THE TRILINGUAL SCIENCE TEACHING AMBASSADOR: EXPLORING THE TRIANGULATION OF SPANISH, ENGLISH, AND THE LANGUAGE OF SCIENCE

by

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(Under the Direction of Norman Thomson and Cory Buxton)

ABSTRACT

The Association for the Advancement of Science (AAAS) calls for scientifically literate citizens by the return of Halley's Comet in 2061. Nationally, however, schools in the United States are not effectively meeting that challenge, as less than one-fifth of Americans currently meet a minimal standard of scientific literacy. The Spanish-speaking Latino population, the largest and fastest growing minority group in the U. S., is not achieving successfully on standardized science exams measuring scientific literacy. Thus, it is imperative that we effectively address the issues associated with the academic underperformance of Latinos, English Language Learners, in particular.

The purpose of this study was to explore teaching strategies that help secondary level Latino science learners develop scientific literacy. Through the use of quantitative and qualitative data collection methods, both teaching and learning strategies were identified. Quantitative tools included the use of pre and posttest examinations that aided in exploring changes in participants' knowledge as a result of their participation in a targeted after school program. Qualitative tools included participant observation, interviews and participants' artifacts. Collectively, these qualitative tools provided evidence of effective teaching and learning strategies, as they occurred in a physical science afterschool enrichment program, with a particular focus on strategies that were identified by the participants.

Findings from this study indicated that Spanish-speaking Latino bilinguals (LBLs) benefitted from bilingual teaching strategies that used and enhanced the acquisition of the Spanish language to support science learning. Science inquiry activities, structured learning and scaffolding approaches were instrumental in co-constructing physical science knowledge with participants. Teaching that triangulated Spanish, English, and the language of science supported trilingualism and multiculturalism in LBLs.

INDEX WORDS: English Language Learners, Latinos, Latino Science Learners, Bilingual Education, Physical Science, Science Teaching, and Enrichment Programs

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DEDICATION

This dissertation is dedicated to my loving children Jason and Lucas.

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CHAPTER I

INTRODUCTION TO THE STUDY

Overview

Scientific literacy involves critical and metacognitive skills, fluency in and deep understanding of inquiry methodology, and other habits of mind to connect and communicate concepts and interdisciplinary ideas and persuade others to make informed decisions (American Association for the Advancement of Science, 1990; Yore, 2001). More specifically, scientific literacy involves a deep knowledge and understanding of the nature of science, the scientific enterprise, science subject matter, mathematics and technology (National Research Council, 2001). The ultimate goal for a scientifically literate populace is to engage in inquiry in all aspects of life. Students who possess strong literacy skills (that is, reading, writing, speaking, computation, comprehension, and basic content knowledge) can better think critically, understand inquiry methodologies, and develop habits of mind necessary to connect and communicate scientific phenomena (National Research Council, 2001).

The Association for the Advancement of Science (AAAS) calls for scientifically literate citizens by the return of Halley's Comet in 2061. Nationally, however, schools in the United States are not effectively meeting that challenge, as less than one-fifth of Americans currently meet a minimal standard of scientific literacy (Miller, Pardo & Niwa, 1997; Miller & Pardo, 2000). According to the Trends in International Mathematics and Science Study (TIMSS), U.S. students lag behind several other countries in basic scientific knowledge (Gonzales, 2008). In addition to the international science gap, disparities in science scores have also been noted among different ethnic student populations in the U. S. For example, the 2005 National

Assessment of Educational Progress (NAEP) illustrates that science scores for African American and Latino 12th grade students lagged behind those of White students by 36 and 28 points, respectively (U. S. Department of Education & National Center for Education Statistics, 2007). Twelfth-grade English Language Learners (ELLs), 79 % of whom are of Latino origin, scored 41 points less than the non-ELL population (Kohler & Lazarin, 2007; National Assessment of Educational Progress, 2005). The effect of such an achievement gap is felt beyond the confines of the academic environment. Substandard basic and scientific literacy impedes future occupational opportunities and democratic participation in U.S. society (Bernardo, 2000; National Commission on Excellence in Education, 1983; Portes, 2005; Wagner, 1992). It is therefore imperative that we effectively address issues that limit participation in a democratic society when one cause is the science achievement gap.

As a Latina science teacher and a former English Language Learner, I have a deep interest in understanding the academic low performance of Latino students in science. As a young Spanish-native immigrant to the United States, I, like millions of others like me, faced the challenges that the educational system presented to me. At first, I had to learn and conform to a new way of participating in my education which included making sense of new instructional strategies, reading, writing and performing in a language unfamiliar to me, while at the same time accommodating into a new culture. In retrospect, I credit much of my success as a student of the sciences to an initial transitional period during which I received some instruction in Spanish. Immersion in a bilingual program allowed me to speak, write and, most centrally in the context of this study, inquire in my native Spanish. My ability to engage in critical thinking flourished, as I was able to enquire about the world without fear that my teachers and my peers would not understand me. However, once I transitioned to monolingual English classrooms, my ability to think critically drastically diminished. Faced with the challenge of performing as well as my English-speaking peers, I realized that I lacked academic language skills that were strong enough to fully understand scientific discourse. In hindsight, I also lacked a support system capable of adequately scaffolding my education. I grew up with a lack of books, mentors and tutors. To overcome educational barriers, I resorted to rote memorization to help me achieve well on tests – at the expense of critical thinking ability. Eventually, and perhaps due to a critical mass of exposure to environments and materials within a science context, my analytical thinking ability was able to develop. As a bilingual science teacher with eight years of experience, I witnessed many of the Latino ELLs that I taught go through similar struggles. I have personal knowledge of, and exposure to, the numerous educational barriers that a Latino ELL may face as a result of her or his participation in the U.S. educational system.

The relevant research literature to date documents the academic low performance of Latino ELLs, especially in the area of science. Latino ELLs face the challenge of acquiring scientific literacy and science content knowledge with a curriculum that is taught in a language that they have not mastered. As a result of this struggle, many Latino ELLs fall behind academically and under-perform in science. In trying to understand how to best reach these students, it is imperative that we look at learning strategies that support cognitive growth among ELLs. Thus, the purpose of this study is to identify educational practices that enhance and support science literacy among Latino ELLs, with a particular focus on developing critical thinking skills. Here, the focus is on those Latino students of Mexican and Central American origin and low socioeconomic status (SES) background attending a high school in a small southeastern U.S. city.

The setting in which the study was conducted is a secondary school with a relatively small number of Latino Spanish-speaking bilinguals and ELL students. The context of the study is an after-school enrichment program aimed at enhancing cognition in the area of physical science that was held on Tuesdays and Thursdays for 15 weeks during the spring 2010 semester. The enrichment program, which was mainly taught by this researcher and four other instructors, consisted of physical science lessons emphasizing various teaching and curricular strategies such as guided inquiry, writing, and journaling that supplemented and enhanced science and Spanish and English language acquisition. While conducting the enrichment program, I audiotaped students' discussions and collected their written products for analysis. At the beginning and end of the program, students were administered a pre- and posttest in an effort to gain an understanding of their knowledge base of physical science and possible change in content knowledge that may have resulted from their participation in the program. Three focus group interviews were conducted to examine students' ideas about the particular teaching and curricular strategies implemented in the program.

Rationale for the Study

Educational policies have aimed to eliminate the disparity in academic performance between Whites and students of color, especially ELLs. Bilingual education programs have been established with various degrees of success since the 1960s in order to respond to the language and academic needs of ELLs. In addition, professional and curricular development have been instituted as a direct response to the No Child Left Behind (NCLB) mandates, which require that every state address the academic needs of ELLs (State Rule § 20-2-156; NCLB, 2001). The academic success of ELLs has been defined by various measures, ranging from cultural and linguistic assimilation into the larger society (Garza & Crawford, 2005; Lipka, 2002), to academic competency as compared to majority students (Gold, 2006; Thomas & Collier, 2002) and bilingualism and biculturalism (Thomas & Collier, 2002).

While there may be a number of factors relevant to all ELL students (for example, language acquisition, relevant pedagogical best practices, and so on), what distinguishes Latino ELLs from other ELLs can be thought of as the “Latino experience.” The U.S. Census Bureau uses the terms Latino and Hispanic interchangeably (Torres-Saillant, 2005). While most public and governmental documents prefer the term Hispanic (denoting a Spanish speaking multicultural group), I prefer to use the term Latino because it acknowledges African and other indigenous ancestries (Murguia, as cited in Nieto, 1995; Romo, 1999). For the rest of this dissertation, the term Latino refers to both male and female Spanish-speaking individuals of Latin American origin residing in the United States. In addition, the term “Latina” can be utilized when specifically referring to Latino females. Latinos/as is a heterogeneous group that includes individuals from different social, political and religious affiliations as well as varied educational and socio-economic backgrounds (Torres-Saillant, 2005). Additionally, Latinos have particular cultural histories in the U.S. While some Latinos are native-born “Americans” and culturally identify themselves with hegemonic groups, other Latinos are recent immigrants or second and third generations who may still identify socially and politically with their native countries.

Latinos may also identify themselves as bilinguals. Hammers and Blanc (2000) identify bilinguals according to the manner in which the native (L1) and host (L2) languages are acquired. Dominant bilinguals (DB) are individuals who are more linguistically competent in one language than the other (i.e., ELLs). Balanced bilinguals (BB) refer to individuals who have equal levels of competence in L1 and L2. Often, educational literature does not make the distinction between DBs and BBs explicit even though cultural identities may be different. An emergent DB may identify himself or herself as learning L2 and remain monocultural while a balanced bilingual may identify him or herself biculturally. In this presentation, the term ELL is used to refer to dominant L1 bilinguals unless otherwise specified. Additionally, I use the term Latino bilingual learner (LBL) to represent Latino balanced bilinguals.

The Latino population is the largest and fastest growing minority group in the United States (Census, 2010). As of 2006, one in five students attending U.S. public schools is of Latino origin (Fry & Gonzales, 2008). What has made the latest wave of immigration different from previous ones is the choice of destination for an increasing number of immigrants. In addition to traditional landing points such as Southern California, South Florida and the cities of the Northeast, there has now also been an influx of Latino immigration to the traditional South (Bohon, Macpherson, & Atiles, 2005).

