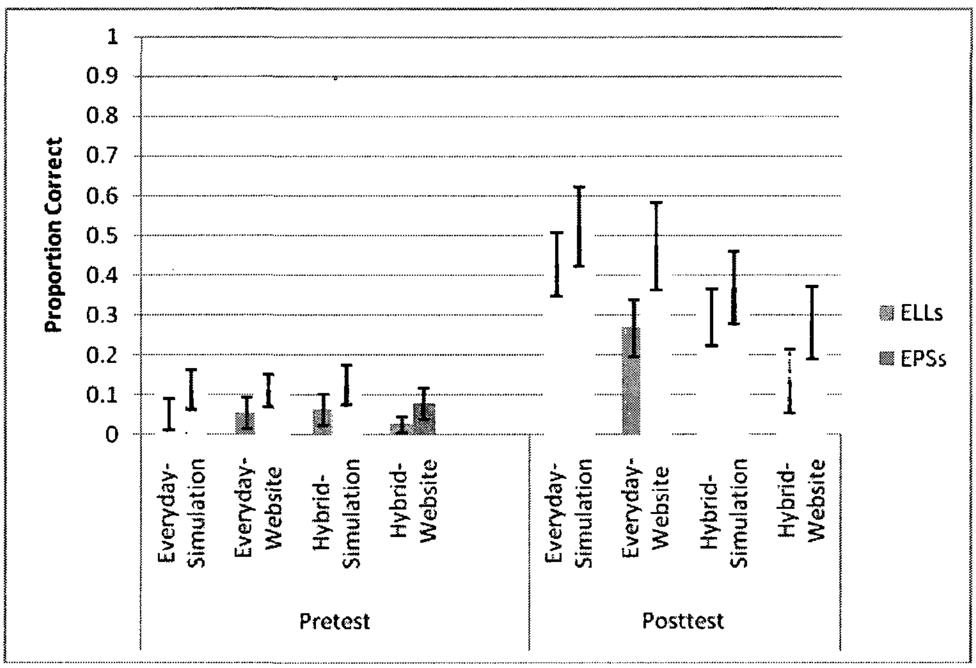


Figure 6.10. Comparison of Mean Scores between ELLs and EPSs on the Pre- and Posttests By Treatment Condition.

Table 6.4

Comparison of Mean Scores between ELLs and EPSs

		N	Mean (SD)	Difference	t	Effect Size
Everyday-Simulation	ELLs	17	10.26 (3.99)	2.26	1.69	0.51
	EPSs	39	12.53 (4.86)			
Everyday-Website	ELLs	18	6.42 (3.58)	4.93	3.62**	1.11
	EPSs	36	11.35 (5.19)			
Hybrid-Simulation	ELLs	17	7.06 (3.36)	1.78	1.51	0.46
	EPSs	37	8.84 (4.29)			
Hybrid-Website	ELLs	16	3.25 (3.66)	3.50	2.81**	0.86
	EPSs	40	6.75 (4.41)			

Summary and Discussion

This chapter has reviewed how teaching science in everyday English and using computer simulation together enhance ELLs' and EPSs' understanding of scientific phenomena, as well as their abilities to articulate their scientific knowledge using scientific language in written form. The analyses of students' performance on the open-ended tests yield several interesting findings. First, both the Everyday Language approach and the Simulation approach were found to be significantly effective in improving ELLs' science learning. In particular, as I hypothesized, the combination of teaching science in everyday English and using computer simulation had the most positive impact on enhancing ELLs' understanding of the scientific concepts and their accurate use of scientific language to explain their ideas. ELLs in the Everyday-Simulation group demonstrated significant improvement between the pre- and the posttests when compared to ELLs in the other three groups. ELLs in the Everyday-Website and the Hybrid-Simulation group demonstrated similar learning gains, whereas ELLs in the Hybrid-Website group achieved the least improvement. These results suggest that it is important not only to help ELLs bridge their understanding of scientific concepts in everyday language and in scientific language, but also to provide them with a variety of opportunities to use scientific language while working on scientific tasks.

Although teaching science in everyday English was also effective in improving EPSs' science learning, the use of computer simulation appeared to have a very marginal impact on EPSs' ability to articulate their scientific understanding in appropriate scientific language. Although EPSs in the Simulation condition still performed slightly better than EPSs in the Website condition, the differences between the two groups were not significant. In particular, regardless of the use of computer simulation, EPSs in the Everyday-Language condition (the Everyday-Simulation and the Everyday-Website groups) performed very similarly, and significantly outperformed their counterparts in the Hybrid-Language condition (the Hybrid-Simulation and the Hybrid-Website).

The other important finding is that the use of computer simulation during problem-solving activities helped close the existing achievement gaps between ELLs and EPSs. The analysis of students' pretest scores showed that, regardless of the treatment condition, EPSs had a significantly better understanding of scientific ideas and a superior ability to elaborate on their understanding by using scientific language when compared to ELLs. However, on the posttest, there were no significant differences between ELLs and EPSs in the Simulation condition (the Everyday-

Simulation and the Hybrid-Simulation groups). By contrast, EPSs in the Website condition (both the Everyday-Website and the Hybrid-Website groups) significantly outperformed ELLs in the same groups, and the gaps between EPSs and ELLs became much more apparent. This result is related to my first finding that the use of computer simulation was more effective in improving ELLs' science learning than in improving that of EPSs, and that its use resulted in the smaller achievement gaps between the two groups.

These findings clearly indicate that the explicit instruction of scientific language can be powerful for helping both ELLs and EPSs develop a more complete understanding of complex scientific concepts; however, what significantly improves ELLs' use of scientific discourse are multiple opportunities that encourage them to use scientific language for different purposes while engaging in scientific tasks. Through this experience, ELLs are able not only to reconstruct their existing understanding or misunderstanding of certain scientific phenomena; they are also able to improve their scientific language skills.

CHAPTER 7: RESULTS OF THE STUDENT INTERVIEWS

Previous chapters have demonstrated that the combination of teaching science in everyday English and using computer simulation to solve scientific problems leads to improvement of both ELLs' and EPSs' conceptual understanding of scientific phenomena and their use of scientific language to articulate their understanding correctly. Another important finding is that the use of computer simulation for problem-solving activities had a positive impact on helping close the achievement gaps between ELLs and EPSs. This chapter explores the effects of these two teaching approaches in improving students' abilities to explain scientific concepts and their applications using accurate scientific language. In this chapter, students' performance on the pre- and post-interviews are examined across the four conditions and by students' English proficiency.

The results of the student interviews consistently showed these same findings as the open-ended tests. The results revealed that the combination of the Everyday-Language and the Simulation approaches dramatically improved both ELLs' and EPSs' conceptual understanding of scientific phenomena and their use of scientific language correctly, much more than the other three conditions. Although both ELLs and EPSs in the Everyday-Simulation group did not have much knowledge about photosynthesis and respiration prior to the study, they all demonstrated a concrete understanding of the concepts and a better ability to articulate their understanding in appropriate scientific language on the post-interview.

The interview was designed to assess how students explain their understanding of photosynthesis and respiration using appropriate scientific language. Each interview was semi-structured with nine questions comprised of equal numbers of retention, inference, and transfer questions (see Appendix D). For the pre- and post-interviews, three students were randomly selected from each classroom, stratified by English proficiency and achievement levels (N=24).[11] All interviewees were either low- or middle-achieving students, according to their academic achievement levels as determined by their performance on the standardized reading and math tests, as well as their teachers' evaluations.[12] Each treatment group had the same number of ELLs and EPSs with the same achievement levels for the interview. All students were interviewed individually for approximately fifteen minutes at their schools during their lunchtime or pulled out from their class for the interview. All were videotaped and fully transcribed.

To establish the reliability of scores, students' responses from the interviews were scored blindly and independently by two different researchers using a five-point (0-4) rubric (Table 7.1). The rubric was designed based on the categorization schemes of other researchers to assess students' level of understanding of the scientific concepts and proficiency in using scientific language accurately (Barnett et al., 2006; Hansen et al., 2004; Simpson & Marek, 1998). The rubric categories ranged from 0 (misconception) to 4 (complete understanding), depending on the accuracy of explanations and the correct use of scientific language. A score of 4 was given to

[11] Three students who missed the second interview were excluded from the analysis.

[12] Because some schools did not have official record of students' science achievement levels, I collected each student's general achievement level based on their standardized test scores on math and reading, as well as their teacher's evaluation.

responses that showed a complete and elaborate understanding of the concepts in scientific language. A score of 3 indicated that the response demonstrated a clear understanding of some concepts but lacked one main concept or contained vague details. A score of 2 showed that the given response was correct, but lacked more than two key concepts. A score of 1 was assigned to responses that provided both correct and incorrect information, which showed that a student was confused. A score of 0 indicated that the student had a fundamental misunderstanding of the concepts, or the student was unable to provide any answer. The inter-rater reliability of the interview was .92.

Table 7.1

Rubric for Scoring Students' Interview Responses

Score	Label	Description
0	Misconception	The response contains fundamental misconceptions or irrelevant information or no response is provided.
1	Confusion	The response contains both a correct understanding and inaccurate information about scientific phenomena.
2	Partial Understanding	The response is accurate but lacks more than two key concepts.
3	Sound Understanding (Incomplete)	The response shows a clear understanding of some concepts but lacks one key concept or contained vague details.
4	Complete Understanding	The response is elaborate, complete, and accurate with details.

Each question was worth four points with a maximum score of 36. Each student's total score was divided by the number of questions (n=9) to measure their level of understanding of photosynthesis and respiration before and after the treatment. In previous chapters, I used students' total scores for the analyses because each question in the multiple-choice and the open-ended tests was scored based on a correct concept instead of a level of understanding. However, analyzing students' total interview scores would not be an accurate assessment of their overall level of understanding. Thus, instead of a total score, the total score divided by the number of questions was used for the analyses.

Results of the student interviews are presented in the following four sections. The first section examines students' pre-interview scores by condition and English proficiency, to ensure that there was no difference in students' prior scientific knowledge and their ability to explain their understanding in scientific language. The second section explores the overall impact of teaching science in everyday English and using computer simulation on students' science learning by comparing their pre- and post-interview scores. The third section examines how these two teaching approaches affected ELLs' performance when compared to that of EPSs'. The fourth section documents whether these teaching approaches helped close the learning gaps between ELLs and EPSs.

Pre-Interview Results

To determine whether there was any difference among the students prior to the study, I conducted a 2 (Language) X 2 (Simulation) univariate ANOVA with scores on the pre-interview. The ANOVA did not reveal any main effects or interaction effects among the variables, indicating that there was no pre-existing difference among the students prior to the study across the four conditions (all Fs < 2.0). Because each cell alone contained a sample size that was too small, the English proficiency variable was not included in the statistical analysis. The descriptive analysis of ELLs' and EPSs' performance on the pre-interview showed that ELLs and EPSs performed similarly in the Everyday-Simulation and the Hybrid-Website groups, whereas there was no noticeable difference between ELLs and EPSs in the Everyday-Website and the Hybrid-Simulation groups (Figure 7.1). These findings indicate that, prior to the study, all students had a similar level of understanding of photosynthesis and respiration, as well as a similar ability to explain their scientific ideas using scientific language. Table 7.2 presents the mean scores and standard deviation (SD) across the four groups.

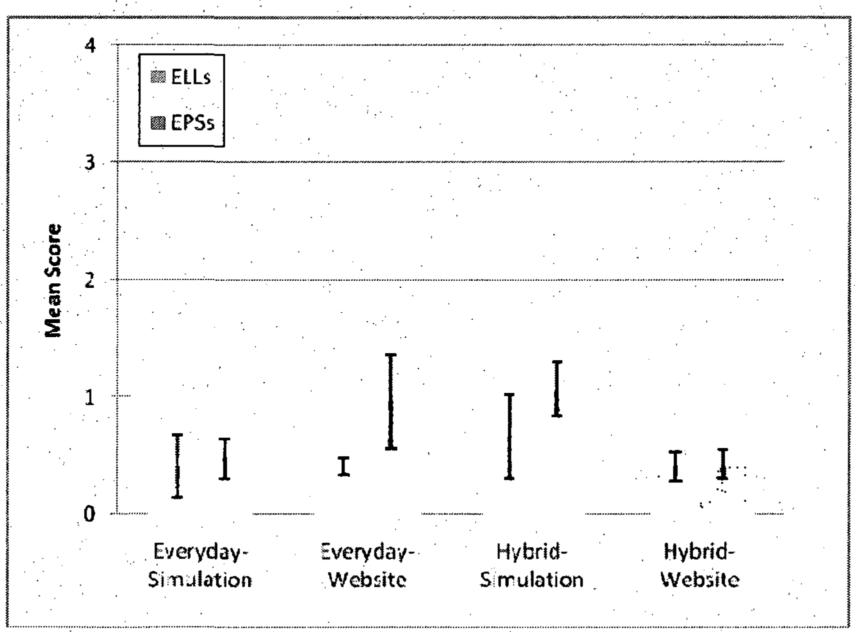


Figure 7.1. Mean Difference Between ELLs and EPSs on the Pre-Interview.

Table 7.2

Means and Standard Deviations for the Pre-Interview

Treatment Group		N	Mean (SD)
Everyday-Simulation	All	6	0.44 (0.41)
	ELLs	3	0.41 (0.34)
	EPSs	3	0.48 (0.55)
Everyday-Website	All	6	0.69 (0.59)
	ELLs	3	0.41 (0.13)
	EPSs	3	0.96 (0.79)
Hybrid-Simulation	All	6	0.87 (0.59)
	ELLs	3	0.67 (0.73)
	EPSs	3	1.07 (0.45)
Hybrid-Website	All	6	0.41 (0.23)
	ELLs	3	0.41 (0.23)
	EPSs	3	0.41 (0.28)

Effects of the Everyday Language Approach and the Simulation Approach

Does the Everyday Language approach and/or the Simulation approach improve students' ability to articulate scientific concepts and their applications?

To test the effects of the Everyday Language approach and the Simulation approach in promoting students' understanding of scientific concepts and their use of scientific language, I conducted a 2 (Language) X 2 (Simulation) X 2 (Learning Gain) repeated measures ANOVA. The between-subjects variables were Language (everyday language or hybrid language) and Simulation (simulation or website), with Learning Gain (the difference in mean scores between the pre- and post-interviews) as a within-subjects factor. Because of the limited sample size, English proficiency was not included in the statistical analysis; instead, the descriptive analyses of ELLs' and EPSs' performance were conducted separately.

Consistent with previous results of the multiple-choice and the open-ended tests, the ANOVA revealed a significant main effect of Learning Gain, $F(1, 20) = 106.37$, $p = .000$. Paired t-tests uncovered that students in the Everyday-Simulation, the Everyday-Website, and the Hybrid-Simulation groups showed a significant improvement over time (all *p*s <.02). Although students in the Hybrid-Website group also performed better on the post-interview, the difference was statistically marginal ($p = .06$). As expected, students in the Everyday-Simulation group again demonstrated the greatest learning gain of 2.56 (SD=0.72) by improving from a mean score of 0.44 (SD = 0.41) to 3.00 (SD = 1.00), whereas students in the Hybrid-Website group showed the least improvement between the pre-interview (M=0.41, SD=0.23) and the post-interview (M=1.20, SD=0.87) by gaining only 0.80 points more. In other words, prior to the study, students in both the Everyday-Simulation and the Hybrid-Website groups did not have much scientific knowledge of photosynthesis and respiration; however, after the treatment, students in the Everyday-Simulation group demonstrated a sound understanding of the scientific concepts by providing a clear, elaborate response with some vague details, whereas students in the Hybrid-Website group showed confusion about photosynthesis and respiration by providing both correct and incorrect concepts in their responses. Similar to the previous findings, students in the Everyday-Website and the Hybrid-Simulation showed similar learning gains, which indicates that either the Everyday Language approach or the Simulation approach alone would have similar effects on students' science learning. Table 7.3 presents students' performance on the pre- and the post-interview by treatment groups.

Table 7.3

Comparison of Mean Scores and Learning Gains between Pre- and Post-Interviews

Condition	n	Pre-Interview (SD)	Post-Interview (SD)	Gain (SD)	Gain Percentage (%)	t	Effect Size
Everyday-Simulation	6	0.44 (0.41)	3.00 (0.65)	2.56 (0.72)	64.00	8.65***	4.71
Everyday-Website	6	0.69 (0.59)	2.26 (0.92)	1.56 (1.02)	39.00	3.77*	2.03
Hybrid-Simulation	6	0.87 (0.59)	2.43 (0.72)	1.57 (0.37)	39.25	10.25***	2.37
Hybrid-Website	6	0.41 (0.23)	1.20 (0.87)	0.80 (0.81)	20.00	2.40	1.24

*p<0.05.
**p<0.01.
***p<0.001.

There was also an interaction effect between Learning Gain and Language, $F(1, 20) = 8.00$, $p = .010$, indicating that students taught in everyday English (namely, the Everyday-Simulation and the Everyday-Website groups) showed a significantly greater improvement than those taught in hybrid language (the Hybrid-Simulation and the Hybrid-Website groups). Similarly, the effect of simulation was also significant in improving students' overall performance, $F(1,20) = 7.67$, $p = .012$. Students who used the simulation program (Everyday-Simulation and the Hybrid-Simulation) to solve scientific problems showed a better ability to articulate their understanding of photosynthesis and respiration, compared to those who used the website (Everyday-Website and the Hybrid-Website groups). These findings indicate that the Everyday Language approach and the Simulation approach are both effective in helping students develop the ability to elaborate their scientific ideas by using accurate scientific language, which clearly supports my hypothesis. There was no three-way interaction effect between Learning Gain and Language on Simulation, $F(1,20) = 0.13$, $p = .73$. Figure 7.2 illustrates students' performance on the pre- and the post-interviews by condition.

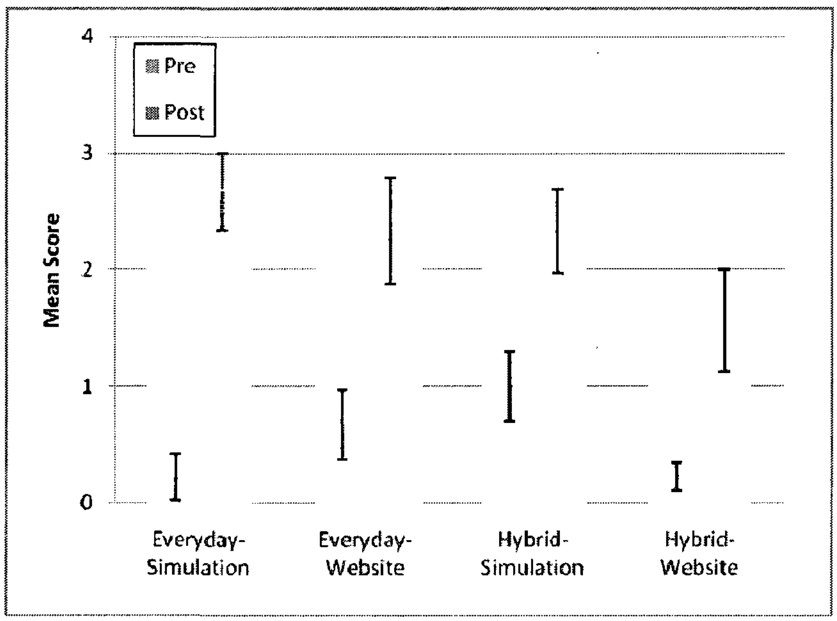


Figure 7.2. Comparison of Mean Scores between the Pre- and Post-Interviews.

Similar to the analyses of the multiple-choice and the open-ended tests, the results of a one-way ANOVA revealed that there was a significant mean gain difference among the four groups, $F(1,20) = 5.27, p = .008$. Post hoc comparisons reported that the mean gain score of students in the Everyday-Simulation group was significantly higher than that of students in the Hybrid-Simulation ($p = .004$). This finding suggests that the combination of the Everyday Language approach and the Simulation approach can be a powerful instructional approach that can improve not only students' understanding of complex scientific phenomena, but also their ability to articulate ideas using appropriate scientific language.

For example, during the pre-interview, when students were asked to explain how the color of Bromothymol blue in three tubes would change (Figure 7.3), none of the students in either the Everyday-Simulation or the Hybrid-Website groups were able to provide a correct answer. However, when they were asked to answer the same question during the post-interview, four students (67%) in the Everyday-Simulation group provided a perfect answer with all the details (receiving a score of 4), and one additional student (17%) demonstrated a sound understanding (receiving a score of 3). By contrast, three students (50%) in the Hybrid-Website group still showed a fundamental misconception (receiving a score of 0), and three students (50%) provided a confused answer that consisted of both correct and incorrect information (receiving a score of 1).

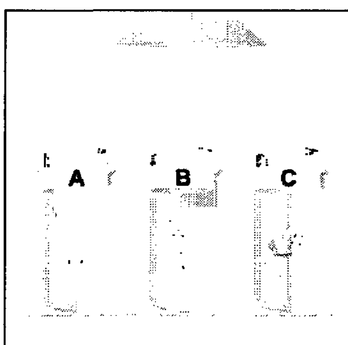
	Bromothymol blue is a special dye that changes its color when there is carbon dioxide. Bromothymol blue is blue in color, but when there is some carbon dioxide, it becomes green. When there is a lot of carbon dioxide, it becomes yellow. There are three tubes. In tube A, I put a water snail and a water plant. In tube b, I put a water plant. And in tube c, I put a water snail. I have dropped some Bromothymol blue into each tube and I have also added carbon dioxide to each tube. So they are all green now. I will keep these tubes under light for 24 hours. After 24 hours, what do you think the color of the water in each tube will be? Why?

Figure 7.3. An Example of the Transfer Questions.

The examples below show the effects of teaching science in everyday English and using computer simulation on students' understanding of the scientific concepts, as well as their ability to apply scientific knowledge to new problems. Two EPSs, Susan[13] from the Everyday-Simulation group and Adrianna from the Hybrid-Website group, who had similar prior knowledge and achievement levels were chosen for comparison (Table 7.4). Both Susan and Adriana were female, middle-achieving EPSs with the same score of six on the multiple-choice pretest. On the open-ended pretest, Adrianna from the Hybrid-Website performed better than Susan.

Table 7.4

Background Information of Susan and Adrinana

	Treatment Group	Gender	Achievement Level	Multiple-choice Pretest (max=18)	Open-ended Pretest (max=24)
Susan	Everyday-Simulation	F	Middle	6	1
Adrianna	Hybrid-Website	F	Middle	6	4.5

During the pre-interview, Susan from the Everyday-Simulation group and Adriana from the Hybrid-Website group used a scientific term, "carbon dioxide," but they both demonstrated a fundamental misconception of the term and failed to provide correct reasoning for their answers (both receiving a score of 0, which indicates their responses contained fundamental misconceptions or irrelevant information). The following excerpt reflects Susan's pre-interview answer for the question.

[13] Pseudonyms were used throughout the study.

> K: ...After 24 hours, what do you think the color of the water in each tube will be?
>
> S: I think tube-A might be yellow because maybe plants have carbon dioxide and so do snails, so it might be yellow. I think tube-B might be...might be...it should stay green because plants have carbon dioxide too. I think tube-C might turn yellow, too, because I think like...I think that maybe the water snail might have more carbon dioxide.

In this excerpt, Susan appeared to have a limited understanding that carbon dioxide is somehow related to plants and water snails, saying that "plants have carbon dioxide and so do snails." However, she failed to use the term "carbon dioxide" accurately by saying that plants and water snails "have" carbon dioxide, instead of "inhaling," "exhaling," or "breathing in/out." Her incorrect answers regarding the color of each tube also demonstrated that she did not have a concrete understanding of photosynthesis and respiration. For example, she predicted that the Tube A would turn yellow (the correct answer is green) and Tube B would stay green (the correct answer is blue) because both plants and snails "have" carbon dioxide. This statement clearly shows that she did not understand that plants inhale carbon dioxide during photosynthesis. Regarding the color of the water in Tube C, Susan predicted correctly that "Tube C might turn yellow," but she did not provide a correct reasoning to support her answer by saying that "the water snail might have more carbon dioxide" (receiving a score of 0).

Similarly, in the following excerpt from the pre-interview, Adriana from the Hybrid-Website group showed some understanding that plants use carbon dioxide for photosynthesis, but she misunderstood that plants exhale carbon dioxide during photosynthesis instead of inhaling it ("plants give off carbon dioxide").

K: ...After 24 hours, what do you think the color of the water in each tube will be?

A: Um, I think that for sure that tube-B is going to be yellow because plants give off carbon dioxide and in (A) I think that it would be the same results as tube-B. And in (C) it would stay green because I don't think the water snails would produce carbon dioxide.

K: Okay. So you think that (A) and (B) will turn yellow. And why do you think that (A) will turn yellow?

A: Because there is a plant in it and a snail.

She also had an incorrect idea that animals do not "produce" carbon dioxide when they breathe ("I don't think the water snails would produce carbon dioxide"). It is unclear from this excerpt whether Adriana did not know the fact that animals breathe just like plants, or whether she understood the fact that animals breathe but mistakenly thought that animals exhale something else other than carbon dioxide during the breathing process (receiving a score of 0).[14]

Although both students initially demonstrated a misunderstanding of photosynthesis and respiration and failed to provide correct reasons for their answers during the pre-interview, on the post-interview, Susan from the Everyday-Simulation group showed significant improvement. After she received science instruction in everyday English and used computer simulation for problem-solving activities, she demonstrated a complete understanding of the scientific concepts and an improved ability to apply her knowledge to solve the problem (receiving a score of 4, which means that she demonstrated an ability to provide elaborate, complete, and accurate

[14] In order to keep the interview procedure fair, I did not ask Adriana an additional question to clarify her answer.

response with details). The following excerpt presents Susan's response to the same question after the treatment.

> K: ...After 24 hours, what do you think the color of the water in each tube will be?
>
> S: I think tube-A will be blue, no wait, I think it will stay green because the snail, it gives out carbon dioxide and the plant, it breathes in carbon dioxide. So the plant, I mean the snail, gives the carbon dioxide to the plant and the plant gives the oxygen to the snail, and I think it will turn it to green because there is...like there is some carbon dioxide.
>
> K: Okay, how about (B)?
>
> S: (B) I am thinking it will be blue because the plant, it only breathes in carbon dioxide during when there is energy and it does not breathe in oxygen.
>
> K: How about (C)?
>
> S: Tube-C will be yellow because the snail only breathes out carbon dioxide and it can't get any oxygen.

In this excerpt, Susan from the Everyday-Simulation group demonstrated a perfect understanding of the process of photosynthesis, by explaining that "[the snail] gives out carbon dioxide and [the plant] breathes in carbon dioxide...[the snail] gives the carbon dioxide to the plant and the plant gives the oxygen to the snail." She also successfully applied her understanding of photosynthesis to the new problem and provided not only accurate answers, but also complete reasoning behind her answers (receiving a score of 4).

By contrast, after the treatment, Adriana from the Hybrid-Website group developed some understanding of the role of carbon dioxide in photosynthesis, explaining that "the water plants will take in the carbon dioxide" but she did not specify when plants would take in the carbon dioxide. She also still showed a misunderstanding of animals' breathing process when she stated that "the water snail doesn't do anything." The following excerpt presents Adriana's response to the same question on the post-interview.

> K: ...After 24 hours what do you think the color of the water in each tube will be?
>
> A: I think that tube-A will be green and then tube-B will green, and then tube-C would be...no, I think that tube-A will be blue and tube-B will be blue, and then tube-C will stay green.
>
> K: Can you explain why you think they will be blue?
>
> A: Because the water plant will take in the carbon dioxide and then the water snail doesn't do anything. And then in (B) the water plant will take in the carbon dioxide. And in tube-C the water snail won't do anything.