Ensuring positive educational outcomes for ELLs remains a challenge for educators as well as curriculum and policy developers, partly because of the difficult task of "bridging" the different cultural, linguistic and scientific discourses between ELLs and scholarly communities. Here, "bridging" refers to two distinct pedagogical processes. Students will learn, and become proficient in, science discourse, and teachers will become proficient in using both student and scientific discourses (National Research Council, 2001). However, efforts to make this bridging possible in classrooms with significant percentages of Latino ELLs have not been as effective as desired, as evidenced by the persistence of underperformance in science. Second language immersion programs are the most prevalent learning environments for ELLs in the U.S. today (US Department of Education, 2005). Immersing ELL students in English-only monolingual classrooms has appeared to be ineffective partly because the aims and goals of immersion programs are to quickly increase English language proficiency at the expense of the native languages and cultures (Gibson, 1988; Ramirez, 1992). It is estimated that it takes anywhere from 4-10 years for language learners to acquire proficient levels in a second language (Ramirez, Pasta, Yuen, Billings, & Ramey, 1991). In this immersion process, scientific literacy (and other cognitive demanding literacies) is sacrificed as ELLs struggle to gain basic literacy along the way. What has worked best for ELLs are programs that teach and value students' native language and culture (Alanis, 2000; deJong, 2002; Thomas & Collier, 2002). The idea here is that students with strong grammatical and cognitive foundations in their native language can transfer these skills to the new host language (Ben-Zeev, 1977; Cummins, 1977).

By the same token, a strong foundation in basic literacy skills is crucial to the successful acquisition of scientific literacy. The ways students think about, discuss, conduct, analyze, understand and value science – the sum of which, collectively, can be termed scientific discourse – becomes more difficult when students fail to reach proficient levels of basic and scientific literacy (Rosebery, Warren, & Conant, 1992).

Various studies have implemented curricular strategies and made recommendations about effective practices that promote scientific literacy and discourse among ELLs. To "bridge" or make compatible the local and indigenous discourse of ELLs and the discourse typical of the scientific community, researchers have reported on creating hybrid spaces (Moje, Collazo, Carrillo, & Marx, 2001), utilizing culturally congruent teaching (Lee & Buxton, 2010), conducting inquiry activities (Amaral, Garrison, & Klentschy, 2002; Bravo & Garcia, 2004; Cuevas, Lee, Hart, & Deaktor, 2005; Hampton & Rodriguez, 2001; Rosebery et al., 1992; Torres & Zeidler, 2002) and using students' existing knowledge (Barton, 2003; Carlo et al., 2004; Moje et al., 2001). The focus of the current study is not, strictly speaking, on curricular strategies that help bridge cultural incongruence. Rather, this study focuses on how ELLs learn topics in physical science and the curricular and instructional strategies that help them learn science effectively. I view cultural and linguistic bridging as a potentially effective means to this end. However, current research has provided the foundation for further studies in this regard. Such future research will serve to take a look at more specific questions concerning Latino ELLs in science classrooms, such as the differences in Latino cultural background, age, learning styles, and classroom setting. With continued research, we can better ask, for instance, if pedagogical best practices developed in one study focusing on Afro-Caribbean Latino ELLs in an urban classroom are equivalently applicable to their Mexican and Central American counterparts in rural classrooms – not only in the classrooms they currently attend, but also the classrooms they left behind in their native countries.

Among the strategies supported by the research literature, academic enrichment programs provide opportunities for students to remain actively involved in learning. Enrichment and related extracurricular academic programs such as tutoring extend, support and strengthen regular school programs (Portes, 2005). When students participate in enrichment programs, they have further opportunities to learn from knowledgeable others, spend time on tasks related to school achievement, and develop social competence regarding learning attitudes, values and motives adaptive to school (Portes, 2005). Huang, Gribbons, Kim, Lee and Baker (2000) found that higher participation in after-school enrichment programs is significantly related to positive achievement on standardized tests and regular school attendance. Barlow and Villarejo (2004) found that college students of color who participated in science and mathematics enrichment programs had a greater propensity to continue developing mathematics and scientific skills, and increased the probability of graduation and continuing to graduate studies.

Extended learning time beyond regular school hours may prove most beneficial for students, including those who are in the process of acquiring a second language (Portes, 2005). According to Cummins (1981), second language learners must first develop basic interpersonal communicative skills (BICS) before they develop cognitive academic language proficiency (CALP). BICS refer to the natural, informal language skills ELLs use to navigate everyday actions. BICS is highly dependent on contextual cues (context-embedded) as ELLs try to negotiate meaning by the use of physical attributes (i.e., physical gestures and verbal intonations). CALP reflects the combination of both language proficiency and cognitive processes. Once ELLs develop BICS, academic cognitive demanding learning can follow.

Conversational fluency, or BICS, generally develops within the first two years of exposure to the host language, while academic or CALP may take an additional five years. BICS is insufficient and superficial when students need to understand the more complex scientific concepts as those found in textbooks and classrooms. ELLs need to become cognizant of the relationships between forms and functions of the native language and the grammatical, morphological and phonological aspects of the host language. Academic learning at the high school level draws upon more advanced critical and metacognitive skills in English, which many high school students already possess. In other words, secondary-level ELL students need to rapidly develop CALP-level discourse (Harper & de Jong, 2004). Enrichment programs, such as the one studied here, can be helpful in supporting the development of such discourse.

Science and second language learning effectively complement each other. “Science is essential for developing student thinking… Science provides a context in which students can continue to develop reading and writing skills” (Amaral et al., 2002, p. 214). The processes of observing, predicting, hypothesizing, analyzing, evaluating and sharing findings about natural phenomena – collectively understood as the scientific process – is aligned with language learning skills including seeking information, comparing, ordering, synthesizing and evaluation of knowledge (Fathman, Quinn, & Kessler, 1992; State Department of Education, 2008b, n.d.). Regardless of how well these two different kinds of cognition complement each other, school-time constraints make it extremely difficult, if not simply impossible, to "offer efficient instruction to allow ELLs to catch up with their English speaking counterparts" (Hakuta, Butler, & Witt, 2000). Thus, a well-designed enrichment program targeted at increasing English proficiency and scientific literacy among Latino bilinguals may serve two objectives with a single effort.

Theoretical Framework

Constructivist models of intellectual development rose to prominence as departures from positivist frameworks that were seen as epistemologically unsound as well as socially irresponsible in the wake of scientific, philosophical and political developments in the late 19th and early 20th centuries. The view that a human being is the constructor of her or his own knowledge and meaning, now generally accepted within the field of education scholarship, has had the additional effect of allowing both maturationist and behaviorist ideas about the origins of intellectual development (by acknowledging the importance of both the learner's internal processes and environmental processes in learning) while moving past both to a more comprehensive view (Wadsworth, 1996). Furthermore, pedagogical methods (as well as the research methods used to analyze them) that are based on a social constructivist approach assume that this construction of meaning is not possible outside of the context of social interaction (Schwandt, 1994). While social constructivism has been used at great length to describe how knowledge is constructed in the science classroom, we can identify two very broad approaches used in describing the trigger for knowledge construction in students. A “Piagetian” approach suggests that the classroom social activity affects enough of a dissonance in the worldview of the student so as to provoke the student into constructing new meanings. On the other hand, a “Vygotskyan” approach presupposes that social activity serves to model the means to, as well as the content for, what amounts to the incremental transmission of culture in its many forms and contexts, including science content knowledge and the means for scientific literacy (Ginsburg & Opper, 1979; Vygotsky, 1978; Wadsworth, 1996).

In Vygotsky’s model, learning drives development and can be advanced through social interactions. Traditional psychology has typically held that learning precedes mental development; learning and comprehension are limited if not impeded when learners have not reached age-appropriate mental maturity. For Vygotsky, on the other hand, learning is advanced when it is ahead of development and thinking is challenged beyond the present actual understanding. From this viewpoint, learning and development are self-regulated in an active process. Learners interacting with more knowledgeable social agents construct and internalize knowledge. In this process, learners are provided with cultural tools (that is, symbolic language and its expressions) that provoke qualitatively improved thinking and reasoning. Thus, intellectual development occurs when external knowledge is first shared interpersonally and then is internalized. Vygotsky (1978, p. 56) explained that the process of internalization consists of a series of transformations. First, when the learner is presented with an external activity or cultural tool such as scientific concepts or language forms and functions, the learner reconstructs the activity internally (that is, conceptually). The learner then transforms the interpersonal experience – that which is experienced at a social level – into an *intrapersonal* one – that which is experienced at the individual level. This process of transformation persists and evolves until it is finally turned inward. For some functions, internalization occurs gradually and in a short period of time; for other functions, external activities remain unresolved. Similar to BICS (Cummins, 1981) in learning social language (including the language of science) children first learn by imitating or "ventriloquizing", that is, speaking through the voice and actions of a more competent other (Wertsch, 1991) until they internalize the language and use it for their own purposes. Once language is internalized, thoughts are organized and actions are regulated. Thus, learning is, for both Vygotsky and Cummins, first a social, then an individual, process.

In Vygotsky's (1978) social constructivist model of learning and development, teachers and other capable others assist or "bridge" the gap between learners' spontaneous, or everyday, concepts and the scientific, or abstract, concepts that learners should be acquiring in the classroom. Learners are provided with cultural tools (that is, all forms of symbolic language and its expressions) that provoke qualitatively improved thinking and reasoning – provided that those tools model knowledge within a zone of development appropriate to each learner. This zone is termed 'the zone of proximal development' (ZPD). From a Vygotskyan perspective, teachers provide learners with the assistance necessary for learners to internalize novel scientific concepts. Learners, having received the mediated modeling necessary for cognitive development, are then able to cooperatively construct knowledge in subsequent learning situations (and, eventually, independently – while within a wider cultural socialization process). For mediated learning to function optimally, teachers and other capable others should be able to shift the instructional discourse in such a way as to effectively direct and respond to learners' feedback. Such adaptive shifts in accordance with learners' respective ZPD and participation in the learning process are collectively termed "semiotic flexibility" (Dixon-Krauss, 1996b). Semiotic flexibility may take on an additional significance when working with learners whose primary language for constructing knowledge is not the typical language of classroom instruction. Thus, an enrichment program targeting Latino bilinguals and taught by a Spanish-speaking Latina would provide an additional component of primary language (L1) interaction so that semiotic flexibility is enhanced, recovered, or, at least, not lost.