From Adriana's excerpt, it was clear that she still had a limited understanding of the concepts of photosynthesis. Even after she received the science instruction and participated in problem-solving activities, she still held her misconception that animals do not exhale carbon dioxide when they breathe. Because of her partial understanding of the concepts, she was not able to provide correct answers for the problem (receiving a score of 1).

These excerpts from Susan and Adriana indicate that the combination of teaching science in everyday English and using computer simulation approaches can not only improve students' understanding of scientific phenomena, but also help them develop a better ability to use their understanding to solve unfamiliar problems. These results suggest that it is indeed important to provide all students with both a transitional step between everyday language and scientific language and multiple opportunities to engage in scientific discourse.

Effects of the Everyday Language Approach and the Simulation Approach on ELLs' Science Learning Compared to EPSs' Science Learning

Does the Everyday Language Approach, and/or the Simulation Approach Improve ELLs' and EPSs' Understanding of Scientific Phenomena Differently?

The descriptive analyses of ELLs' and EPSs' performances on the pre- and post-interviews revealed results consistent with those found from the open-ended tests. As expected, both ELLs and EPSs in the Everyday-Simulation group outperformed the other three groups, particularly their counterparts in the Hybrid-Website group (Figure 7.4). More specifically, both ELLs and EPSs in the Everyday-Simulation group had a significant misconception about photosynthesis and respiration prior to the study, but, after the treatment, they demonstrated a more concrete understanding of the concepts and were better able to illustrate their understanding with details. By contrast, ELLs and EPSs in the Hybrid-Website group showed the least improvement over time among the four groups. In particular, ELLs did not show much improvement even after the treatment and still demonstrated a significant misunderstanding of photosynthesis and respiration.

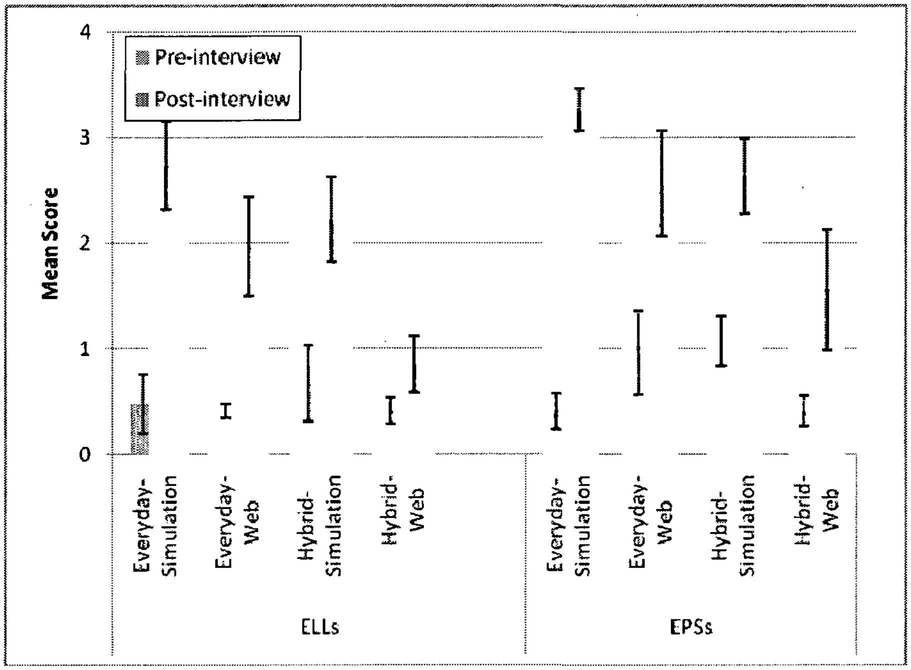


Figure 7.4. Mean Differences Between the Pre- and Post-Interview Across the Four Treatment Groups by English Proficiency.

For example, one of the interview questions asked students to explain what photosynthesis is. During the pre-interview, only one ELL in both the Everyday-Simulation and the Hybrid-Website group showed a limited, partial understanding of photosynthesis, while two ELLs in both groups did not have any understanding of the concept of photosynthesis (receiving a score of 0), or showed fundamental confusion (receiving a score of 1). On the post-interview, however, these ELLs' responses to the same question revealed major differences between the two groups. Two of the three ELLs in the Everyday-Simulation group demonstrated a sound or complete understanding of photosynthesis (a score higher than 3), whereas none of the ELLs in the Hybrid-Website group demonstrated any improved understanding.

The examples below show how two ELLs in the Everyday-Simulation and the Hybrid-Website groups developed their understanding of photosynthesis after the treatment. Two ELLs who had similar prior knowledge, as well as the same CELDT level and achievement level, were chosen for comparison (Table 7.5).

Table 7.5

Background Information of Maria and Brandon

	Treatment Group	Gender	CELDT	Achievement Level	Multiple-choice Pretest (max =18)	Open-ended Pretest (max =24)
Maria	Everyday-Simulation	F	3	Low	4	2
Brandon	Hybrid-Website	M	3	Low	3	2

Maria from the Everyday-Simulation group and Brandon from the Hybrid-Website group were ELLs with CELDT Level 3 and were identified as low-achieving students. During the pre-interview, they both failed to demonstrate confidence in their answers and seemed confused about the role of oxygen and carbon dioxide in photosynthesis (receiving a score of 1, which indicates that the response contained both a correct understanding and inaccurate information about scientific phenomena). The following excerpt is from Brandon's answer (Hybrid-Website group) to a question about the concept of photosynthesis during the pre-interview.

K: Okay, can you explain photosynthesis?

B: Um…photosynthesis is….[long pause] I'm not sure.

K: Okay, sure. It's okay. What do plants need for photosynthesis?

B: Water? [pause] and the sun…and…carbon dioxide.

K: What is that [carbon dioxide]?

B: I don't know…um…some water and sun…[long pause] …and oxygen?

K: And what is oxygen?

B: Oh, oxygen…oxygen is…um… what..um.. we…um…breathe, breathe.

K: And what is carbon dioxide?

B: What we breathe out.

K: What do plants produce during photosynthesis?

B: Um…the water?...and… the…sun.

In this excerpt, Brandon showed a confused idea about the process of photosynthesis. He first correctly listed the three elements for photosynthesis by saying that plants need "water?...and the sun…and…carbon dioxide," but when he was asked to explain the definition of carbon dioxide, he modified his answer to "some water and sun, and oxygen" This indicates that he did not have a clear understanding of oxygen and carbon dioxide in photosynthesis. He also misunderstood that plants produce "water and the sun" during photosynthesis (receiving a score of 1).

Similarly, Maria in the Everyday-Simulation group was able to use some scientific vocabulary to describe photosynthesis, such as "carbon dioxide" and "oxygen," but just like Brandon, she was confused about the role of oxygen and carbon dioxide during photosynthesis.

> K: Okay, can you explain photosynthesis?
>
> M: Um, photosynthesis is, I think, is…it comes from the plants, I think. The food, I guess.
>
> K: Okay. What do plants need for photosynthesis?
>
> M: Um, uh, I think it will need some water, sun and air to make photosynthesis.
>
> K: What kind of air?
>
> M: Carbon dioxide…and wait! oxygen.
>
> K: What is carbon dioxide?
>
> M: Carbon dioxide is like, um…it is a type of air, I guess.
>
> K: What is oxygen?
>
> M: Like the air that we breath e in.
>
> K: What do plants produce during photosynthesis?
>
> M: Plants produce, um, carbon dioxide and, um, it helps, um...it like...it helps...it helps the animals and the people around.

Maria initially provided the three elements for photosynthesis accurately, stating that plants need water, and air. When she was asked to specify what she meant by "air," she provided an accurate scientific term, "carbon dioxide," but soon to change her answer to "oxygen." She also demonstrated a misconception that "plants produce carbon dioxide" during photosynthesis. She appeared to have limited understanding that plants produce a type of air which helps plants but failed to articulate her understanding in appropriate scientific language (receiving a score of 1).

These examples were typical of most students' responses before the treatment, including the responses of EPSs, such that there was a lack of connection between students' understanding in everyday language and in scientific language. However, after the treatment, Maria from the Everyday-Simulation group demonstrated an improved understanding of both the content and the language of science. She provided a complete answer with many details – such as, what photosynthesis is, what plants need for photosynthesis, and what plants produce during photosynthesis – and used scientific language to articulate her understanding accurately.

> K: Okay. Can you explain photosynthesis?
>
> M: Photosynthesis is when the plant breathes out oxygen and breathes in carbon dioxide.
>
> K: What do plants need for photosynthesis?
>
> M: Plants need energy from photons, so they can make glucose. It is a sugar that helps us people get help.
>
> K: What kind of energy do plants need for photosynthesis?
>
> M: Photons.
>
> K: What are they?
>
> M: Um, like, little...little types of particles of energy from the sun.
>
> K: Okay. What else do plants need for photosynthesis?
>
> M: Plants need carbon dioxide.
>
> K: What is carbon dioxide?
>
> M: Bad air that people and animals breathe out of.
>
> K: Okay. What do plants produce during photosynthesis?

M: Plants produce glucose and it helps the people and animals that...oh yeah! first the animals and then after they are humans and, um, we get health by glucose sometimes and that is what keeps us alive.

K: Um, what else do plants produce during photosynthesis?

M: They, um, produce some, um, they produce oxygen because they only breathe in carbon dioxide, but they breathe out oxygen.

K: What is oxygen?

M: Oxygen is a clean air that we breathe in now that helps us breathe and stay alive.

In this excerpt, Maria successfully explained both the process and the byproduct of photosynthesis by using accurate scientific language. She demonstrated a correct understanding that plants need "photons," which are "little types of particles of energy from the sun" and carbon dioxide, which is "Bad air that people and animals breathe out of." She also elaborated that during photosynthesis, "plants produce glucose and oxygen" and even provided an additional explanation that they "helps the people and animals."

By contrast, in his post-interview, Brandon from the Hybrid-Website group was still unable to provide a clear understanding of photosynthesis and continued to struggle with the accurate use of scientific language.

K: Okay, can you explain photosynthesis?

B: Photosynthesis…is…[long pause] photosynthesis is [long pause] I am just forgetting right now. Photosynthesis is…is like…[long pause]… is...photosynthesis is, ummm…is something inside the plant…that helps the plant catch carbon dioxide?

K: What is carbon dioxide?

B: It is…carbon dioxide is something that we breathe out.

K: Okay. So what do plants need for photosynthesis?

B: Carbon dioxide.

K: Anything else?

B: The sun, the water…the soil.

K: What do plants produce during photosynthesis?

B: They produce oxygen. Yeah. No, they produce, they produce what they suck in…No, they produce…carbon…no they produce carbon dioxide.

K: And what is carbon dioxide again?

B: Something that we breathe out.

K: Is there anything else that they produce?

B: They produce…[long pause]…water vapor.

From Brandon's excerpt, it was evident that he remembered some scientific facts from the instruction that he had received, such as the definition of carbon dioxide ("carbon dioxide is something that we breathe out"), but was confused about several sub-concepts of photosynthesis. For example, when he was asked to explain photosynthesis, he thought photosynthesis was "something inside the plant that helps the plant catch carbon dioxide," which indicates that he confused the process itself with the definition of stomata, which absorb carbon dioxide during photosynthesis. He also managed to use scientific language (e.g., carbon dioxide and oxygen), but failed to use it accurately to explain the concepts. When he was asked to explain what plants produce during photosynthesis, he confused the byproduct of photosynthesis with that of respiration, by saying that "[plants] produce water vapor." These excerpts from

Maria and Brandon suggest that teaching science in everyday English and using computer simulation can help ELLs acquire a concrete understanding of scientific concepts and the ability to use specialized language to describe those concepts.

Effects of the Everyday Language Approach and the Simulation Approach in Decreasing Achievment Gaps between ELLs and EPSs

Does teaching science in everyday English, and/or using computer simulation decrease learning gaps between ELLs and EPSs?

To examine whether the Everyday Language apporach and/or the Simulation approach helped decrease the gap between ELLs and EPSs, I compared ELLs' pre- and post-interview scores to those of EPSs across the four conditions. As shown in Figure 7.5, EPSs showed a slightly better understanding of photosynthesis and respiration than ELLs, regardless of the condition on the pre-interview, except for the Hybrid-Website condition. Both ELLs and EPSs in the Hybrid-Website condition achieved the same score on the pre-interview, indicating that they had a similar level of understanding of photosynthesis and respiration prior to the study.

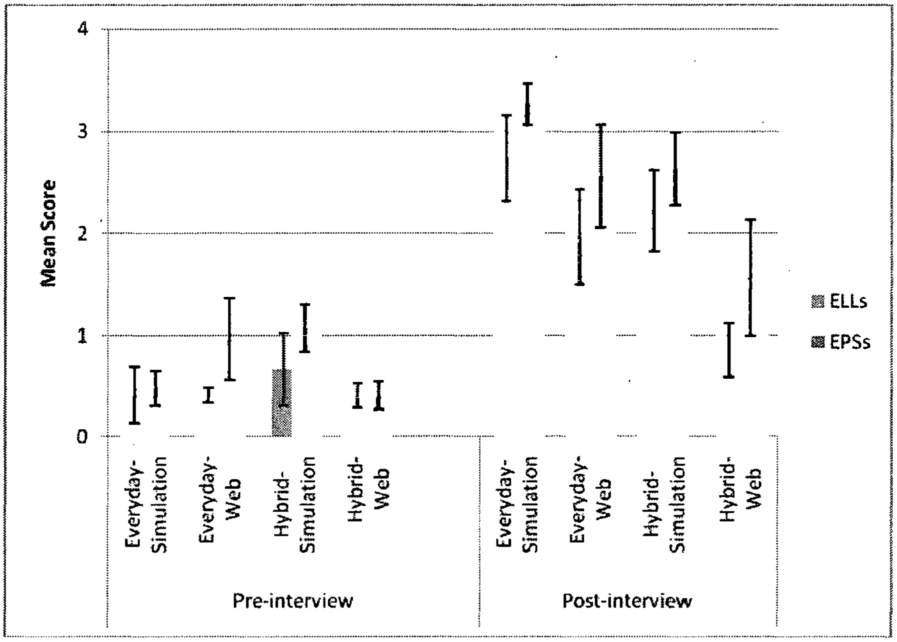


Figure 7.5. Mean Differences between ELLs and EPSs by Treatment Condition.

The descriptive analyses of ELLs' and EPSs' performance on the interviews revealed that, although both EPSs and ELLs demonstrated improved scientific knowledge and a better ability to use accurate scientific language after the treatment, EPSs still outperformed ELLs on the post-interview, regardless of the treatment groups. The gaps between ELLs and EPSs in the Everyday-Website and the Hybrid-Simulation groups can be explained by the initial differences between ELLs and EPSs on the pre-interview. By contrast, despite the lack of prior difference between ELLs and EPSs on the pre-interview, EPSs in the Hybrid-Simulation group performed better than ELLs in the same group on the post-interview. The mean difference between the two groups of students was also relatively noticeable as compared to the other groups, which has been a consistent finding across the measures. Due to the relatively small sample size in each cell, it is statistically difficult to conclude that the Everyday Language and/or the Simulation approach could help decrease the gap between ELLs and EPSs in articulating their scientific ideas in scientific language. Nevertheless, this finding indicates that the potential disadvante of teaching science in hybrid language and using the website on ELLs' science learning, as compared to other teaching approaches. For a more accurate analysis,future research needs to include a larger sample of ELLs and EPSs.

Summary and Discussion

This chapter has reviewed the impact of teaching science in everyday English and using computer simulation on students' understanding of photosynthesis and respiration and their ability to demonstrate their understandings by using appropriate scientific language in spoken form. Consistent with the results of the multiple-choice and open-ended tests, the analyses of students' pre- and post-interviews revealed that the combination of the Everyday Language approach and the Simulation approach was most effective, both in advancing students' understanding of the scientific concepts and in improving their ability to articulate the scientific knowledge in the specialized scientific language. In particular, the combination of these two instructional approaches was significantly more effective in enhancing students' science learning, as compared to the combination of teaching science in hybrid language and using the website. For example, prior to the study, students in both the Everyday-Simulation and the Hybrid-website groups were either unable to provide an answer, or showed a serious misunderstanding of photosynthesis and respiration. However, after the treatment, students in the Everyday-Simulation group not only demonstrated a more elaborate and complete understanding of photosynthesis and respiration, but also used scientific language accurately to articulate their understanding and reasoning.

By contrast, even after the treatment, students in the Hybrid-Website group were still confused about the complex processes of photosynthesis and respiration, particularly how they were related to each other and how they were different from one another. Students in this group also had difficulties making connections between their understanding and the proper use of scientific language. Although many students showed a better ability to recall scientific terms on the post-interview than on the pre-interview, they frequently failed to use the scientific terms accurately to articulate their understanding of the concepts. They were particularly confused about the roles of carbon dioxide and oxygen in photosynthesis and respiration. These results suggest that it is important not only to teach students scientific language to better understand scientific phenomena, but also to provide students with an opportunity to use the newly acquired language by working on scientific tasks with others.

The individual effects of the Everyday-Language approach and the Simulation approach were also significant in advancing students' ability to use scientific language. The use of either approach alone (the Everyday-Website and the Hybrid-Simulation groups) had a similarly positive impact on the improvement of students' understanding of the scientific phenomena and the ability to elaborate their understanding in appropriate scientific language. Like other students, students in both groups started with a fundamental misconception about photosynthesis and respiration; however, they both demonstrated a partially accurate understanding of the concepts after the treatment.

Of particular interest is that students in the Hybrid-Simulation group demonstrated a similar improvement to those in the Everyday-Website group because students taught in hybrid language tended to have a confused understanding of the scientific concepts even after the treatment. This finding implies that the simulation environment can help students modify their misconceptions, thereby increasing their understanding of scientific ideas. One possible explanation is that students in the Simulation condition could easily reconstruct their understanding of the concepts by testing their hypotheses and seeing the immediate results. During the problem-solving activities, I observed that several triads initially formulated incorrect hypotheses reflecting their misconceptions of photosynthesis and respiration. Yet after watching the results of their experiments from the simulation program, they soon realized that their prediction was incorrect and were suddenly able to rectify their previous misconceptions.

Another explanation is that the use of the simulation program activities provided students with more opportunities to share their scientific knowledge with the members of the triad and to learn from each other. Students in the Simulation condition were observed to spend more time in solving each problem because they were allowed to test as many hypotheses as they wanted. During this process, all three members in the triad had multiple opportunities to make predictions, explain the reasoning behind their suggestions, and argue about any conflicts with their triad members, all of which led them to participate in the discussion more actively than those in the Website condition. A more adequate explanation of this finding can be found through a closer examination of students' discussions collected during the problem-solving activities. Even though it was not possible due to current time constraints, in the future, I intend to analyze the videos of group discussions and interactions and explore how the use of computer simulation affected the process of students' knowledge building and their development of scientific language.

Given the positive effects of both the Everyday-Language and the Simulation approaches on students' science learning, I examined whether these approaches had different influences on ELLs' and EPSs' performance. The results revealed that the combination of the Everyday-Language and the Simulation approaches dramatically improved both ELLs' and EPSs' conceptual understanding of scientific phenomena and their use of scientific language correctly, much more than the other three conditions. Although both ELLs and EPSs in the Everyday-Simulation group did not have much knowledge about photosynthesis and respiration prior to the study, they all demonstrated a concrete understanding of the concepts and a better ability to articulate their understanding in appropriate scientific language on the post-interview.

Consistent with the results of overall effects, both ELLs and EPSs in the Everyday-Website and the Hybrid-Simulation groups achieved similar learning gains, demonstrating a partial understanding of the concepts after the treatment. On the post-interview, EPSs in the Everyday-Website and the Hybrid-Simulation performed better than ELLs in those same groups, which can be partially explained by their higher scores on the pre-interview.

The most interesting finding was the learning gap between ELLs in the Everyday-Simulation and the Hybrid-Website groups. ELLs in both groups did not seem to have much understanding of photosynthesis and respiration prior to the study. After the treatment, however, ELLs in the Everyday-Simulation developed both a concrete understanding of the scientific phenomena and a better ability to use scientific language in their responses. By contrast, ELLs in the Hybrid-Simulation group still held clear misconceptions about the processes of photosynthesis and respiration and frequently used scientific language incorrectly. In particular, none of the ELLs in the Hybrid-Simulation group showed a sound understanding of the concepts (a score of 3) in any of the nine interview questions. These results clearly indicate that introducing new concepts about scientific phenomena using unfamiliar scientific language indeed hinders ELLs from understanding both the concept and the language of science. The results also demonstrate that providing ELLs with collaborative activities does not always or necessarily lead to positive outcomes; therefore, it is important to find ways that can enhance their collaborative learning and increase students' scientific discourse during the activities. These findings suggest the strong potential advantage of the combination of the Everyday Language and the Simulation approaches for improving ELLs' science learning.

Although the descriptive analyses revealed that there was a noticeable achievement gap on the post-interview between ELLs and EPSs in the Hybrid-Website group than in the other three groups, it was statistically difficult to determine whether the Everyday Language approach and the Simulation approach helped decrease the gaps between ELLs and EPSs due to the small sample size of the interview participants. For future research, it is important to have a larger number of participants.

CHAPTER 8: CONCLUSION

Given the rapid increase of the ELL population in the United States, it is essential to provide access to high quality education that can help ELLs develop both a strong conceptual understanding of academic subjects and a mastery of the appropriate level of academic language necessary to succeed in school. This is a particularly important challenge in science education because science employs a specialized language that consists of extensive technical vocabulary and complex grammar, fundamentally different from the everyday language which most ELLs use in their everyday lives. The purpose of this study was to explore effective instructional approaches that can improve ELLs' science learning and also help decrease achievement gaps between ELLs and EPSs. The study examined the effects of teaching science in everyday English and using computer simulation on fostering ELLs' scientific knowledge and their ability to use scientific language accurately, compared to EPSs.

In this study, 220 fifth-grade students participated in six one-hour long consecutive science sessions about the concepts of photosynthesis and respiration. For the first three sessions, students received individual science instruction about the scientific concepts using a computer program. Students in the Everyday-Language condition (the Everyday-Simulation and the Everyday-Website groups) were taught in everyday language prior to the introduction of scientific language. By contrast, students in the Hybrid-Language condition (the Hybrid-Simulation and the Hybrid-Website groups) were taught simultaneously in both everyday language and scientific language (hybrid language). For the last three sessions, students were randomly assigned to triads stratified by gender and English proficiency, and each triad participated in a series of problem-solving activities. Students in the Simulation condition (the Everyday-Simulation and the Hybrid-Simulation groups) used a computer simulation program, whereas students in the Website condition (the Everyday-Website and the Hybrid-Website groups) used a simple website. Before and after the study, all students took multiple-choice and open-ended tests, and three students randomly selected from each class participated in pre- and post-interviews.

This concluding chapter highlights the most important findings of this study by returning to the research questions. The following sections then address several limitations of the study, the study's implications for the science education of ELLs, the contributions this research makes to the larger fields of science education and educational technology, and finally, suggestions for future research directions.

Summary of Findings

In this section, I highlight the findings of the study by answering the research questions addressed in Chapter 1.

1. ***Does teaching science in everyday language (the Everyday Language approach), and/or using computer simulation (the Simulation approach) improve students' science learning?***

The findings of the study supported the hypotheses that both the Everyday Language approach and the Simulation approach would be helpful in enhancing all students' science learning. Students taught in everyday English prior to the introduction of scientific language significantly outscored those taught in hybrid language on both the multiple-choice and the open-ended tests, and also showed a better ability to use scientific language to explain their understanding of key concepts during the post-interview. Similarly, students who used computer simulation during problem-solving activities performed significantly better than those who used the website, and also provided more correct answers using appropriate scientific language during the interview. These results provide strong evidence that teaching science in everyday English and using computer simulation can have potential benefits for enhancing students' scientific knowledge and their use of scientific discourse.

In addition to the individual effect of these two instructional approaches, the combination of the Everyday Language and the Simulation approaches had the most significant impact on improving students' scientific knowledge and their use of scientific discourse across the measures. Students in the Everyday-Simulation group significantly outperformed those in the Hybrid-Simulation and the Hybrid-Website groups on both the multiple-choice and the open-ended tests. They even demonstrated a better ability to articulate their understanding of the concepts in scientific language, compared to those in the Everyday-Website group. These findings supported the related hypothesis which proposed that the combination of the Everyday Language and the Simulation approaches would be most successful in increasing students' scientific knowledge and their ability to use scientific discourse.

2. ***Does the Everyday Language approach and/or the Simulation approach Improve ELLs' and EPSs' understanding of scientific phenomena differently?***

As hypothesized, the results of the study demonstrated that the combination of the Everyday Language and the Simulation approaches was most effective in improving ELLs' scientific knowledge and their ability to use scientific language appropriately. An unexpected finding was that the combination of these approaches also significantly helped EPSs master both the new concepts and the related language of science. Both ELLs and EPSs in the Everyday-Simulation group not only demonstrated the greatest learning gains, they also outperformed their counterparts in the other three groups. In particular, they showed a significantly better understanding of scientific concepts and a superior ability to articulate their scientific knowledge in appropriate scientific language, compared to ELLs and EPSs in the Hybrid-Website group.

The analysis of students' interviews consistently showed these same findings. For example, prior to the study, students in both the Everyday-Simulation and the Hybrid-Website groups were either unable to provide an answer, or showed a serious misunderstanding of photosynthesis and respiration. However, after the treatment, students in the Everyday-Simulation group not only demonstrated a more elaborate and complete understanding of photosynthesis and respiration, but also used scientific language accurately to articulate their understanding and reasoning. By contrast, even after the treatment, students in the Hybrid-Website group were still confused about the complex processes of photosynthesis and respiration, particularly how the two concepts were related to each other and how they were different from one another. Students in this group also had difficulties making connections between their understanding and the proper use of scientific language.

Although the combination of the two approaches was beneficial for both ELLs and EPSs, the effects of the Everyday Language approach and the Simulation approach on ELLs' and EPSs' science learning were different. The use of the Everyday Language approach significantly improved both ELLs' and EPSs' science learning, whereas the effects of computer simulation were significantly beneficial for only ELLs. ELLs in the Everyday-Website and the Hybrid-Simulation groups performed similarly, whereas EPSs in the Everyday-Website outscored EPSs in the Hybrid-Simulation group. In other words, employing either the Everyday Language approach or the Simulation approach alone had similarly positive impacts on ELLs' science learning. However, for EPSs, the use of everyday language in science instruction had a more significant effect on improving their science performance.

These findings suggest that the use of everyday language with which students are more familiar can reduce the cognitive loads experienced by both ELLs and EPSs when they learn science. As discussed in Chapter 2, when learning science in the classroom, students need to understand new information of scientific concepts, decode the definitions of new scientific language, make meanings between the concepts and the new language, and articulate their scientific language in both written and spoken form, all of which significantly increase their cognitive loads. This process is much more cognitively challenging for ELLs because they need to use their second language to complete this learning process. Teaching science in everyday language can reduce ELLs' cognitive loads by providing a transitional step to understand both the language and the content of science so that they would not need to receive all new information simultaneously. Although the study did not accurately measure how ELLs' cognitive loads would have changed after the treatment, the findings show evidence that the Everyday Language approach can decrease ELLs' cognitive loads, which eventually can help them more successfully acquire both scientific knowledge and scientific language proficiency. The findings also indicate that teaching scientific language to ELLs does not automatically guarantee their ability to use it appropriately when talking and writing about science. In order to overcome this additional challenge, ELLs should be exposed to a variety of academic contexts in which they are encouraged to use scientific language to communicate their ideas to other people. The positive outcomes of the study demonstrated that the use of computer simulation during problem-solving activities can create more of these opportunities for ELLs to share their understanding and communicate their ideas with peers while experiencing the process of scientific inquiry, compared to the use of the website.