Research Questions for the Study

Using Vygotsky's social constructive model of learning and development, this study deals with science knowledge acquisition among ELLs participating in a bilingual Spanish-English science enrichment program. The focus is on determining the change in participants' abilities to develop scientific literacy and to construct science content knowledge as a result of their experiences in an enrichment program. In addition, students' ideas about effective curricular and instructional strategies that help in learning science were examined. The research questions explored in this study were as follows:

1. What science knowledge do secondary-level Spanish-speaking Latinos participating in an enrichment program possess about physical science at the outset of the intervention?
2. What science content knowledge did the participants construct as a result of their participation in the enrichment program?
3. What are the curricular and instructional practices that secondary-level Latino bilinguals found beneficial in the construction of their science content knowledge?

We don't exactly know the level of content knowledge that Latino ELLs (or any students for that matter) have constructed -- beyond what they demonstrate on standardized and other national exams – which is only one (arguably weak) measure of understanding. In terms of the descriptive power of the tests, there is not a useful level of granularity that can be used to help educators address ELL-specific issues. For instance, these tests do not identify ELLs in terms of time they have been in the country, what level of English have they acquired, and so on. Put simply, the tests give a general picture of what all students know, but we cannot really tell who is who or who knows what.

Even prior to testing, moreover, the level of science content knowledge among Latino ELLs varies – and to an unknown extent. On one hand, without effective bilingual programs (with appropriate Spanish-language or bilingual learning material), Latino ELL science content knowledge is difficult to determine, as the students themselves often cannot clearly communicate what they know and what they're having trouble learning. On the other hand, a number of Latino ELL students enter into the classroom with an already established base of science knowledge. It could be that this knowledge is not self-identified or identified by educators as "science knowledge." This potential source of content knowledge base has been so well internalized that it "flies under the radar." Some male Latino ELLs, for example, work in auto mechanic shops, wherein they must daily work with machines, electrical wiring, and so on.

The participants of this study were provided with the opportunity to learn physical science content in Spanish. For most, this was the first time in their schooling in the U.S. that they had such an opportunity. In addition, participants in the Latino After-school Physical Science (LASPS) program had more time to study some topics in depth (often not possible during regular classes). Participants were exposed to previously taught physical science knowledge and studied and reviewed them in depth. Thus, participation in LASPS had the potential to increase participants' chances of passing state-mandated end of course tests and the science graduation test. Knowing of any changes in their knowledge of physical science helped me look at some of the curricular and teaching strategies that may help these particular students learn science better. The use of both formal and informal assessments (i.e., pre- and posttest) and authentic assessments (journals, individual and group projects) helped shed light on the process of student learning, as proposed by proponents of Vygotsky.

To date, researchers have not documented the curricular and instructional strategies that secondary level Latino bilinguals found most useful in learning science. Data collected from this study may provide better direction for future research in this area and the development of more effective curricula and instructional strategies for high school Latino bilinguals.

CHAPTER II

LITERATURE REVIEW

Overview

This chapter presents the history of the development of science education, with the primarily focus on the idea of scientific literacy. As educators' ideas about scientific knowledge evolved, so did their ideas about what form its dissemination should take in the science classroom. Also presented in this chapter is a model of scientific literacy -- in its most fundamental sense -- as the ability to effectively engage in empirical inquiry and discovery activity. However, scientific literacy cannot exist without being situated in the larger pedagogical context of the classroom. This issue becomes more salient when considering Latino Spanish-speaking English Language Learners (ELL). Thus, test data and analysis of the National Assessment of Educational Progress (NAEP) are also reviewed in this chapter, leading to a discussion of both known and potential pedagogical best practices for effectively imparting scientific literacy and second language (L2) acquisition to Latino ELL science learners.

A Historical Look at Science Literacy

Throughout modern history, scientific literacy as a concept and as a goal has been defined in a variety of ways; it has meant different things at different times. Regardless of which phase of the history of education in the U.S. (and the cultural West in general) we consider, features of the contemporary definition of scientific literacy or knowledge are anchored in two main points of debate: First, what content knowledge and characteristics of science are most valuable to teach in science education programs and second, what should be the outcomes of such education. Today, education reforms highlight the realization of three main outcomes or benefits of scientifically literate citizens: that of a need for skilled workers that can function and compete effectively in a highly technological and global society, a need for knowledgeable citizens capable of full participation in a democratic society, and the need for a portion of citizens who choose to pursue careers that make use of the skills and competencies acquired in the science classroom (National Commission on Excellence in Education, 1983; National Research Council, 2001; Oliver et al., 2001, 2006).

Educational policies as well as curricular and pedagogical approaches associated with science education are closely linked to prevailing ideas about what constitutes science literacy or science knowledge in the first place. As ideas about scientific knowledge evolve, both in response to changing historical circumstances and through the advances in our understanding of how people learn, so do educators' ideas about the value and methods of educating students in science. From the Renaissance through the European Enlightenment, and well into the Industrial Revolution, the model for boys' and girls' academies focused on the classics and the development of individuals proficient in leadership, entrepreneurial and other civic vocational roles. Science education consisted of a variety of courses offered in natural philosophy and the like, without any kind of standardization across school systems. Since boys' schools were maintained along the well-entrenched classical model, consisting of Latin, Greek, arithmetic, rhetoric, and so on, those reformers who wished to include a practical study of natural science found their best opportunity in girls' schools and seminaries; natural philosophy, chemistry, botany and natural history were taught more preponderantly in girls' schools than in boys' schools in the first half of the 19th century (Tolley, 1996).

The value of science -- or, as it was discussed up until the early 19th century, natural philosophy -- was not universally agreed upon. While efforts were made to update U.S. schools in order to improve the teaching of natural science as early as 1798 (deNemours, 1923), there emerged voices that openly questioned the place of scientific knowledge in classrooms, calling such knowledge "dead facts," as the 19th century philosopher Hubert Spencer did, or as a closed set of accumulated facts that is relevant only to a small circle of academics, as Spencer's contemporary, James Wilkinson of the Royal College of Surgeons did (Hurd, 1997; Spencer, 1859). The latter, however, was of the opinion that science education need not be that way by definition; rather, science education should, for Wilkinson, involve at least as much the "doing" of science as the learning of facts (Wilkinson, 1847). This clarifying focus on science as an active process, rather than as the passive reception of factual knowledge, continued on through to the next phase in U.S. education, beginning with the mid-19th century and coinciding with the Industrial Revolution.

With the advent of the middle to late 18th century, however, there emerged the need for U.S. citizens to be properly prepared for the variety of roles in the new industrial settings. While the focus was not immediately or specifically on educating students to be scientifically literate in any form, the acknowledged need to stimulate industrial research seemed to spur a change in thinking about what is practical or not. Science education, as long as it encompassed knowledge that was applicable -- and thus relevant -- to the U.S. public in the new Industrial Age was encouraged. Unlike scientific endeavor in the West up until that point, which was apparently the domain of a small minority with the leisure and means to engage in such activity, the new Industrial Age social order needed elements and strata of society at large to be at least functionally literate in technical thinking. Proponents of the inclusion of science topics in contemporary academic curricula went a step further in proposing that the value of science education lies not only in enhancing a learners' ability to understand and apply scientific endeavors but also in the general development of one's cognitive skills (Buxton & Provenzo, 2011). Edward Livingston Youmans, in his *Culture Demanded by Modern Life* (1867), boldly stated that science education, by its very nature, was also helpful in imparting the same core of intellectual competencies that proponents of classical education claimed for their own curricular models (Youmans, 1867). At the turn of the 20th century, Dewey (1916) stated that enabling learners to learn by discovery had the additional benefit of creating citizens who were best able to contribute as members of the civic body, leading to a stronger democracy. Thus, the curricular changes brought on by the Industrial Revolution were seen as a necessity for broad-based cognitive, economic and social uplifting.

The new models of implementation of science education curricula in U.S. schools appeared to suit the needs of the nation until the middle of the 20th century. The U.S. reaction to the launching of two satellites in the 1950s by its Cold War adversaries, the Soviet Union, was to return to a basic look at the reasons for the loss of intellectual momentum. This included a new focus on scientific literacy. Educational theorists and practicing scientists were tasked with understanding the state of U.S. education as it concerned its ability to produce scientists that could lead the nation from the Industrial to the Space Age. Educational theory began to be intermingled with theories of cognitive development, and a new drive to increase learners' abilities to "do science" ensued.

In 1983, almost 30 years after the launching of Sputnik, the National Commission on Excellence in Education published *A Nation At Risk* (National Commission on Excellence in Education, 1983), which sought to address the mounting concerns over the perceived persisting academic gap between U.S. students and their counterparts in other industrialized countries. A central focus of the report was the state of U.S. education's ability to impart the literacies its students needed to have in order for the nation to maintain its scientific, economic, military and other key leadership positions. The report also included the recommendations of the NCEE in terms of how to enhance science education in U.S. classrooms. Central to the NCEE's reform approach is inquiry-based learning and teaching (National Commission on Excellence in Education, 1983).

In the decades following the calls for progressive reform of science education, efforts to define ideals and propose plans of action have resulted in the emergence of national educational standards and benchmarks. Founded in 1848 as a scientific society seeking to "advance science for the benefit of all people", the American Association for the Advancement of Science (AAAS) has been behind much of the most influential dialog and effort behind science education reform at the national level. In 1985, the AAAS began Project 2061, a long-term initiative seeking to reform science education through science literacy at all levels nationwide. One of the most important initial objectives of Project 2061 was to define what was meant by scientific literacy. The culmination of that effort was Project 2061's first publication, *Science for All Americans* (American Association for the Advancement of Science, 1990).