3. ***Does teaching science in everyday English, and/or using computer simulation decrease learning gaps between ELLs and EPSs?***

The findings of the study demonstrate that the use of computer simulation during problem-solving activities helped close the existing achievement gaps between ELLs and EPSs on the open-ended posttests. The analysis of students' performance on the open-ended pretests revealed that, regardless of the treatment condition, EPSs had a significantly better understanding of scientific ideas and a superior ability to elaborate on their understanding by using scientific language when compared to ELLs. However, on the posttest, there were no significant differences between ELLs and EPSs in the Simulation condition (the Everyday-Simulation and the Hybrid-Simulation groups). By contrast, EPSs in the Website condition (both the Everyday-Website and the Hybrid-Website groups) significantly outperformed ELLs in the same groups, and the gaps between EPSs and ELLs became much more apparent. This result is related to my first finding that the use of computer simulation was more effective in improving ELLs' science learning than in improving that of EPSs, and that its use resulted in the smaller achievement gaps between the two groups.

These findings clearly indicate that explicit instruction in scientific language can be powerful for helping both ELLs and EPSs develop a more complete understanding of complex scientific concepts; however, ELLs' use of scientific discourse improves further when they are given multiple opportunities that encourage them to use scientific language for different purposes while engaging in scientific tasks. Through this experience, ELLs are able not only to reconstruct their existing understanding or misunderstanding of certain scientific phenomena; they are also able to improve their scientific language skills.

Overall, the results of this study suggest that both teaching science in everyday language and using computer simulation to solve scientific problems can be beneficial for ELLs' science learning. However, in order for ELLs to master both the content and the language of science, it is important to provide them not only with access to scientific language, but also with multiple opportunities to use this scientific language in different academic contexts because understanding scientific language does not always sufficiently prepare ELLs to be able to use the language to communicate their understanding of scientific ideas appropriately. In this study, ELLs taught in everyday language prior to the introduction of scientific language significantly outperformed ELLs taught in hybrid language. This finding indicates that teaching science in ELLs' everyday language can decrease the cognitive loads generated by multiple layers of science learning, such as understanding new concepts, decoding new scientific language, and making meanings between the two.

Among those ELLs taught in everyday language, ELLs who used computer simulation during problem-solving activities demonstrated both an improved understanding of scientific phenomena and a superior ability to use scientific language accurately for different purposes, compared to ELLs who used the website to solve scientific problems. Of particular interest is that the effects of computer simulation were found to be only significant on ELLs' science learning, whereas the use of computer simulation did not have a significant impact on EPSs' science learning. It is difficult to explain why the computer simulation was only beneficial for ELLs without analyzing the videos of students' interactions with the simulation program and group discussions. However, one possible explanation is that the manipulation function of the computer simulation program provided more opportunities for ELLs to change their misconceptions and to engage in different types of scientific talk using scientific language. For example, in the simulation environment, ELLs could easily reconstruct any misconceptions they previously held by testing different hypotheses and observing the immediate results of their scientific experiments. During this process, ELLs had to develop different hypotheses, manipulate virtual objects to design new experiments, and reason about the results of their experiments, all of which required them to use scientific language. At the same time, ELLs had multiple opportunities to listen to how their English-proficient peers explained scientific concepts and learned from their use of scientific language.

The results of the study also indicate the potential advantage of computer simulation for decreasing the learning gap between ELLs and EPSs. The use of computer simulation was more effective in enhancing ELLs' scientific knowledge and their use of scientific language than the use of the website, but the simulation was not beneficial for EPSs' science learning. Since ELLs' performance improved so markedly with the use of computer simulation, while that of EPSs remained roughly the same, this form of pedagogy resulted in no significant achievement gap between ELLs and EPSs taught in this manner.

Limitations

This study had several limitations that should be addressed for future research. One significant limitation is the small sample size. Although the study involved 220 participants, they were assigned to four different treatment groups, with the result that each cell contained a relatively small sample size of students. The findings from the interview data are particularly affected by the small sample size; these results cannot be generalized because only 24 students participated in the pre- and the post-interviews. Future research must include a larger number of students in order to generalize the relevance of the findings for a broader application in science teaching and learning.

Another limitation that must be addressed before we are able to generalize the findings is the single curriculum unit used in the study. Although results of the study demonstrated strong positive outcomes of the Everyday Language approach and the Simulation approach, since students were only taught about photosynthesis and respiration, the results produced by the study might not be duplicated in other curriculum units or other science domains. In particular, it is important to note that the Everyday Language approach might have had positive effects on improving ELLs' science learning because of the taxonomical nature of biology. However, it might not be appropriate for other science subjects, such as physics, which consists of a number of scientific words that have multiple meanings in different contexts (e.g., volume). Conducting other studies examining the effects of the Everyday Language and the Simulation approaches on multiple science subjects and topics would contribute further to creating a more general context of science teaching and learning for ELLs.

The third limitation of the study involves the test instruments. Since the study did not employ a standardized assessment tool, there is a possibility that the test instruments used in this study might not have accurately measured students' understanding of the core concepts of photosynthesis and respiration. Of particular concern for further research is whether some of the test items might have been too difficult for fifth-grade students, particularly ELLs, due to heavy use of technical terms and unfamiliar questions (e.g., transfer questions). For example, the test items contained a larger amount of scientific vocabulary and complex syntax, compared to standardized science assessments that the students in the study have taken at school. In addition to these syntactical and vocabulary challenges, 33% of the test questions were transfer items that asked students to apply their understanding of scientific concepts to new problems. It must be noted that these are not the typical questions these students would have encountered prior to the study. Future research should incorporate standardized science items to measure students' science learning in a more broadly applicable manner.

The final limitation is the aggregated data for English proficiency. Although each ELL has a different level of English proficiency ranging from CELDT level 2 to level 5, the study did not disaggregate ELLs' English levels in the analysis. Because of the limited sample size in each cell, it was not possible to break ELLs into four different sub-groups based on their CELDT levels and to conduct further analysis on how the Everyday Language and the Simulation approaches affected science learning for ELLs with different levels of English proficiency. In order to understand fully how to improve science learning for all ELLs, future studies should conduct a systematic investigation with a larger number of ELLs with varying CELDT levels that should then be examined for differing performances based on different levels of English proficiency.

Implications

The results of this study revealed that the combination of the Everyday Language and the Simulation approaches was most effective in enhancing not only ELLs' but also EPSs' understanding of scientific phenomena and also had a strong impact on all students' abilities to use scientific language accurately. More specifically, teaching science in everyday English prior to introducing scientific language (the Everyday Language approach) had a positive impact on both ELLs' and EPSs' scientific knowledge and their use of scientific language, regardless of the use of the Simulation approach. By contrast, the use of computer simulation was more beneficial for ELLs' science learning, particularly their ability to articulate scientific knowledge in proper scientific language. These findings suggest a number of implications for our understanding of how to improve science learning for ELLs theoretically, practically, and technologically.

Implications for Theory

One theoretical implication of this study regards the use of everyday language with which ELLs are familiar as a powerful way to decrease the cognitive loads encountered by students when they are learning science. As Cummins argues, academic language proficiency is difficult to acquire not only because it is often used in context-reduced situations with limited contextual cues, but also because it is more cognitively demanding than developing everyday language proficiency. Although there are a few studies exploring how visual support can be helpful for ELLs' science learning, we have had a limited understanding of possible ways to reduce ELLs' cognitive loads generated by scientific language. The findings of this study provide strong evidence that, although there is a clear dichotomy between everyday language and scientific language, using everyday language prior to introducing scientific language in science instruction can help lower ELLs' cognitive loads, thereby helping them better develop not only their understanding of scientific phenomena, but also their ability to use scientific language. This new perspective on the role of everyday language in ELLs' science learning is valuable because scientific language proficiency is a key to scientific literacy as defined by many researchers.

The second theoretical implication involves the use of computer simulation for ELLs' science learning. Despite numerous research studies on technology-enhanced science learning, the potential advantages of technology for ELLs' science learning had not yet been explored before this study. Similarly, the effects of computer simulation in science education have been widely examined across science subjects; however, the role of computer simulation in improving students' ability to use scientific discourse had not yet been examined. Findings from this study suggest that the use of computer simulation during problem-solving activities can be quite effective in helping ELLs practice scientific language in different academic contexts and thereby develop their proficiency in scientific language.

On a related note, the results of the open-ended tests indicated that the use of computer simulation has a potential benefit for decreasing achievement gaps between ELLs and EPSs. Although EPSs significantly outscored ELLs in all four groups prior to the study, on the posttest, ELLs and EPSs in the Simulation condition performed similarly, whereas EPSs in the Website condition still demonstrated a significantly better ability to use scientific language to articulate their scientific ideas than did ELLs.

The results from this study do not clearly explain why only ELLs benefited from computer simulation, but one possible explanation is that ELLs might have needed more support to acquire linguistic proficiency than EPSs and that the use of the simulation program activities created more opportunities to practice scientific language for different functions, such as making predictions. Although future research needs to be conducted in order to understand why computer simulation had a strong positive effect on only ELLs' science learning, the findings of this study do highlight how computer simulation can be used effectively to improve the science literacy of ELLs, who currently remain one of the more frequently-overlooked populations in American schools.

Implications for Educational Practice

This study has numerous implications for educational practice, the first relating to instructional approach. The results suggest that teaching science in everyday language prior to introducing scientific language can be a powerful instructional approach that can assist not only ELLs but also EPSs in developing a deeper understanding of scientific concepts and a better ability to use scientific language appropriately. The results of the study further suggest that rather than teaching complex scientific phenomena and scientific language simultaneously, teachers should observe how ELLs use everyday English to explain scientific concepts and should then focus on integrating ELLs' everyday language into science instruction.

Teachers can also use more contextual cues, such as visualization of scientific phenomena, to help ELLs communicate their ideas in scientific language more effectively. As Cummins argues, although academic language itself is cognitively demanding, it is much harder for ELLs to acquire because it is often used without any contextual support. In other words, when ELLs study science in the classroom, they often need to rely on the language itself to communicate rather than using contextual cues, such as any surrounding objects or gestures. Although it was not the main focus of the study, the potential advantage of visual support for ELLs' science learning was observed during the interviews and students' discussions. For example, during the interview, ELLs often used what they observed from animations and graphics in the computer instruction to articulate their understanding of photosynthesis and respiration. During the problem-solving activities, ELLs also used virtual objects on the screen of the simulation program to communicate their understanding of photosynthesis and respiration with group members. These findings suggest that teachers can use more visuals when explaining complex scientific concepts or during class discussions, particularly visuals that demonstrate those concepts that may not be easily observable in students' everyday lives (e.g., photosynthesis), in order to develop ELLs' conceptual understanding and to assist them in using scientific language more effectively.

Another implication for educational practice is the importance of providing ELLs with multiple opportunities to engage in using scientific language through social interaction, particularly scientific investigation. Currently, many elementary school curricula are centered on math and literacy, rather than science, and most science instruction focuses on teaching students scientific facts, rather than providing students opportunities to engage in inquiry-based activities. Consistent with the results of other studies, this study also shows that ELLs can better develop their proficiency in scientific language and strengthen their understanding of the concepts by working on inquiry projects with their peers. These opportunities are particularly important for ELLs because many of them often do not have such opportunities to engage in scientific discourse and inquiry at home, compared to their middle-class or upper-class English-proficient peers. Therefore, when teaching science to ELLs, teachers should design science inquiry activities which allow ELLs to practice newly acquired scientific language to communicate their scientific ideas with others, while working on scientific investigation.

Despite the potential advantages of scientific investigation activities for ELLs' science learning, many teachers face significant challenges in designing such activities in the classroom because they not only require supplemental materials and access to a fully stocked science lab, but they also take a longer period of time to complete. For example, if a teacher wanted her/his students to conduct an experiment with Bromothymol Blue solution used in this study (see Chapter 3), s/he would have to prepare all materials for each triad, such as water snails and Bromothymol Blue solution—basic preparatory work that would take away from the time the teacher could spend on more complicated pedagogical tasks. Additionally, the experiment would take much longer to complete because in order to test hypotheses multiple times, students need to repeat the entire process, from planning the experiment to executing it, several times. Substituting this lengthy process with computer simulation allows students to conduct multiple scientific experiments easily in the classroom without requiring teachers to spend too much time on planning.

The results of this study indicated that by using computer simulation, teachers can easily design inquiry projects that enable students to conduct scientific experiments and experience the process of scientific inquiry. For example, computer simulation does not require any preparation for supplemental materials because it allows students to manipulate objects and conduct experiments in virtual worlds. Since computer simulation allows students to test different hypotheses and design multiple experiments in a short amount of time, teachers can focus more on students' learning during the activities, rather than worrying about how students handle materials for their experiments. The use of computer simulation can be beneficial for those teachers who are concerned about the amount of time for preparation, or who have limited support to design such activities.

Another benefit of computer simulation is that it can enhance ELLs' use of scientific discourse. ELLs who used the computer simulation during problem-solving activities showed significant improvement in their grasp of both the content and the language of science, compared to ELLs who used the website. They demonstrated a greater ability to use scientific language for different purposes, such as formulating hypotheses and asking questions, while engaging in challenging scientific tasks. The results of the study indicate that teachers can integrate computer simulation into their science instruction to facilitate students' science-oriented discussions and to increase ELLs' use of scientific language in the classroom.

The last educational implication concerns teacher development. As addressed in Chapter 1, although many teachers have strong content knowledge in science subjects, they may not be well trained to provide appropriate instruction to meet the special needs of ELLs. In order for teachers to understand and implement a variety of instructional approaches for ELLs' science learning, it is critical to provide professional development that can enhance teachers' ability to effectively integrate science learning and language development for ELLs. Professional development should help teachers understand the additional challenges that ELLs face in learning science, the significant differences between everyday language and scientific language, and the design and implementation of effective teaching methods for ELLs.

Professional development is particularly important for the use of technology in the science classroom because, despite its potential for ELLs' science learning, many teachers may not know how to integrate technology into their science teaching and may not know what technological resources are available. For example, there are a number of online resources for science lessons, such as games, animations, and tutorials, but using these technological tools for science lessons will require teachers to have considerable knowledge of both the technology environment and their schools' computer resources. Therefore, it is important to provide teachers with workshops regarding the types of software that can be used in their school's computers, a list of available online resources for science subjects, and teach them how they can successfully integrate different technologies for different science activities in their classrooms.

Implications for Instructional Technology

The findings of this study also provide promising implications for the design of instructional technology. The first implication relates to the restriction of a student's control in the program. My observations of students' interactions with the computer-based science programs revealed that, even with limited control to advance to the next page, some students still tried to skip the lessons by randomly clicking before they read the text thoroughly or before the narration was completed. In order to help students engage in every instructional page, it is important to have more restrictions on the amount of control students have in navigating the program. One idea is to provide a formative assessment at the end of each lesson, which requires a student to answer a certain number of questions correctly before they are able to advance to the next lesson. If a student cannot achieve the minimum score, the program will automatically repeat the same lesson. In this way, students will be encouraged to read the text and listen to the narration more carefully so that they do not go through the same lesson twice. Additionally, formative assessments can help students test how much they have learned and can provide their teacher with an opportunity to understand the learning process of each student.

Another implication for the design of instructional technology is for tracking students' interactions with the program. The last step of the computer-based science programs provided a series of virtual experiments associated with photosynthesis and respiration. Some of these experiments asked students to type their predictions, evidence, and conclusions. The written data from students can be logged into a database, which promises to be a great resource for teachers by helping them understand and record each student's thinking process and the types of language they use to articulate their understanding. These written answers from students can also show students' conceptual understanding of scientific phenomena and any misconceptions they hold. Teachers can then use the data to adjust their next lesson, provide individualized instructional support for their students, and design a more effective science curriculum for future students who might benefit from improved lesson plans based on these students' difficulties.

Finally, the study revealed that in order for computer simulation to aid the students' scientific inquiry effectively, it is important to provide more guidance regarding how to use computer simulation for scientific experiments. Since both conducting experiments and using computer simulation were new experiences to most students, even when given prompting questions and guidance from the computer program, some students still had difficulties designing experiments, controlling the simulation program, and engaging in scientific discourse simultaneously. For example, during the last problem-solving activity, which asked students to find relationships between light intensity, the amount of carbon dioxide, and photosynthesis, most triads appeared to be overwhelmed with the type of problem they had to solve and the number of variables they needed to manipulate on the simulation program. Even after watching the instructional video about how to use the simulation program, many students asked for help regarding what they were supposed to do. Some were confused when they were asked to interpret the results of their experiments. This finding indicates that the simulation program should include a help function which students can access when they are lost, and which will provide some basic examples to teach students how to solve similar problems using the same simulation program.

Future Research

The positive results of this study suggest that the combination of teaching science in everyday English and using computer simulation can be an effective tool not only for ELLs' science learning, but also for that of EPSs. The use of computer simulation during problem-solving activities was particularly beneficial for ELLs' science learning and helped decrease the long-standing achievement gaps between ELLs and EPSs. This investigation of the effects of the Everyday Language and the Simulation approaches on ELLs' science learning opens up a variety of research questions in the area of science education for ELLs through the use of innovative technology. In this section, I present specific key areas and research questions for future research.

Impact of Technology-Enhanced Science Learning on a Broad Range of Learners

The results revealed the positive outcomes of the technology-enhanced instruction focusing on the Everyday Language and the Simulation approaches on both ELLs' and EPSs' science learning. Despite the positive outcomes, this study does not yet provide clear evidence of how different features of students' backgrounds (e.g., achievement levels) may have influenced the results of the study. Future studies should examine the impact of these instructional approaches on science learning for ELLs with different English proficiency levels and EPSs with different achievement levels. For this study, I collected students' background information, and I plan to continue analyzing my data to explore whether these approaches have different impacts on low-, middle-, and high-achieving students, both ELLs and EPSs. Similarly, future research should also explore whether the Everyday Language and the Simulation approaches would enhance the science learning of students from different ethnic groups.

Assessment of Different Aspects of Science Learning

As noted in Chapter 3, there are three dimensions of science learning: conceptual, linguistic, and social. In order to have a more complete understanding of what aspects of science learning the Everyday Language and the Simulation approaches can enhance, future research needs to consider each of these three dimensions of science learning. For example, the analysis of group discussions and interactions during problem-solving activities can provide powerful insights into what types of linguistic resources ELLs and EPSs used while working on scientific tasks, and how the use of simulation modified students' misconceptions of certain scientific concepts. I plan to analyze the videos of group discussions collected during problem-solving activities to explore how the use of computer simulation affected ELLs' and EPSs' use of scientific discourse.

A related area for future research is the impact of the instructional approaches on different types of scientific knowledge. Although this study analyzed only students' overall scores on the multiple-choice and open-ended tests, future research should look closely at three types of questions (retention, inference, and transfer) and explore whether the Everyday Language and the Simulation approaches are more effective in increasing any particular type of scientific knowledge. Such a study would help us better understand how to enhance different types of scientific knowledge for ELLs and EPSs through the Everyday Language and the Simulation approaches.

Integration of Computer Technology into the Science Classroom for ELLs' Science Learning

A particularly interesting area for further exploration is the integration of computer technology into the science classroom with the goal of improving ELLs' science learning. Despite the large number of studies examining the effects of technology-enhanced science learning, there are only two studies exploring how computer technology can be used in the classroom to enhance ELLs' science learning. In addition to the positive outcomes of this study, my observations of students' interactions with the computer programs revealed that multiple representations of scientific concepts in the computer environment, such as narration, text, and animation, were particularly helpful to enhance ELLs' understanding of scientific phenomena and their scientific language proficiency. For example, describing photosynthesis and respiration through animation helped students understand the complex processes of these phenomena. When the program introduced new scientific terms, ELLs could learn how to read them by listening to the narration. Future studies can explore which modes of representation in multimedia, such as animation and narration, can be most effective in improving ELLs' science learning. Future research should also focus on developing web-based science lessons or interactive materials for scientific inquiry, such as simulation, for those students who do not have many opportunities to practice science in their school.

Another important benefit of integrating computer technology into science teaching is that it can keep students engaged throughout the science instruction. A variety of interactive activities which resemble computer games excited students and increased their interest in the instruction. Continued research is necessary to investigate which factors of computer learning environments and what types of instructional technology are most effective for ELLs' science learning. On a related note, the relationship between students' engagement in the instruction and their achievement must also be investigated. Future research also needs to explore how teachers integrate different technologies into their science teaching. In order to prevent teacher effects in this study, all six sessions were taught by a computer program, and a teacher had only limited interaction with students as a facilitator. Because of this limitation, it was not possible to investigate the role teachers would have played in the integration of technology into the science instruction. In particular, the absence of teacher-student interactions during the problem-solving activities might have affected the results of the study because students did not receive any feedback or guidance regarding the design of their scientific experiments. Further studies should explore how teachers use computer simulation for different purposes, such as developing students' scientific knowledge or their inquiry skills, and how the use of computer simulation mediates student (particularly ELL)-teacher discourse.

In conclusion, my work offers a unique perspective on the role of everyday language in learning science as a medium to reduce ELLs' cognitive load and shows how to bridge the differences between everyday English and scientific language. This study also fills the gap in the literature by examining the impact of technology on ELLs' science learning through an experimental study. This contribution is valuable because most contemporary studies addressing the challenges that ELLs face in learning science consist primarily of anecdotal case studies or ethnographic studies. Similarly, despite the large number of studies examining the use of technology in science education, the effects of technology on ELLs' science learning have received little attention. Additionally, my research has implications for a new technology-enhanced pedagogy that can help ELLs and EPSs master both the content and the complex language of science. Moving beyond the science classroom, my study also contributes to our understanding of how the use of computer simulation can enhance students' ability to use scientific language accurately to communicate their scientific ideas.

APPENDIX A: WORKBOOK FOR PROBLEM-SOLVING ACTIVITIES

Photosynthesis & Respiration Workbook

Please write down your names.

Member Name:______________________________

Member Name:______________________________

Member Name:______________________________

Before you start using the computer program, you need to READ all the directions and questions to each other CAREFULLY and ALOUD.

Please read each question and first come up with an answer by your self. Then talk about your answers with your team members.

If your team members have different ideas from yours, please talk about whose answer is the best one until all three members agree with one idea.

If you have a question, please raise your hand quietly.

Experiment 1: What Is the Relationship Between Plants and Humans?

Do you think plants are important to humans and animals? Do you think humans and animals are important to plants? Let's find out their relationship by doing some experiments! Think carefully and find answers for each question in complete sentences. Use scientific words like scientists do.

1. Before you start the computer program, imagine you put a mouse ALONE in the glass box and closed it. What do you think would happen to the mouse?

Why do you think so?

2. Now test your prediction. Drag and drop the mouse into the glass box and click the test button. What happened to the mouse?

Why do you think it happened?

3. Before you start another experiment, imagine you put the plant ALONE into the glass box and watered it. What do you think would happen to the plant?

Why do you think so?

4. Now test your prediction. Drag and drop the plant into the glass box and click the test button. Do not forget to water your plant. What happened?

Why do you think it happened?

5. Please find out a way to keep both the plant and the mouse alive in the glass box.

Why do you think your way would keep both the plant and the mouse alive? Explain your answer.

6. Suppose that you put the mouse, the plant, and water in the box, but the mouse ate all of the leaves off the plant. What do you think would happen to the mouse when there were no leaves?

Why do you think so?

Experiment 2: Candles and Gases

Do you know that a candle **produces** a gas when it burns? Do you know that a candle **needs** a gas when it burns? You are going to do some fun experiments and find out!

Please read questions before you start doing experiments. Think carefully and find answers for each question in complete sentences. Use scientific words like scientists do.

Your first mission is to find out what kind of gas a candle produces when it burns. Use the computer program to figure out what gas the candle makes when it burns.

1. From your experiment, can you tell what gas a candle produces when it burns?

2. How do you know that a candle produces this gas when it burns? What evidence supports your statement?

3. How did you find out what kind of gas a candle produces when it burns? Write down each of the steps you used in the test you made to find out your answer.

1) ______________________________

____

2) ______________________________

____

3) ______________________________

____

4) ______________________________

____

Your second mission is to find out what kind of gas a candle uses when it burns. Use the computer program to figure out what gas the candle uses when it burns.

4. From your experiment, can you tell what gas a candle needs when it burns?

5. How do you know that a candle uses this gas when it burns?? What evidence supports your statement?

6. How did you find out what kind of gas a candle uses when it burns? Write down each of the steps you used in the test you made to find out your answer.

1) ______________________________

____

2) ______________________________

____

3) ______________________________

____

4) ____

Experiment 3: Why Is Photosynthesis Important?

You will do some experiments with water plants and water snails that can breathe in the water. Please read questions before you start doing your experiment.

Complete the worksheet as you are doing your experiments. Think carefully and find answers for each question in complete sentences. Use scientific words like scientists do.

1. The color of the Bromothymol Blue in each tube is GREEN. What gas makes the Bromothymol Blue green?

2. How can you change the color of the Bromothymol Blue from green to BLUE?
Drag and drop snails and water plants into the tubes and find TWO DIFFERENT ways to change the color of the bromothymol blue from green to BLUE.

Original Color	Changed Color	Number of Snails you put in the tube	Number of Plants you put in the tube	Did you put light?
Green	Blue			Yes or No
Green	Blue			Yes or No

3. Why do you think the color of the Bromothymol Blue turned blue?

4. How can we keep the color of the Bromothymol Blue GREEN?
Drag and drop snails and water plants into the tubes and find TWO DIFFERENT to keep the color of the Bromothymol blue Green.
!! Hint! You must put something into the tube.

Original Color	Changed Color	Number of Snails you put in the tube	Number of Plants you put in the tube	Did you put light?
Green	Stayed Green			Yes or No
Green	Stayed Green			Yes or No

5. Why do you think the color of the solution stayed green?

Experiment 4: Light Intensity, Carbon Dioxide, and Photosynthesis

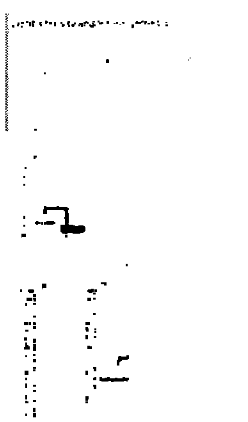
Light Intensity (How strong the light is) and the Rate of Photosynthesis [Read carefully]

You've learned that plants need light to grow. Today you will find out **how much light** plants need to grow fast. In other words, you will find out how light can change how fast a plant produces oxygen **(the rate of photosynthesis)**.

Because plants produce **oxygen** during photosynthesis, you can measure **how fast oxygen is produced** and this will tell you **the rate of photosynthesis**.

In your computer program, you can change ***light intensity (how strong the light is)*** *and the amount* of **carbon dioxide**. HOWEVER, you should only change ONE of these two things at a time. Because you are interested in how light can change the rate of photosynthesis, you should only change the light intensity.

EXPERIMENT 1 ***Be sure to follow these directions.***



1. Click the **Graph** Tab. Be sure that you pick the **light intensity** for the two choices you see above the graph.
2. Set your **Carbon Dioxide** level at **1.0%** (on the side of your graph).
3. Set your **Light Intensity** at 0.0% and click the record button.
4. Increase your **Light Intensity** to 10%. Click the record button.
5. Repeat these steps at each light intensity you can (20%, 30%, 40%, and 50%). Be sure to click the button **every light intensity**.
6. Copy the data from the graph on the graph page.

Hint: You may want to connect dots.

4

EXPERIMENT 1: QUESTIONS

1. Look at your graph. As you increased light intensity, how fast did the plants produce oxygen (the rate of photosynthesis)? Does increasing light intensity always increase the amount of oxygen produced? Be sure to discuss it with your teammates and describe what you see in the graph.