Science for All Americans starts with definitions of what science is and what its characteristics and qualities are. Science operates with the assumption that the universe exhibits patterns that are observable and understandable. Humans can and ought to understand as much as possible in order to enhance our physical, cultural, economic, and civic well being. For the knowledge gained to be the most durable and useful, it must be gained through empirical inquiry (Bruner, 1961; Dewey, 1938; Holloway, 2000; Piaget, 1971). In addition, scientific inquiry should be conducted with an eye on issues facing our society today; that is, science literacy should be a socially relevant literacy.

In order to make any future proposal for improvement in science literacy possible, some basic requirements about scope and technique in science instruction were defined. Traditional educational methodologies (especially in terms of how students learn) in which science instruction consisted largely of rote memorization were found to be deficient in light of advances in cognitive neuropsychology (Bruner, 1961; Jones & Paolucci, 1998; Mestre, 1994; Piaget, 1971; Vygotsky, 1978). What *Science for All Americans* proposes is that the focus should move to teaching students the process of acquiring scientific knowledge. This process should emphasize team effort, hands-on experience and practice, and feedback between teacher and student and knowledgeable peers (American Association for the Advancement of Science, 1990; Vygotsky, 1978). Knowing something should come from finding it out. Again, scientific learning should ideally have relevance, leveraging what students know about current events (for example, the environment, AIDS, cloning, etc.) and everyday experiences as well as what they've previously learned in a classroom environment. Of note was the insistence that the guidelines as outlined in *Science for All Americans*, as well as any set of guidelines for that matter, be seen as standards but not as expectations. Students' involvement in science literacy acquisition must be active and spontaneous, not passive and mechanical (American Association for the Advancement of Science, 1990). An important legacy of the work of the AAAS was the eventual formulation and national adoption of the benchmarks that they defined for each grade level from kindergarten through the 12th grade. These benchmarks, unprecedented up until that point in U.S. history, are very specific in suggesting the level and amount of science content knowledge that students need to know at the end of each grade level.

Science for All Americans (SFAA) (1993) provides a broad overview of the essential content that every student in a science education program should know and be able to do. According to SFAA, the essential content knowledge includes qualities of science (habits of mind, nature of science), subject matter (physical and biological sciences), social sciences (human society), the designed world (engineering and technology) and the mathematical world. Here, qualities of science refer to the ways scientists think and do science. Nature of science refers to the history of science and the accompanying paradigms that evolve from it. Collectively, habits of mind and the nature of science are referred to as characteristics of science. Subsets within each category present the big ideas, specific concepts and skills deemed important for scientific literacy. For optimal effect, SFAA recommends that categories be weaved into the curriculum so that students connect knowledge across disciplines and build upon prior knowledge. To teach the essential content, the AAAS presented educators with a guide, based on SFAA, entitled *Benchmarks for Scientific Literacy*. The "*Benchmarks"* provided guidelines for content knowledge by grade level (AAAS, 1993). The guidelines specified the common core of content that students should know at grade level 2, 5, 8 and 12. Specific concepts across the grade levels increase in complexity and build upon each other. Table 1 provides an example of the knowledge students in physical science should possess at the end of each grade. Along with the specific "content matter", students should also know and practice the characteristics of science.

Table 1

Required Physical Science Content Knowledge at the End of Four Selected Grade Levels as Defined by the Benchmarks.

Grade level	Physical setting: What students should know
2	Objects can be described in terms of their properties. Some properties, such as hardness and flexibility, depend upon what material the object is made of, and some properties, such as size and shape, do not.
5	A lot of different materials can be made from a small number of basic kinds of materials.
8	All matter is made up of atoms, which are far too small to see directly through a microscope.
12	Atoms are made of a positively charged nucleus surrounded by negatively charged electrons. The nucleus is a tiny fraction of the volume of an atom but makes up almost all of its mass. The nucleus is composed of protons and neutrons, which have roughly the same differ in that protons are positively charged while neutrons have no electric charge.

Note. From The Physical Setting: The Structure of Matter by American Association for the Advancement of Science, 1993, *Benchmarks online*. Retrieved from http://www.project2061.org/publications/bsl/online/index.php?chapter=4. Copyright 1993, 2009 by American Association for the Advancement of Science.

Parallel in time and purpose to the work of Project 2061 is that of the National Research Council, an agency created by the National Academy of Sciences to assist the science and technology communities in providing services to the federal government. In 1996, the NRC released the *National Science Education Standards* (NSES), similar in scope to *Science for All Americans*. The NSES also proposes reforms to science education, centrally involving science as an active process rather than an acquisition of facts (National Research Council, 2001). The aim of such an approach is the enhancement of the quality of students' lives outside of the science classroom. Although any approach applicable to this endeavor is encouraged in the NSES, there is a stated emphasis on inquiry as both a method of teaching and a method of "doing" science.

The National Science Education Standards (2001) represent criteria to judge the quality of science teaching, science programs, supportive systems, assessment practices, policies and student learning. More importantly, the science standards serve as the yardstick to measure progress at a national level toward a unified vision of what a scientifically literate individual should be (National Research Council, 2001). Specific standards are designed and developed for each practice group and are meant to be used collaboratively. Within each practice group, there are subsets or categories that identify the knowledge and abilities that need to be addressed. The content standards for instance, outline what students should know, understand and be able to do in the natural sciences. Eight categories are identified within the content standards and include: unifying concepts and processes in science, science as inquiry, physical science, life science, earth and space science, science and technology, science and personal and social perspectives, and history and nature of science. The eight categories of content standards are designed to be used in conjunction with each other. The organization of the categories is incremental, building upon the foundations of prior exposure to each theme. Table 2 outlines the major concepts and understandings that students in physical science should possess by each grade level.

Table 2

NSES-defined Standards for Required Physical Science Content Knowledge, Binned into Three Grade Level Groupings Across K-12.

Grade level	Physical setting
K-4	1. Properties of objects and materials
	2. Position and motion of objects
	3. Light, heat and electricity, and magnetism
5-8	1. Properties and properties of changes in matter.
	2. Motions and forces
	3. Transfer of energy
9-12	1. Structure of atoms
	2. Structure and properties of matter
	3. Chemical reactions
	4. Motions and forces
	5. Conservation of energy and increase in disorder
	6. Interactions of energy and matter

Note. From *National Science Education Standards* (table 6.2, p. 106), by National Academy of Sciences, 1996, Washington, DC: National Academy Press. Copyright 1996 by the National Academy of Sciences. Reprinted with permission.

Olsen and Loucks-Horsley (2000), seeing the processes with which scientists acquire new knowledge as essentially the same as those that the NSES recommends for science students, offer examples from recent scientific discoveries to describe a set of core competencies as suggested by the NSES (Olsen & Loucks-Horsley, 2000). At first, an observation is made. This observation is ideally spontaneous and is not necessarily part of a pre-defined method. The observation provokes curiosity, while relevant knowledge that was previously gained is used in order to formulate questions about the nature of the observation. Empirical evidence is gathered using technology and mathematics, and an explanation is proposed for the observation. The observation, as well as its proposed explanation (along with the relevant background and acquired data), is shared with others. The feedback gained, along with any new evidence, would successively improve upon the explanation until the knowledge gained becomes durable enough to be added to the corpus of human knowledge (Olsen & Loucks-Horsley, 2000). Science instruction as mere rote memorization is not adequate if true scientific inquiry is to be expected of students. Again, the acquisition of inquiry skills is here proposed as the focus of science education.

The current climate brought on by the findings and suggestions of the AAAS and the NRC has further led to conceptions of discrete levels of scientific literacy. Shamos (1995) and Bybee (1997) have outlined a continuum of scientific literacy. The first level in this conceptual framework is scientific illiteracy; i.e., the inability to conceive of phenomena in a science related fashion. Moving along the continuum of science knowledge, we arrive at a level of a general, passively acquired familiarity with science-related topics. Today in the United States, media coverage of science related events (for example, forensic investigation and DNA testing in criminal cases, the global warming debate, NASA, medical-themed shows, etc.) has introduced scientific terminology and ideas to the general public (National Science Foundation: Division of Science Resources Statistics, 2006). Higher levels of scientific literacy involve the understanding of knowledge that is more complex and the processes used to attain it. Finally, at the highest level of scientific literacy, an individual understands how scientific processes and knowledge influences -- and is influenced by -- social, cultural, and economic factors. Scientifically literate individuals can make use of evidence to evaluate and assess various kinds of scientific claims (Maienschein, 1999). Though scientific literacy may be gauged in a graded fashion, the understanding remains, however, that scientific literacy is a lifelong pursuit (Koballa Jr., Kemp, & Evans, 1997).

The issue of what is worth teaching in the classroom has always been a concern of U.S. educators. The value of science education has increased, as did the global importance of scientific literacy. Today, scientific literacy is deemed one of the foundational competencies that should be imparted in U.S. schools. The challenge to maintain U.S. leadership, or at least parity, in the global village through effective education is still a concern, as is evidenced in recent Federal initiatives such as No Child Left Behind, which represents another attempt at improving the basic ability of schools to educate students so that they may be relevant and productive members of U.S. and global society. Part of what groups such as the NCEE, AAAS and NRC advocate in this vein is the inclusion of pedagogical components that maximize students' ability to think critically and engage in inquiry, both in science and, by extension, in daily life. However, the discourse about where the value in science education really lies or what scientific competencies are most (or least) important is most certainly still ongoing.

To this day, there is still a wide range of sometimes conflicting voices in the education community about what is most important concerning science education. Even a brief sampling of voiced positions shows how there are different notions of what takes priority in the science classroom. Norris and Phillips (2003) espouse the idea that one cannot reduce scientific knowledge to the mere concatenation of facts (Norris & Phillips, 2003). Eisenhart, Finkel and

Marion (1996) question the idea that inquiry-based science instructional methods, as outlined in the standards, are actually likely to lead to the predicted outcomes of those documents, namely, the development of individuals ultimately capable of participation in meaningful scientific discourse (Eisenhart, Finkel, & Marion, 1996). Hurd (1997) stresses the importance of metacognitive skills and competencies associated with scientific inquiry. These positions do not necessarily conflict with each other, but point out the limitations of school systems – especially as many struggle to meet Federally mandated standards – to realistically accommodate the various “add-on” components in their science classrooms that are proposed by the reform documents. Thus, the search continues for a consensus “core set” of pedagogical approaches that will optimize science learning according to the prevailing standards or benchmarks.