2. When did the oxygen stop growing and stay the same?

If you've answered all the questions, clear your data.

EXPERIMENT 2 ***Be sure to follow these directions.***

- Now we will repeat Experiment 1 with **2% Carbon Dioxide** instead of 1% carbon dioxide.

1. Click the **Graph Tab**. Be sure that you pick the **light intensity** for the two choices you see above the graph.
2. This time, set your **Carbon Dioxide** level at **2.0%** (on the side of your graph).
3. Set your **Light Intensity** at 0.0% and click the record button.
4. Increase your **Light Intensity** to 10%. Click the record button.
5. Repeat these steps at each light intensity you can (20%, 30%, 40%, and 50%). Be sure to click the button **every light intensity**.
6. Copy the data from the graph on the graph page.

Hint: You may want to connect dots.

EXPERIMENT 2: QUESTIONS

1. Look at your graph. As you increased light intensity, how fast did the plants produce oxygen (the rate of photosynthesis)? Does increasing light intensity always increase the amount of oxygen produced? Be sure to discuss it with your teammates and describe what you see in the graph.

2. When did the oxygen stop growing and stay the same?

If you answer all the questions, clear your data.

EXPERIMENT 3 ***Be sure to follow these directions.***

- Now we will repeat Experiment 1 with **3% Carbon Dioxide** instead of 1% carbon dioxide.

1. Click the **Graph Tab**. Be sure that you pick the **light intensity** for the two choices you see above the graph.
2. Set your **Carbon Dioxide** level at **3.0%** (on the side of your graph).
3. Set your **Light Intensity** at 0.0% and click the record button.
4. Increase your **Light Intensity** to 10%. Click the record button.
5. Repeat these steps at each light intensity you can (20%, 30%, 40%, and 50%). Be sure to click the button **every light intensity**.
6. Copy the data from the graph on the graph page.

Hint: You may want to connect dots.

EXPERIMENT 3: QUESTIONS

1. Look at your graph. As you increased light intensity, how fast did the plants produce oxygen (the rate of photosynthesis)? Does increasing light intensity always increase the amount of oxygen produced? Be sure to discuss it with your teammates and describe what you see in the graph.

2. When did the oxygen stop growing and stay the same?

3. Compare the three graphs from Experiments 1, 2, and 3. What do you see from your graph? Do they have the same patterns or shapes? Explain the patterns of the three graphs.

4. Based on Experiments 1, 2, and 3, how can you explain the relationship between the light intensity and the rate of photosynthesis?

Hint: Be sure to give me specific details.

5. Imagine you are growing plants for a science fair contest. Whoever can grow plants the fastest will win the science fair prize.

Your plants will grow faster if you help them produce more oxygen. You can spend some extra money on light and carbon dioxide so that you can grow plants faster.

Each light intensity costs $10. For example, if you want 20% light intensity, it will be $20. If you want 50% light intensity, it will be $50.

Each carbon dioxide level also costs $10. For example, if you want 1% carbon dioxide, it will be $10. If you want 4% carbon dioxide, it will be $40.

You've given **$100** to grow your plants for the science fair contest. You want to grow your plants the fastest **without spending more money than you need to.**

If you want to grow your plants the fastest and do not spend more money than you need to, how much light and how much carbon dioxide would you give to your plants?

Light Intensity: _________ (%) & Carbon Dioxide: _____________ (%)

Why do you think so? Explain your answer.

How much would this cost you?

Now you can clear your data!

Carbon Dioxide and the Rate of Photosynthesis

You've just learned about how to find the relationship between light intensity (how strong the light is) and the rate of photosynthesis (how fast plants produce oxygen). Can you find **the relationship between the amount of carbon dioxide and the rate of photosynthesis** without new help?

You've done all these experiments. Now you get to design your own experiment! You can look back the other experiments if you think it will help you.

You will investigate how the amount of **carbon dioxide** changes how fast a plant produces oxygen (the rate of photosynthesis). You will also find out the relationship between the amount of carbon dioxide and the rate of photosynthesis.

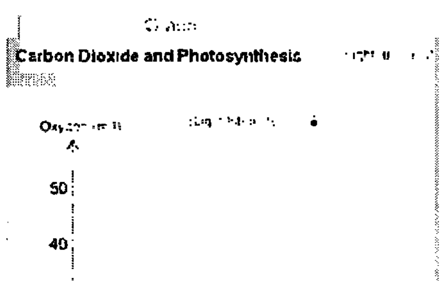
Because **oxygen** is a product of photosynthesis, we can measure how fast plants produce oxygen and this will tell you **the rate of photosynthesis**.

Repeat the experiment you just did on light intensity. But this time, find out how the **carbon dioxide** changes how fast plants oxygen (the rate of photosynthesis).

In your computer program, you can change **light intensity (how strong the light is)** and the amount of **carbon dioxide**. HOWEVER, you should only change ONE of these two things at a time. Because you are interested in how **light** can change the rate of photosynthesis, you should only change the light intensity.

Design your own experiment to find out the relationship between the amount of carbon dioxide and the rate of photosynthesis.

When you click the **Graph Tab**, be sure that you pick the **carbon dioxide** for the two choices you see above the graph.



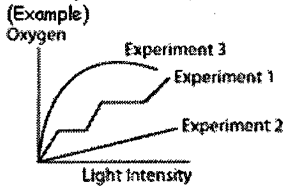
Questions

1. As you increased carbon dioxide, how fast the plants produced oxygen (the rate of photosynthesis)? Does increasing carbon dioxide always increase the amount of oxygen produced? Discuss it with your teammates and describe what you see in the graph.

2. Are there certain carbon dioxide changes that do not increase the amount of oxygen? When did the oxygen stop growing and stay the same?

3. Look at your graph. What does it look like? Draw it below.
!! Hint: You can copy the dots from the graph and connect them.

4. Compare three graphs from Experiments 1, 2, and 3. Draw all three shapes on the same graph from Experiment1, Experiment 2, and Experiment 3. What do you see from your graph?
(Example)



Q4. Based on Experiments 1, 2, and 3, what can you say about carbon dioxide and the rate of photosynthesis?

Q5. Imagine you are growing plants for sale. You could grow plants faster if you help plants produce oxygen more. You can spend some extra money on light and carbon dioxide so that you can grow plants faster. You want to spend the least amount of money possible for the best result.

If you want to grow plants faster but spend the least amount of money, how much light and how much carbon dioxide should you give to your plants?

Light Intensity: _________(%) & Carbon Dioxide: _____________(%)

Why do you think so? Explain your answer.

APPENDIX B: MULTIPLE-CHOICE TEST

Your Full Name: ______________________________ Are you a BOY or a GIRL (circle one)?
Home Language: ______________________________

Read questions carefully and think hard. Please do your best.

#	QUESTION			ANSWER CHOICES
1	Which part of the plant takes in carbon dioxide during photosynthesis?		A	chloroplast
			B	stomata
			C	roots
			D	xylem

2	Plants need energy for photosynthesis. Where does the energy for photosynthesis come from?		A	carbon dioxide
			B	water
			C	photons
			D	oxygen

3	Which one of these sentences is correct?		A	The chloroplast is where plants make glucose.
			B	The chloroplast is a part that takes in water.
			C	The chloroplast is a tube that carries glucose from the leaf to other parts of the plant.
			D	The chloroplast is the place where carbon dioxide enters the plants.

4	What is the main function of roots?		A	absorbing carbon dioxide from the air
			B	absorbing water from the soil
			C	absorbing energy from light
			D	carrying water from the soil to the leaves

5	What is the green pigment that captures energy from light?		A	stomata
			B	phloem
			C	xylem
			D	chlorophyll

6	Which one of these sentences is correct?		A	Photons are the small particles of light.
			B	Photons are small holes in the leaf.
			C	Photons are green pigments inside of the leaf.
			D	Photons are food that plants make.

7	Fill in the blanks: Plants need water, __(a)__, and __(b)__ in order to produce glucose.		A	(a) dirt, (b) carbon dioxide
			B	(a) photons, (b) carbon dioxide
			C	(a) oxygen, (b) carbon dioxide
			D	(a) oxygen, (b) photons

8	Which one of these sentences is correct?		A	During the day, only photosynthesis occurs.
			B	During the day, only respiration occurs.
			C	At night, only photosynthesis occurs.
			D	At night, only respiration occurs.

1

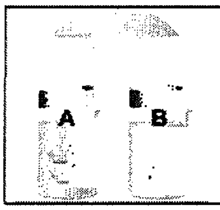
9	Fill in the blanks: During photosynthesis, plants give off __(a)__, and during respiration, plants give off __(b)__.		A	(a) carbon dioxide, (b) carbon dioxide
			B	(a) carbon dioxide, (b) oxygen
			C	(a) oxygen, (b) oxygen
			D	(a) oxygen, (b) carbon dioxide

10	During respiration, what do plants make?		A	oxygen and glucose
			B	oxygen and water vapor
			C	carbon dioxide and water vapor
			D	carbon dioxide and glucose

11	Which gas(es) do plants breathe in during the day when there is light?		A	carbon dioxide only
			B	oxygen only
			C	carbon dioxide and oxygen
			D	none

12	Which one of these sentences is <u>**NOT** true</u>?		A	Phloem carries water to the leaf, while xylem carries glucose to other parts of the plant.
			B	Respiration happens all the time, while photosynthesis happens when there is light.
			C	Plants make glucose during photosynthesis.
			D	Plants take in water from the soil.

[Read carefully] Bromothymol blue is a special dye. It changes its color when it is in water with <u>carbon dioxide</u>. Bromothymol blue is **BLUE** <u>at first</u>, but if there is <u>some carbon dioxide</u>, it turns **GREEN**. If there is <u>a lot of carbon dioxide</u>, it turns **YELLOW**. If there is <u>no carbon dioxide</u>, it goes back to being **BLUE**.



Tube A has two water snails in water, and Tube B has two water plants in water. A scientist has dropped bromothymol blue and added some <u>carbon dioxide</u>, so the color of the water in both tubes is now **GREEN**.

Both tubes are all closed, so no air can get in or out of the tubes.

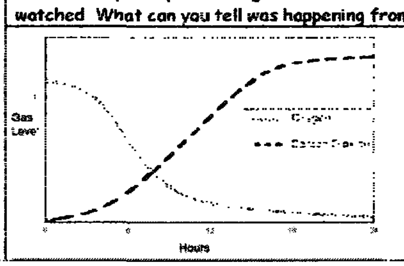
13	The scientist puts both tubes **under the sun**. After 24 hours, what will the color of the water be in **Tube A**?		A	green (it won't change)
			B	yellow
			C	blue
			D	colorless (clear)

14	The scientist puts both tubes **under the sun**. After 24 hours, what will the color of the water be in **Tube B**?		A	green (it won't change)
			B	yellow
			C	blue
			D	colorless (clear)

15	Imagine Tube B will be kept outside under the sun for several days. When will the tube have the smallest amount of oxygen?		A	just before sunset
			B	midnight
			C	just before sunrise
			D	mid-afternoon

16	Which of these can be used to measure the rate of photosynthesis?		A	Amount of light (%)
			B	Amount of oxygen produced (mL/hr)
			C	Amount of carbon dioxide (%)
			D	All of the above

17 A scientist put a plant in a glass box and watched it for 24 hours. The graph below shows what she watched. What can you tell was happening from this graph?



	A	Respiration was happening
	B	Photosynthesis was happening.
	C	Both respiration and photosynthesis were happening.
	D	Nothing was happening.

18 A scientist wants to find the best amount of light for growing plants. He grows plants in four test groups as shown in the table below. What was wrong with the experiment?

Group	Amount of Carbon Dioxide	Amount of Light
A (10 plants)	1%	0%
B (10 plants)	2%	50%
C (10 plants)	3%	20%
D (10 plants)	4%	30%

	A	He should only grow one plant in each group.
	B	He should only change the amount of light for each group.
	C	He should add another group with 0% of carbon dioxide.
	D	There is nothing wrong with the experiment.

APPENDIX C: OPEN-ENDED TEST

Open-Ended Test

19. In the space below, explain what each of these plant parts does (not what each of them is). Even if you are not sure of your ideas, you will get some points if you do your best to write down some thoughts about what they do.

What does a chloroplast do?	
What do stomata do?	
What do roots do?	
What does a chlorophyll do?	

3

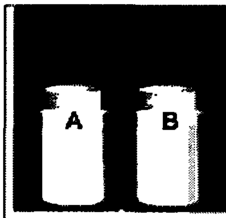
20. **Using scientific words**, explain everything that a stem does. Give as many details as possible. Even if you are not sure of your ideas, you will get some points if you do your best to write down some thoughts.

21. Can you compare photosynthesis and respiration like a scientist? **Using scientific words**, explain **FOUR differences between photosynthesis and respiration**. Even if you are not sure of your ideas, you will get some points if you do your best to write down some thoughts.
[Example: Photosynthesis does....., but respiration does....]

Difference 1
Difference 2
Difference 3
Difference 4

22. **Using scientific words**, explain why photosynthesis is important to humans. Please give as many details as possible. Even if you are not sure of your ideas, you will get some points if you do your best to write down some thoughts.

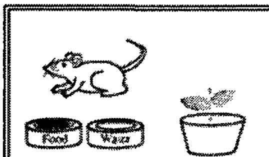
23. Bromothymol blue is a special dye that changes its color when it is in water with carbon dioxide. Bromothymol blue is **BLUE** at first, but if there is some carbon dioxide, it turns **GREEN**. If there is a lot of carbon dioxide, it turns **YELLOW**. If there is no carbon dioxide, it goes back to being **BLUE**.



Tube A has two water snails in water, and Tube B has two water plants in water. A scientist has dropped bromothymol blue and added some carbon dioxide, so the color of the water in both tubes is now **GREEN**. Both tubes are all closed, so nothing can get in or out of the tubes.