Literacy and Academic Achievement

Educators are charged with the task of imparting the competencies required for an individual to function successfully within the larger collective. The Nation At Risk report called for individuals who are informed and competitive in a more global and scientific society (National Commission on Excellence in Education, 1983). Basic among these competencies are the levels of literacy associated with different occupational contexts. Basic literacy collectively refers to the skills (reading, writing, speaking, computation, comprehension, and basic content knowledge) that are needed to pursue life goals and to participate in society as an informed citizen (Bernardo, 2000; Wagner, 1992). Basic literacy provides individuals the opportunity to be independent thinkers and long-life learners (NCEE, 1983). However, an achievement gap has been noted for different populations among U.S. citizens. The academic achievement gap is better understood as the gap in basic and scientific literacy across socioeconomic status (SES) lines. Therefore, a look into literacy is essential for an understanding of issues associated with it, such as excellence and equity.

A strong foundation in basic literacy skills is necessary for scientific literacy skills. Students who are confident with their scientific literacy skills (grasp scientific literacy) are encouraged to take more challenging or rigorous curricula (honors, advanced courses). In turn, colleges reward these students in a number of ways, including academic scholarships and accelerated class placements (Marcus, 2004). Higher educational attainment translates into higher salaries (U. S. Census Bureau, 2006). High school students who graduate with strong science and mathematics backgrounds earn more than those with lower corresponding scores (Kober, 2000). Even high school graduates with no college training and with high literacy skills, earn more money than those with low literacy skills (National Center for Education Statistics, 2007).

Socioeconomic Status and Academic Achievement

Educational outcome leads to SES outcome, which, in turn, leads to students' children coming in a generation later with either a built-in disadvantage due to a low SES background or a built-in advantage due to higher SES background. When SES outcome is low for groups labeled as "underclasses" or "outgroups," then the cycle of justification through myths, discrimination, and behavioral asymmetries (Pratto et al., 2000) – eventually leading to low SES conditions – is perpetuated (Portes, 2005). Why? Because of the fewer total number of access points (i.e., points of access to the meritocratic system that members of the hegemonic group have seamless access to) available to "outgroups" (African American, Latino, Native American) relative to the number of access points available to hegemonic and assimilated groups. Initiatives designed to achieve parity in educational outcomes (e.g., United Negro College Fund, La Raza, school scholarships) are made available based on a student's academic performance – which itself relies, in large part, on critical thinking and other cognitive skills that are beyond the level of basic literacy. So, a pattern emerges within which the span of a student's time in a school system appears to be hopelessly cyclical: a low-SES/”outgroup” student has some chance to acquire basic literacy but not a high chance of acquiring more advanced (e.g., science) literacy. However, the little access he or she has to situations ensuring (or, at least, encouraging) the acquisition of science literacy requires this very access. It makes little sense to demand that students from the traditional underclasses develop the metacognitive skills, critical thinking and higher-order computational ability, and ambition when they are barely able to keep up in terms of basic literacy and retention rates (Kober, 2000; Vernez, Krop, & Rydell, 1999).

Socioeconomic background is tied to the opportunity for an equitable education. Despite an increasing number of Latinos making their home in the traditional South, the majority of Latinos still reside in major cities (Bohon et al., 2005; National Research Council, 2006). Children of Latinos of low SES backgrounds tend to cluster in low SES ethnic enclaves, often located in low SES areas (NRC, 2006). The schools that serve low SES communities tend, due to the diminished tax base representative of low SES communities, to be lacking in the components making up the access to equitable education. These schools tend to be overcrowded, underfunded and staffed by under qualified teachers (Barton, 2003; Orfield & Yun, 1999). To compound matters, Latino students, like their low-SES counterparts of other ethnic backgrounds, are often tracked, resulting in their placement in less rigorous learning environments (Oakes, 1995; Zarate & Pachon, 2003). These situations have the effect of further reducing Latino students’ access to equitable science education. Latino science learners end up in science learning environments that lack proper supplies and equipment and more likely than not have limited opportunities to conduct authentic science research (Kozol, 2005; Lynch, 2000; Zuniga, Olsen, & Winter, 2005).

Virtually all professions, whether in academia, industry, government, and so on, require some measure of critical thinking and higher-order problem-solving ability – abilities that are supported through the acquisition of scientific literacy (American Association for the Advancement of Science, 1993; National Research Council, 2001; Yore, 2001). Children of Latino immigrants and other traditional Latino populations are less likely to improve their socio-economic status due to their initial SES background. They, in turn, are likely to inherit the SES of their parents, thus perpetuating cycles of inequality and poverty. The acquisition of scientific literacy can play a crucial role in an escape from these cycles (Portes, 2005).

Research on the Knowledge of Students: What Science Content Knowledge Should U.S. Students Possess?

At the local level, each state has developed student performance standards for each content area, including science. The State Performance Standards (SPS) for science are typically aligned with both NSES and the *Benchmarks*. The SPS outlines the minimum standards a student should know and be able to do in science. The three categories of standards included in the SPS are associated with characteristics of science (habits of mind, the nature of science) and content knowledge. The SPS outlines the major concepts that students completing 8th and 12th grade should know and be able to do as a result of their participation in a science program. Table 3 lists the major concepts for physical science programs.

Table 3

The State Performance Standards for Required Physical Science Content Knowledge and Skills for Grades 8 and 12, Including Characteristics of Physical Science for all Students Between Grades 8 and 12.

Grade level	Major concepts and skills for physical science
8	The nature of matter, Atomic theory/periodicity
	Conceptual acid/base- phase changes, Law of Conservation of Matter
	Law of Conservation of Energy, Conceptual Laws of Motion and Forces
	Conceptual energy transformation,
	Electrical/Magnetic forces, Wave properties
12	Transformation,
	Electrical/magnetic forces, Wave properties

Note. All students in grades 8-12 should know and do characteristics of science. From "Eighth Grade Science Curriculum" by State Department of Education, 2004.

To effectively develop these kinds of knowledge and ways of thinking in students, a curriculum developer such as a physical science teacher should address all three SPS standards within each lesson. For instance, in an 8th grade lesson identifying chemical and physical properties of matter, a teacher must include and identify each standard that is being met by the particular lesson. Then the teacher may choose from a list of standards and elements (subcategories) for the lesson. For her lesson, a teacher may include the following three standards and elements: Science grade 8 Characteristics of Science Standards # 6 element a

(S8CS6 a): Students will communicate scientific ideas and activities clearly and will write clear, step-by-step instructions for conducting scientific investigations, operating piece of equipment, or following a procedure. Science grade 8 Characteristics of Science Standards # 9 element b (S8CS9 b): Students will understand the features of the process of scientific inquiry and will understand that scientific investigations usually involve collecting evidence, reasoning, devising hypotheses, and formulating explanations to make sense of collected evidence as a result of this lesson. Science grade 8 Physical Science Standard #1 element d (S8PS1 d): Students will examine the scientific view of the nature of matter and distinguish between physical and chemical properties of matter as physical (i.e., density, melting point, boiling point) or chemical (i.e., reactivity, combustibility).

How is students' knowledge measured?

The National Center for Education Statistics provides educators and researchers with the results from three assessment measures aimed at evaluating the performance of students in various academic disciplines. Both the International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) are international measures that assess the performance of students in key subject areas. TIMSS measures 4^{th} and 8^{th} graders' knowledge of mathematics and science. The 2007 TIMSS was administered to 4^{th} graders in 36 countries and to 8^{th} graders in 48 countries (U. S. Department of Education & National Assessment of Educational Progress, 2007). PISA measures 15-year-old students' knowledge in mathematics, science, and reading literacy. The 2006 PISA was administered to 15-year-olds in 57 countries (U. S. Department of Education & National Assessment of Educational Progress, 2007). The National Assessment of Educational Progress is the only national assessment for the United States. The NAEP assesses students in reading, mathematics, science, writing, the arts, civics, economics, geography, and U.S. history and is administered in grades 4, 8 and 12. For TIMSS, PISA and NAEP assessments, samples of students are measured periodically. Tests results from all three exams are then compiled and segregated for analysis into different categories that include mean averages in terms of gender, race and ethnicity, geographic locations and various other special interest groups. NCES provides The Nations' Report Card, a report compiled using NAEP data that shows and explains national trends and comparisons among groups of students. NAEP and NCES provide a web-accessible database from which test data can be mined according to a wide array of user-defined variables such as ethnicity, SES, region, grade level, etc.

Measuring science knowledge in the United States.

Despite attempts in the NSES, the *Benchmarks* as well as in the state and local standards to clearly outline the knowledge and skills needed to develop a scientifically literate populace, a number of surveys show that U.S. students come up well short of those goals. By some measures, less than one-fifth of U.S. citizens meet a minimal standard of scientific literacy (Miller & Pardo, 2000; Miller, Pardo, & Niwa, 1997). On a number of TIMSS and PISA assessments, U.S. students lag behind other developed countries in science and mathematics (Gonzales, 2008). While students are able to demonstrate at least a superficial knowledge of science-related concepts (for example, DNA), most U.S. citizens do not apply the process of scientific inquiry (National Science Foundation: Division of Science Resources Statistics, 2006). In a 2004 NSF survey, only 23% of U.S. citizen respondents could explain in their own words what it means to study something scientifically. Many U.S. citizens still reject the Darwinian theory of evolution (National Science Foundation: Division of Science Resources Statistics, 2006) and accept unsupported claims as those advocated for in pseudoscientific beliefs, e.g., astrology, magnetic therapy, lucky numbers, etc. (Losh, Tavani, Njoroge, Wilke, & Mcauley, 2003).

That students currently studying in U.S. schools are lagging behind their peers in other industrialized nations in terms of test performance is evident from the available data (Gonzales, 2008; National Science Foundation: Division of Science Resources Statistics, 2006). However, it is important to also take into account the fact that U.S. citizens are not a homogeneous group whose level and rate of progress can be measured collectively. Students attending U.S. schools are descended from, identify with, and represent a great variety of groups of diverse cultural and ethnic heritages. Within these cultural and ethnic self-definitions are contained a variety of beliefs about the relationship of the self to the "American" collective -- which includes the value and efficacy of compliance with, and trust in, institutions such as the U.S. education system. In addition, due to the history of the social, cultural and economic actions that these groups undertook as they reacted and adapted to the U.S. society they encountered, there emerged certain trends associated with the academic achievement of their youth in U.S. schools. It has become apparent that students from a number of cultural-ethnic groups are lagging behind their peers in terms of academic achievement. This is most evident in the observed trends in academic performance associated with groups such as Latinos and African Americans. These groups, along with others such as Native Americans, have informally yet effectively been grouped into socioeconomic "underclasses" by the collective, as seen in prevailing and dominant discourses that justify and reinforce beliefs about the ability of individuals in these groups to fully benefit from the presumed meritocracy that partly defines U.S. society. The results of such reinforcement of stereotypical belief are most apparent in, for example, the persistent gap in academic performance between Latino U.S. students and their peers.

By convention, the term "academic achievement gap" has referred to differences in academic performance on various educational measures (i.e., TIMSS, PISA, etc.) for distinct populations, especially groups identified by race/ethnicity, gender and socioeconomic class (Anderson, Medrich, & Fowler, 2007) data accessed from the NAEP test database suggest a number of trends. Among U.S. students in U.S. schools, Latinos are among the lowest scoring groups as suggested by the prevailing measures. Latinos historically have not, on average, done as well on standardized examinations such as the NAEP as compared to White and Asian students (Center on Education Policy, 2007). The 1973 – 2004 mathematics and reading trends as reported by the NAEP report that the average score of Latino 17-year-old students was roughly the same as that of a 13-year-old White student (National Center for Education Statistics, 2007). By extension, Latinos and Spanish-speaking ELLs many of whom do not possess basic literacy, do poorly on measures for scientific literacy. For instance, the average scores of twelfth grade Latinos in the science portion of the 1996, 2000 and 2005 NAEP are 27 points behind their White counterparts (U. S. Department of Education & NCES, 2007, table 13-2). Twelfth-grade English Language Learners (ELLs), 79 % of who are of Latino origin, scored 41 points less than the non-ELL population (Kohler & Lazarin, 2007; NAEP, 2005). At the state level, the percent of Latinos meeting and exceeding state standards in biology and physical sciences as measured by State' s End of Course Exams (EOCT) has increased over the 2007-2008 testing period (+4% and +4%, respectively). The percent of ELLs meeting and exceeding the standards in physical science portion of the EOCT increased by 16%. The percent of ELLs meeting and exceeding the standards in the biology portion of the EOCT remained the same. Overall, however, Latinos have persistently lagged behind White and Asian peers (Georgia Department of Education, 2009).

Educational Interventions: Their Nature and Their Goals

Performance measures indicate that Latinos and Spanish-speaking ELLs are not performing up to their potential academically. Educational interventions have been instituted at all grade levels in an effort to decrease the academic underachievement experienced by Latinos, especially Spanish-speaking ELLs. Here, intervention refers to “an educational program (such as whole school reform), product (such as a textbook or curriculum), practice (such as mixed-age grouping), or policy (such as class size reduction) aimed at improving student outcomes” (What Works Clearinghouse, n.d.). Educational interventions present an array of programs as well as pedagogical and curricular practices leading to different outcomes; for instance, NSF funds programs at the university level that increase the participation of Latinos in geoscience careers. Thus, to meet the goal of increased participation, interested institutions devise specific interventions such as creating an educational “pipeline” emphasizing rigorous science and mathematics coursework at the secondary and post secondary levels (Levine, Gonzalez, Cole, Fuhrman, & Floch, 2007; Stokes, Baker, Briner, & Dorsey, 2007). NCLB identifies supplemental education as an educational intervention for students who have not met the reading and mathematics expectations required by the state (U. S. Department of Education, n.d.). NCLB also identifies bilingual education as an educational intervention for students acquiring the English language. Here a distinction must be made regarding the goals and aims of bilingual education. Bilingual education can be considered as both an intervention and as a pedagogical model, depending on the nature and goals of a given bilingual program (as well as the way in which educators involved in such a program see it). Such a program would be an intervention if the aim of it is to quickly bring ELLs to parity with their English monolingual peers. Short-term placements in such a program would bring students to an acceptable level of English language competency while educating them in the content knowledge and skills of the various subjects that the students are given. However, in the sense that ELL students' already existing L1 and culturally specific subject content knowledge and skills, bilingual education could be seen as a pedagogical model, in which students' pre-existing knowledge would be recognized as beneficial and as constituting building blocks for their further language and subject content knowledge acquisitions.

State of bilingual education and the need for English language acquisition.

The current NCLB mandate requires that all students (including ELLs) become proficient in English as well as in content areas "and meet the same challenging state academic content and student academic achievement standards as all children are expected to meet" (No Child Left Behind, 2001). Under Title I and Title III, all states are required to assess ELL proficiency in content and the English language in a valid and reliable matter. In addition, all states are mandated to show that ELLs are making academic yearly progress in the development and attainment of the English language as well as meeting the same content standards as those imposed on native English speakers (Menken, 2006; No Child Left Behind, 2001).

States designate the type of bilingual education ELLs receive. Schools can choose from an array of bilingual education programs. Bilingual education programs are chosen from a continuum ranging from two-way instruction to total immersion. The most effective bilingual program has generally been shown to be the two-way instruction program where students receive instruction in both native (native language or L1) and host language (Language two or L2) (Alanis, 2000; deJong, 2002; Thomas & Collier, 2002). Two-way instruction is highly recommended by experts because it has been found that when L1 is developed and sustained, cognitive knowledge is transferred to L2, thus facilitating both L2 and academic acquisition

(Ben-Zeev, 1977; Cummins, 1977). Immersion programs, common implementations of bilingual education, place or "immerse" ELLs in English-only classrooms. Immersion programs are highly varied. In some immersion programs, students are "pulled out" for a brief period of time (usually an hour everyday) to receive English instruction. In other programs such as sheltered instruction, teachers modify lessons in order to teach English and academic subjects. Immersion programs are considered less effective because of L1 (i.e., Spanish) devalorization, lack of trained professionals, lack of resources and length of implementation (Garza & Crawford, 2005).

Current tools for assessing English acquisition in ELL students are helpful in understanding what is typically seen as constituting L2 acquisition in its broadest sense. For instance, the Accessing Comprehension and Communication in English State to State (or ACCESS) test for ELLs is specifically designed to assess the English language proficiency of ELLs in many states including the state in which this study is being conducted. ACCESS was designed by the World Class Instructional Design and Assessment (or WIDA), a multi-state consortium dedicated to the academic achievement of ELLs (Georgia Department of Education, n.d.). ELLs are tested in four domains (reading, writing, listening and speaking). ELLs are first screened with the use of an instrument titled W-APT (WIDA-ACCESS Proficiency Test) and are then placed in different levels according to English proficiency level. The levels range from Level 1, Entering – reflecting only rudimentary knowledge of and skills in English – to Level 6, Reaching – the level at which students can succeed academically in English on par with their English proficient peers in speaking, listening, reading, and writing (Board of Regents, University of Wisconsin, WIDA Consortium, 2007).

Curricular and Instructional Interventions that have Worked for Students, Including ELLs, In increasing both English and Science Literacy.

Schroeder, Scott, Tolson, Huang, and Lee (2007) conducted a literature review to understand which teaching strategies work best for all students to achieve in science. The authors used quantitative studies dating from 1980 to 2004 that looked at teaching strategies in U.S. schools and their impact on student achievement on standardized exams (Schroeder, Scott, Tolson, Huang, & Lee, 2007). To guide their literature search, Schroeder et al., (2007) used Wise's (1996) definitions of traditional and alternative teaching styles. Wise distinguished traditional teaching styles as teachers acting as dispensers of knowledge to passive student audiences, using only textbooks as science curricula and providing limited hand-on experiences to students. Alternative teaching styles are described by Wise as including a variety of teaching techniques that use questioning, focusing, manipulation, enhanced materials, testing, inquiry, enhanced context and instructional media. Sixty-one studies on teaching styles and teaching techniques were binned, analyzed and compared. Enhanced context strategy, a strategy that relates topic to previous experience and engaging students' interest was found to have the largest effect on student achievement. Collaborative learning strategies such as "flexible heterogeneous grouping and group inquiry projects" were found to be the second most effective pedagogical strategy for increasing student achievement. Alternative teaching styles overall and enhanced context and collaborative work in particular were found to be the most powerful tools for science knowledge acquisition when combined with inquiry and an effective teacher.

Highly rated, rigorous curricula utilizing inquiry-based methods develop can both science knowledge and increase English language proficiency. (High-quality) curricula that use inquiry-based instruction can accommodate students' different ways of knowing and learning. When inquiry-based science curricula are designed to additionally develop linguistic competencies, ELLs can acquire both L2 and science literacy (Calderon, 2001; Lynch, Kuipers, Pyke, &

Szesze, 2005). Inquiry-based science education provides ELLs with the opportunity to interact with their environment, manipulating materials and activating prior knowledge. It also allows students to interact with another, providing opportunities for verbal interactions with peers in a less formal environment. The language barrier need not represent a barrier against science learning. Cuevas et al. (2005) conducted a quantitative study on elementary school ELLs in a large, urban school district located in the southeastern U.S. The intervention, implemented over one academic year, used the inquiry approach delineated by the standards to teach science and literacy and consisted of instructional units, teacher workshops, and classroom practices. The researchers determined that the intervention enhanced inquiry ability of all students regardless of grade, achievement, gender, ethnicity, socioeconomic status (SES), home language, and English proficiency.

Rosebery, Warren, and Conant (1992) studied science knowledge acquisition of Haitian Creole bilingual students with an inquiry-based approach (collaborative group work). Two groups of students participated in this study. One group consisted of 7th and 8th grade students and the other group consisted of high school students considered at risk of dropping out of school. Both groups of students were academically underperforming and some of the students were bi-illiterate (lacking reading and writing skills in both the Haitian and English language). Over the course of one academic year, students worked in groups and conducted authentic science inquiry. The authors noted that the inquiry approach allowed the students to articulate scientific discourse and that scientific knowledge and reasoning positively changed.