A scientist puts both tubes in the **DARK** place where there was **NO LIGHT**. **After 24 hours, what will the color of the water be in Tube A and Tube B? Using scientific words, explain your answer.** Provide as many details as possible. Even if you are not sure of your ideas, you will get some points if you do your best to write down some thoughts.

Tube A will be	because
Tube B will be	because



24. A scientist put some green plants and a mouse in a glass box. She also put enough water and food for the mouse, and enough water for the plants. She closed the box so **no air could get in the box**. She put the box outside where it would get some **sunlight**.

After 24 hours, what do you think happened to the mouse and the plants? Why do you think so? Explain your answer by using scientific words. Provide as many details as possible. Even if you are not sure of your ideas, you will get some points if you do your best to write down some thoughts.

The plants	because
The mouse	because

APPENDIX D: INTERVIEW PROTOCOL

1. Can you explain photosynthesis? What do plants need for photosynthesis? What do they produce during photosynthesis? [What does it mean? (any scientific word)]

2. Can you explain respiration? What do plants need for respiration? What do they produce during respiration? [What does it mean? (any scientific word)]]

3. Can you explain why photosynthesis is important to humans?

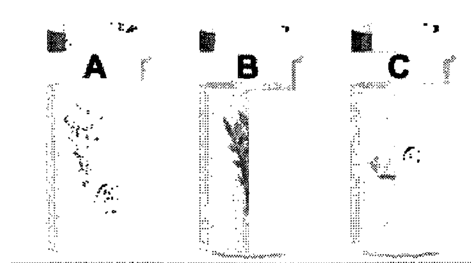
4. Can you explain how carbon dioxide goes into the plant during photosynthesis? [is there any particular plant part that takes in carbon dioxide?]

5. Can you explain how respiration is different from photosynthesis?

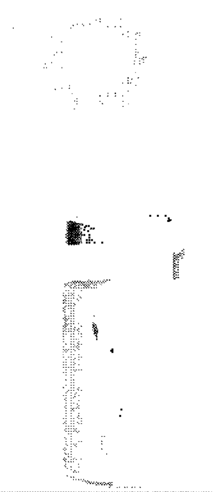
6. How do plants and humans help each other out?

7. Bromothymol blue is a special dye that changes its color when there is carbon dioxide. Bromothymol blue is blue in color, but when there is some carbon dioxide, it becomes green. When there is a lot of carbon dioxide, it becomes yellow. There are three tubes. In tube A, I put a water snail and a water plant. In tube b, I put a water plant. And in tube c, I put a water snail. I have dropped some Bromothymol blue into each tube and I have also added carbon dioxide to each tube. So they are all green now. I will keep these tubes under light for 24 hours. After 24 hours, what do you think the color of the water in each tube will be? Why?

Carbon dioxide level	**Bromothymol Blue**
No Carbon dioxide	Blue
Some Carbon dioxide	Green
A lot of Carbon dioxide	Yellow



8. You have water plants in a tube. You added Bromothymol Blue and added carbon dioxide. So it is green color. Imagine you will keep this tube outside under the sun for several days. When will the tube have the smallest amount of oxygen?

	a. Just before sunset b. Midnight c. Just before sunrise d. Mid-afternoon

9. I put a large water plant and a snail in a glass box. I closed the glass box so nothing could go in or out of the box. Then, I kept the glass box for several days under the sun. After several days, I opened the box and I found that both the plant and the snail were alive and they appeared to be healthy. Why do you think it happened?

REFERNCES

American Association for the Advancement of Science. (1990). *Science for All Americans*. New York: Oxford University Press.

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.

Barnett, M., Wagner, H., Gatling, A., Anderson, J., Houle, M., & Kafka, A. (2006). The Impact of Science Fiction Film on Student Understanding of Science. *Journal of Science Education and Technology, 15*(2), 179-191.

Ballenger, C. (1997). Social Identities, Moral Narratives, Scientific Argumentation: Science Talk in a Bilingual Classroom. *Language and Education, 11,* 1–14.

Barron, B. (2000). Achieving Coordination in Collaborative Problem-Solving Groups. *The Journal of the Learning Sciences, 9,* 403–436.

Brown, A. L. (1992). Design Experiments: Theoretical and Methodological Challenges in Creating Complex Interventions in Classroom Settings. *The Journal of The Learning Sciences, 2*(2), 141–178.

Brown, B., & Ryoo, K. (2008). Teaching Science as a Language: A "Content-First" Approach to Science Teaching. *The Journal of Research in Science Teaching, 45*(5), 529-553.

Brünken, R.; Plass, J. L.; Leutner, D. (2004) Assessment of Cognitive Load in Multimedia learning with Dual-task Methodology: Auditory Load and Modality Effects. *Instructional Science*, *32*, 115-132.

Buxton, C. (1999). Designing a Model-based Methodology for Science Instruction: Lessons from a Bilingual Classroom. *Bilingual Research Journal,23* (2–3). 147-177.

Buxton, C., Lee, O., & Santau, A. (2008). Promoting Science Among English Language Learners: Professional Development for Today's Culturally and Linguistically Diverse Classrooms. *Journal of Science Teacher Education, 19*(5), 495-511.

Cobb, P., diSessa, A., Lehrer, R., Schauble, L. (2003). Design Experiments in Educational Research. *Educational Researcher, 32*(1), 9–13.

Coleman, F. M. (1997). Software Simulation Enhances Science Experiments. *T.H.E. Journal, 25*, 56-58.

Collins, A. (1992). Toward a Design Science of Education. In E. Scanlon&T. O'Shea (Eds.), *New Directions in Educational Technology* (pp. 15–22). New York: Springer-Verlag.

Cummins, J. (2003). BICS and CALP. In *J. Cummins Bilingual Education Web*, htttp://www.iteachilearn.com/cummins/bicscalp.html: University of Toronto.

Cummins, J. (2000). *Language, Power and Pedagogy: Bilingual Children in the Crossfire*. Clevedon, UK: Multilingual Matters, Ltd.

Cummins, J. (1979). Cognitive/Academic Language Proficiency, Linguistic Interdependence, the Optimum Age Question and Some Other Matters. *Working Papers on Bilingualism, 19*, 121-129.

Cummins, J. (1981). Empirical and Theoretical Underpinnings of Bilingual Education. *Journal of Education.*

Dede, C. (2004). If Design-Based Research is the Answer, What is the Question? *Journal of the Learning Sciences, 13(*1), 105-114.

Dwyer, W. M., & Lopez, V. E. (2001). *Simulations in the Learning Cycle: A Case Study Involving "Exploring the Nardoo".* Paper presented at the National Educational Computing conference proceedings, Chicago, IL.

Echevarria, J., Short, D., & Powers, K. (2003). School Reform and Standards-based Education: How do Teachers Help English Language Learners? *(Technical report).* Santa Cruz, CA: Center for Research on Education, Diversity & Excellence

Fang, Z. (2005). Scientific Literacy: A Systemic Functional Linguistics Perspective. *Science Education, 89*(2), 335-347.

Gee, J. P. (1992). *The Social Mind: Language, Ideology, and Social Practice.* New York: Bergin & Garvey.

Gee, J. P. (2005). Language in the Science Classroom: Academic Social Languages as the Heart of School-based Literacy. In R. Yerrick & W-M. Roth (Eds.), *Establishing Scientific Classroom Discourse Communities: Multiple Voices of Teaching and Learning Research* (pp. 19–37). Mahwah, NJ: Lawrence Erlbaum Associates.

Hakuta, K., Butler, Y.G., & Witt, D. (2000). How Long does it Take English Learners to Attain Proficiency? *University of California Linguistic Minority Research Institute Policy Report 2000-1.* Santa Barbara, CA: University of California-Santa Barbara.

Hampton, E, & Rodriguez, R. (2001). Inquiry Science in Bilingual Classrooms. *Bilingual Research Journal, 25*(4). 461-478.

Hansen, J. A., Barnett, M., & MaKinster, J. G. (2004). The Impact of Three-dimensional Computational Modeling on Student Understanding of Astronomy Concepts: A Quantitative Analysis. *International Journal of Science Education,26*(11), 1365-1378.

Homer, Bruce., Plass, Jan., & Balke, Linda. (2008). The Effects of Video on Cognitive Load and Social Presence in Multimedia-learning. *Computers in Human Behavior, 24*(4), 786-797.

Jonassen, D. H. (1996). *Computers in the Classroom: Mind tools for critical thinking.* Columbus, OH: Merrill/Prentice-Hall.

Kirschner, P.A. (2002) Cognitive Load Theory: Implications of Cognitive Load Theory on the Design of Learning. *Learning and Instruction, 12*(1), 1–10.

Lee, O. (2005). Science Education With English Language Learners: Synthesis and Research Agenda. *Review of Educational Research, 75*(4), *491-530.*

Lee, O., & Fradd, S., H. (1996). Literacy Skills in Science Learning among Linguistically Diverse Students. *Science Education, 80*(6), 651-671.

Lee, O., Fradd, S. H., & Sutman, F. X. (1995). Science Knowledge and Cognitive Strategy Use among Culturally and Linguistically Diverse Students. *Journal of Research in Science Teaching, 32,* 797–816.

Lee, O., Luykx, A., Buxton, C. A., & Shaver, A. (2007). The Challenge of Altering Elementary School Teachers' Beliefs and Practices Regarding Linguistic and

Cultural Diversity in Science Instruction. *Journal of Research in Science Teaching*, 44(9), 1269 – 1291.

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

Mercer, N. & Wegerif, R. (1999). Is 'Exploratory Talk' Productive Talk? In K. Littleton & P. Light (eds.), *Learning with Computers: Analyzing Productive Interaction* (pp. 79-101). New York: Routledge.

Merino, B., & Hammond, L. (2001). How do Teachers Facilitate Writing for Bilingual Learners in "Sheltered Constructivist" Science? *Electronic Journal in Science and Literacy, 1*(1).

Moje, E., Collazo, T., Carillo, R., & Marx, R. W. (2001). "Maestro, What is Quality?": Examining Competing Discourses in Project-based Science. *Journal of Research in Science Teaching, 38*(4), 469–495.

Moreno, R. (2004). Decreasing Cognitive Load in Novice Students: Effects of Explanatory versus Corrective Feedback in Discovery-based Multimedia. *Instructional Science*, *32*, 99–113.

National Assessment of Educational Progress (2006). *The Nations' Report Card, 2005.* Retrieved May 24, 2006, from http://nationsreportcard.gov/science_2005/

National Clearinghouse for English Language Acquisition. (2007). *The Growing Numbers of Limited English Proficient Students*. Washington, DC: Author. Retrieved January 16, 2008 from http://www.ncela.gwu.edu/policy/states/reports/statedata/2005LEP/GrowingLEP_0506.pdf.

National Commission on Excellence in Education. (1983). *A Nation at Risk.* Washington, D.C.: U.S. Government Printing Office.

National Research Council. (1996). *National Science Education Standards.* Washington, D. C: National Academy Press.

Norris, S.P. & Phillips, L.M. (2003). How Literacy in its Fundamental Sense is Central to Scientific Literacy. *Science Education, 87,* 224-240.

Pawley, D., Ayres, P., Cooper, M., & Sweller, J. (2005). Translating Words into Equations: A Cognitive Load Theory Approach. *Educational Psychology, 25,* 75-97.

Plass, J. L., Chun, D. M., Mayer, R. E., & Leutner, D. (2003). Cognitive Load in Reading a Foreign Language Text with Multimedia Aids and the Influence of Verbal and Spatial Abilities. *Computers in Human Behavior, 19,* 221-243.

Rivard, L. P., & Straw, S. B. (2000). The Effect of Talk and Writing on Learning Science: An Exploratory Study. *Science Education, 84,* 566-593.

Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating Scientific Discourse: Findings from Language Minority Classrooms. *Journal of the Learning Sciences, 21,* 61-94.

Roth, W.-M. (1995). Affordances of Computers in Teacher–Student Interactions: The Case of Interactive Physics(TM). *Journal of Research in Science Teaching, 32,* 329-347.

Schnotz, W., Boeckheler, J., & Grzondziel, H. (1999). Individual and Co-operative Learning with Interactive Animated Pictures. *European Journal of Psychology of Education, 14*(2), 245-265.

Simon, S., Erduran, S., & Osborne, J. (2006). Learning to Teach Argumentation: Research and Development in the Science Classroom. *International Journal of Science Education, 28*(2–3), 235–260.

Simpson, W. D., and Marek, E. A. (1988). Understandings and Misconceptions of Biology Concepts Held by Students Attending Small High Schools and Students Attending Large High Schools. *Journal of Research in Science Teaching,25* (5), 361–374.

Songer, N. B., Lee, H.-S., & Kam, R. (2002). Technology-rich Inquiry Science in Urban Classrooms: What are the Barriers to Inquiry Pedagogy? *Journal of Research in Science Teaching* , *39*(2), 128-150.

Sweller, J., 1994. Cognitive Load Theory, Learning Difficulty and Instructional Design. *Learning and Instruction, 4*, 295–312.

Sweller, J. (1999). *Instructional Design in Technical Areas.* Camberwell, Victoria, Australia: Australian Council for Educational Research.

Thomas, W.P., & Collier, V.P. (2002). A National Study of School Effectiveness for Language Minority Students' Long-term Academic Achievement. Santa Cruz, CA, and Washington, DC: Center for Research on Education, Diversity & Excellence. www.crede.ucsc.edu/research/llaa/1.1_final.html

Warren, B., Ballenger, C., Ogonowski, M., Rosebery, A., & Hudicourt-Barnes, J. (2001). Rethinking Diversity in Learning Science: The Logic of Everyday Language. *Journal of Research in Science Teaching, 38*(5), 529–552.

Wellington, J., & Osborne, J. (2001). *Language and Literacy in Science Education.* Philadelphia, PA: Open University Press.

Zietsman, A. I., & Hewson, P.W. (1986). Effect of Instruction Using Microcomputer Simulations and Conceptual Change Strategies on Science Learning. *Journal of Research in Science Teaching, 23*, 27-39.