Inquiry-based science instruction has been shown to increase L2 literacy. Hampton and Rodriguez (2001) found that ELLs in three elementary schools in El Paso, CA increased both their Spanish and English language proficiency and science content knowledge when a hands-on curriculum (Full Option Science Series, or FOSS) was used. Similar results were found in a study conducted on K-8 ELLs attending schools in El Centro Elementary School District, CA. Similarly, Amaral et al., (2002) used the FOSS curriculum in addition to having the students use science notebooks for journaling and other writing practices. Inquiry-based science helped all students achieve higher in science, math, reading and writing.

Bravo and Garcia (2004) used an inquiry-based thematic science curriculum to examine scientific inquiry, language, literacy and collaborative interactions among fourth grade ELL students attending four elementary schools in a mid-size urban school district. Bravo and García found that when teachers used students' constructed knowledge (already existing in language and culture) in conjunction with inquiry-based (hands-on) science emphasizing literacy skills (working on authentic tasks for reading and writing couched in science), students' understanding about "writing like scientists" matured and students' abilities to write expository texts were enhanced. Students were able to write science reports that reflected their understanding of the scientific inquiry model. In a quasi-experimental study focusing on the effects of discourse and writing language activities in the science classroom, Rivard (2004) found that among Canadian bilingual 8th graders from four different schools, discourse (in peer groups) accompanied by writing proved most beneficial for science knowledge acquisition among all students, especially among low-achievers who scored higher on two subsequent post-tests (Rivard, 2004).

Carlo et al. (2004) conducted a quasi-experimental study on Spanish-speaking ELLs and English monolingual fifth graders attending four different elementary schools in California, Massachusetts and Virginia. Carlo used a curriculum intervention with specific strategies (cognates, words in contexts, direct teaching of words and incidental learning) to increase vocabulary acquisition among the students. The researchers found that vocabulary acquisition increased for both ELLs and English-Only fifth graders after the 15-week intervention period (Carlo et al., 2004).

The quality of science curricula is as important as L2 acquisition strategies in order for both science and L2 literacy acquisition to be most efficacious and meaningful. In other words, it is best if both factors are considered and implemented simultaneously. Lynch et al. (2005) exposed middle-school students of diverse linguistic and cultural backgrounds to a highly rated science curriculum. Fifteen hundred 8th grade students enrolled in five middle schools in the Montgomery County Public Schools (MCPS) located in the Washington, DC, metropolitan area, were pre- and posttested on their science knowledge after being exposed to a hands-on, minds-on highly-rated chemistry curriculum unit (as rated by those involved with Project 2061). Researchers determined that all students from diverse linguistic and cultural backgrounds exposed to the curriculum outperformed their peers. The mean score of ELL students transitioned out of ESOL also was significantly higher. The only group not showing a marked increase in post-test scores was the group of ELL students currently in ESOL tracks.

The manner in which L2 is utilized in inquiry-based instruction is key to ELLs' acquisition of both science and L2 literacy. Torres and Zeidler (2002) recommend that curriculum be metacognitively demanding, involving both cognitive and critical thinking skills. In their study, the authors examined the effects of language proficiency on the acquisition of science content knowledge by Latino English Language Learners. They set out to test if higher levels of English proficiency and reasoning skills are prerequisites for acquisition of science content knowledge. The authors used Cummins' (1981) work on cognitive academic language proficiency necessary for ELLs to succeed academically as a theoretical foundation to examine these effects. Students who have not developed CALP could be at a disadvantage for learning science content knowledge. Torres and Zeidler also referred to Lawson's (1989, 1991) work on formal reasoning. According to Lawson, formal reasoning skills (i.e., hypothetico-deductive reasoning skills) are not only necessary for most high school science courses but are necessary to acquire new scientific knowledge. Their study consisted of 380 ELL students in the 10th grade taking science courses enrolled in high school located in an urban city in the northeastern part of the United States. Students were administered pre- and post-tests of English proficiency and scientific reasoning skills. Researchers found that "both higher order of English language proficiency and scientific reasoning skills were shown to predict success in learning science concepts" (Torres & Zeidler, 2002, p. 50). The authors recommend that science curricula adopt or integrate Cummins' and Lawson's work as theoretical bases for efforts to enhance academic performance in science content matter among ELLs.

ELL students need to be exposed to both BICS and CALP. BICS allows ELLs to increase speech competencies and articulate thoughts and processes with the aid of contextual cues. However, CALP is necessary to conduct scientific inquiry. ELLs need to learn how to question, hypothesize, synthesize, argue and explain concepts, ideas and conclusions. Exposure to English by means of cooperative groups with native English speakers is not enough to develop CALP because it is often the case that conversations between ELLs and their English speaking peers are limited, brief and superficial in nature (Harklau, 1999). In this context, teachers should step in as a model for science and L2 fluency. In this reciprocal teaching situation, the teacher plays strategic roles, scaffolds and models scientific inquiry (Palinscar & Brown, 1984). For example, the teacher may role play with a group of students and ask herself, "Why are most leaves green?" The teacher then audibly reads a passage on photosynthesis and the light spectrum. As she reads, she asks questions, stops, thinks and checks on student comprehension. She writes down her synthesis of the passage. She then models and uses the scientific method in an investigation, highlighting her scientific reasoning, deductive and inductive skills and ability to draw conclusions. At first, she provides lots of help and feedback and removes her help over time (Australian Government of Education, 2002; Walqui, 2006). In short, students are shown how "science is done using L2" by the teacher and then are encouraged to "mimic" the teacher's activity and discourse. The level of language used in this context introduces discipline-specific technical terms as well as terms used in empirical inquiry.

Science teachers should not hesitate to introduce and establish the practice of science journaling among their ELL students. Students should become accustomed to writing their scientific inquiries, making sense of their observations, questioning, hypothesizing, assumptions, and conclusions (Akerson & Young, 2005). Teachers then have an opportunity to provide appropriate and constructive feedback, clarifying grammatical and morphological errors (Peyton & Reed, 1990) such as verb tenses, plural and possessive forms of nouns, and the use of articles (Ferris, 2002). Often, these grammatical errors in L2 are influenced by the students' native language because of differences in grammatical structure between L1 and L2.

Teachers need to provide different forms of expressions that harness their understanding of linguistic concerns. Teachers need to keep in mind that it may take between 7 to 10 years to become academically proficient in L2 (Ramirez et al., 1991); a given ELL student could be at any stage of L2 acquisition, and no assumptions can be made in that regard until assessment data is available. ELLs can become proficient with specific forms of L2 first; for instance, an ELL student can read at proficient levels but have not yet mastered oral skills. Lesson planning needs to address conceptual and linguistic development. Alternatively (or in conjunction with other techniques), a number of in-class strategies could be used to reduce linguistic demands. Teachers could use models to explain concepts, graphic organizers to connect ideas and synthesize key concepts, and nonverbal support such as visual representations (Ashton, 1996; Dixon-Krauss, 1996a; Ellis, 1994; Facella, Rampino, & Shea, 2005).

Science teachers cannot provide the means for students to learn science content without providing students with the tools of science discourse (Huang, 2004). Often, problems in articulating science concepts through discourse (spoken, written) are attributed to lack of fluency in the English language. However, it could be the case where the teacher is not modeling or provoking a meaningful construction of science knowledge for the student because that teacher is not sharing a 'language' of science discourse with the students in general, and with the ELL students in particular (Moje, Collazo, Carrillo, & Marx, 2001). Along those lines, students who show a low level of 'language' mastery will likely show a low level of 'content' mastery, regardless of their L2 (English language) mastery (Huang, 2004). Furthermore, ELLs, especially those whose native culture is not the same as the dominant local culture, feel alienated and marginalized when they fail to adapt to the school's cultural and scientific discourse (Bravo & Garcia, 2004; Lee, 2003; Moje et al., 2001).

Numerous studies, anchored in Vygotsky's social constructivist model, propose that teachers use students' funds of knowledge and build congruent third spaces to bridge discourses used outside (spontaneous knowledge) and inside the classrooms (scientific knowledge). Moje et al. (2004) recommend that teachers build congruent third spaces where students' "different discourses, knowledge of the discipline, and students' lives are brought together to enhance science learning and scientific literacy" (Moje et al., 2004). For instance, Calabrese-Barton and Tan (2008) found that when 6th grade science students in a predominantly Latino urban middle school were provided with the opportunity to share their culture and funds of knowledge, students were more motivated and engaged in a unit on nutrition (Calabrese-Barton & Tan, 2008). Similarly, Lee and Fradd (1998) present the idea of instructional congruence whereby teachers who develop an understanding and appreciation of their students' language and culture facilitate communication and understanding as it pertains to science concepts and knowledge acquisition (Lee, & Fradd, 1998). In a study conducted by Tobin (2008), students from diverse backgrounds attending an urban impoverished secondary school were more involved in scientific inquiry and discourse when the teacher connected what they were doing in a laboratory exercise with everyday "spontaneous" knowledge.

The literature review presented in this section suggests that collaborative science inquiry activities that are cognitively demanding enhance both L2 competencies and scientific literacy. Furthermore, constructivist-driven curricular and instructional approaches also nurture and support L2 acquisition. However, research that supports the development of Spanish, English and science languages simultaneously in high school Latino balanced bilinguals is scant or altogether missing.

Research on Enrichment Programs

Supplemental education also known as enrichment programs or formal after-school programs, are programs designed to support and provide extended learning time for students after regularly scheduled school days. Several academic enrichment programs aimed toward the "economically disadvantaged" owe their beginning to President Lyndon B. Johnson's War on Poverty initiatives. Early childhood programs such as Head Start and Even Start, adolescent programs such as Upward Bound, GEAR UP and college undergraduate support systems for "disadvantaged" students have aimed to increase the academic readiness for continued successful schooling (Fields, 2001; The White House and President Barack H. Obama, 2009). Furthermore, under the No Child Left Behind Act, schools who do not meet AYP are required to provide supplemental education in reading and writing in an effort to help students in their schools achieve and succeed academically (National Coalition for Parental Involvement, 2007; U. S. Department of Education, 2009).

Gullatt and Jan (2003) suggest practices for effective pre-college enrichment programs geared toward secondary school students. Among the 10 best practices mentioned are high standards for program students and staff, personalized attention for students, adult role models, peer support, and evaluation designs that attribute results to interventions (Gullatt & Jan, 2003). Project EXCITE employed all of these practices with great success (Lee, Olszewski-Kubilius, & Peternel, 2009).

Overall, the literature on the success of supplemental education in improving and increasing academic knowledge and skills for “disadvantaged” students reports mixed results. Different variables such as duration (extent of after-school programs or summer programs), services provided (e.g. types of outreach, parental involvement and education, assistance in college admissions), and types of academic enrichment support (tutoring, study groups, college preparation subject matter, advising and counseling) make it very difficult to measure the success of enrichment programs (Gullatt & Jan, 2003).

Huang, Gribbons, Sung Kim, Lee, and Baker (2000), however, found that higher participation in after school enrichment programs is significantly related to positive performance on standardized tests and regular school attendance (Huang, Gribbons, Sung Kim, Lee, & Baker, 2000). Riggs and Greenberg (2004) reported increased academic performance among Latino and non-Latino low-SES, low-performing elementary students after their participation in an after-school enrichment program (Riggs & Greenberg, 2004). Similar results were reported by Posner and Vandell (1994) for low-SES students attending after-school programs. At the secondary and college level, enrichment programs appear to work effectively for "disadvantaged" students in enhancing their academic performance. In a survey conducted by the College Board on pre-collegiate academic development programs, the authors found significant academic benefits for "disadvantaged" students attending such programs as compared to their more privileged counterparts (Swail & Perna, 2002). Barlow and Villarejo (2004) found that college students of color who participated in science and mathematics enrichment programs had a greater propensity to continue developing mathematics and scientific skills, and increased the probability of graduation and continuing to graduate studies.

Studies focusing on science enrichment programs have also reported academic benefits for students, especially Latinos. Stake and Mares (2005) reported positive effects on attitudes toward science after 88 gifted secondary students were exposed to a summer science enrichment program (Stake & Mares, 2005). Enrichment projects such as EXCITE aimed at preparing gifted African American and Latino students for high school advanced tracks in mathematics and science generated increased interest and motivation toward mathematics and science among its participants (Lee, Olszewski-Kubilius, & Peternel, 2009).

Missing from the literature on the effects of enrichment programs are studies that measure secondary level Latino ELLs' acquisition of scientific literacy in a two-way bilingual Spanish-English enrichment program. Not only does this study hold the promise of an exciting new direction for meaningfully and effectively reaching out to Latino ELLs, but the results of this study will, regardless of its findings, fill a significant gap in the relevant literature.

Summary

One aim of reform efforts of U.S. science education has been to increase the level of scientific literacy among its citizens, such that citizens are most able to function in today's world. Fundamental to scientific literacy is the ability to critically solve problems. Basic literacy, content knowledge and other key characteristics of science are necessary components of scientific literacy. National standards such as the NCES, the *Benchmarks*, as well as state standards, specify the knowledge and skills that every student possesses. National and international assessments such as TIMSS, PISA and NAEP are the primary measures that indicate what students know and can do. Results from these assessments can also be mined in order to compare academic achievement among students. In general, Latino students perform lower on these exams as compared to their White counterparts. Lower performance is directly tied to academic achievement. Lower academic achievement, in turn, has been linked to decreased opportunities in future academic endeavors, job opportunities and a trans-generational cycle of poverty.

Various curricular and instructional practices have been applied and studied in an effort to understand what works best for all students in science education programs. Alternative teaching techniques, such as enhanced context strategies, collaborative experiences and inquiry teaching, are the best teaching tools to enhance science knowledge acquisition (Schroeder et al., 2007). Hands-on, collaborative work and inquiry activities, coupled with rigorous curricula and culturally congruent teaching have been shown to work best for increasing both English proficiency and scientific literacy among Spanish-speaking English Language Learners. Along the same lines, educational interventions such as bilingual programs and supplemental education have been found to lead to positive academic and linguistic outcomes for English Language Learners.

CHAPTER III

METHODS AND PROCEDURES

Overview

The purpose of this study was to explore teaching strategies that help secondary level Latino science learners develop scientific literacy. Through the use of quantitative and qualitative data collection methods, both teaching and learning strategies were identified. Qualitative tools included participant observation, interviews and participants' artifacts. Quantitative tools included pre and posttest examinations that aided in exploring participants' knowledge change as a result of their participation in a targeted after-school program. Collectively, these qualitative and qualitative tools provided evidence of effective teaching and learning strategies, as they occurred in situ and especially as identified by the participants.

This section outlines the methodology and praxis that was involved in this study. It begins with a discussion of the theoretical basis of the proposed methodology and proceeds to definitions and discussions of the methods themselves. Selection strategies and descriptions of the setting and participants will follow, concluding with a listing of some key materials to be used in the study.

Introduction

Academic or “scientific” knowledge is gained through the interactions between teachers and more knowledgeable peers as long as it is practiced within a student’s zone of proximal development (ZPD). Social interactions in the classroom take many forms – from teacher lectures, active involvement of students with the lesson, demonstrations and illustrations of concepts and models, to students sharing ideas with classmates during academic exercises and inquiry activities. One common mode of social interaction that occurs in the classroom involves what Wertsch (1980) calls semiotic flexibility. Semiotic flexibility is experienced in the classroom when the teacher adjusts his/her speech to provide responses or directives to students (Wertsch, 1984), especially when the teacher presents new information. At first, the teacher provides explicit directives using informative language (often referred to as academic language) to allow students to develop conceptual understanding. As students gain more control of the concepts, the teacher progressively moves away from direct and explicit instruction and towards a position in which s/he provides students with vague hints and suggestions until a final, relatively "hands-off" situation in which the students can apply, synthesize and evaluate knowledge independently. In this manner, the teacher provides support and modeling as students develop creative understandings during the social interaction (Cole, 1990, as cited in Dixon-Krauss, 1996). The possibility for the emergence of semiotic flexibility exists for both science and ELL-targeted education contexts. Inquiry-based instruction, for instance, capitalizes on semiotic flexibility. In inquiry-based instruction, the teacher demonstrates a procedure or task (usually in front of the class), and students model (structured inquiry), reconstruct (guided inquiry) or experiment to develop solutions independently (open inquiry) for the questions or problems that the provided tasks entail (Colburn, 2000).

Proponents of Vygotskian instructional methodology use scaffolding as a form of semiotic flexibility (Bliss, Askew, & Macrae, 1996; Dixon-Krauss, 1996a; Wai & Tao, 2004). Scaffolding is often recommended when working with ELLs (Fradd, Lee, Sutman, & Saxton, 2001; Walki, 2006). In inquiry-based instruction as well as in scaffolding, the teacher initially provides, defines and models the language, terminology and concepts specific to the lesson (Dixon-Krauss, 1996, p.195; Fradd, Lee, Sutman, & Saxton, 2001). Other scaffolding techniques that could be used to assist language and science learning include questioning and knowledge structuring. When used as a scaffolding technique, assisting and assessment questions help teachers and students connect and develop linguistic interchange through reciprocal feedback. Assisting questions help in guiding learners derive (or recall) prior concepts. Assessment questions help with gaining an understanding of students' prior knowledge so as to appropriate effective scaffolding techniques (Tharp & Gallimore, 1988). Another scaffolding technique suggested by Tharp and Gallimore includes cognitive structuring. There are two kinds of cognitive structuring: Type I and Type II. Type I provides explanations that structure knowledge. An example of Type I cognitive structuring in physical science consists of providing learners with facts such as "Light rays travel in straight lines." Type II cognitive structuring occurs when the teacher helps the learner organize (or structure) raw knowledge or functions. For instance, in an exercise of formulaic manipulations, a teacher may describe the sequence of steps necessary to isolate a variable.

Instructional strategies such as journaling, hands-on activities and verbally communicating findings and conclusions further support internalization in addition to increasing literacy and scientific skills. Journaling is an excellent instructional method that allows students to work within their own respective ZPD. Journaling provides students the opportunity to write creatively, to solidify ideas and share findings and conclusions and to reflect on what they learned through a nonrestrictive medium (Bravo & Garcia, 2004; Combs, 1996, p. 41; Rivard, 2004). In order to guide and challenge students to write within their own ZPD, the teacher provides explicit directives such as when posing open-ended questions or providing prompts. Students can then respond freely, tapping into their already internalized knowledge. This strategy is particularly helpful in developing more cognitive demanding language, or CALP, as students attempt to analyze and evaluate information (Cummins, 1989). With journaling, the teacher must always remain flexible, open to new ideas and self-expression. When working with ELLs, it is also important that the teacher allow journaling students to write freely, i.e., without penalizing students for spelling, grammar or other errors typically associated with essay writing. However, attention to grammatical and morphological aspects of the English language at appropriate times is important so that students can write and communicate more effectively (Fillmore & Snow, 2000, p. 30). As ELLs improve their knowledge of the English language, and receive supportive guidance about writing in science, errors in their writing should lessen as they increasingly self-organize and regulate their own writing.

Inquiry-guided instruction provides students with the opportunity to experience, manipulate, investigate and draw conclusions about science through a hands-on approach. Inquiry-guided instruction also increases the opportunity for ELLs to communicate in written and oral forms as they speak and share ideas with their peers (Lee, Penfield & Buxton, 2011). While conducting inquiry activities, ELLs must be allowed the freedom to speak in the language that they feel most comfortable with. As with journaling, as ELLs increase language competency in L2, they become more comfortable with the English language while at the same time enhancing their scientific discourse, both intrapersonally and interpersonally. Similarly, group projects and discussions among peers and teacher and students, provide the medium with which ELLs improve their literacy skills (verbal, writing and comprehension) and scientific skills such as those associated with the characteristics of science (investigating, communicating information, using technology, etc.). Other teaching strategies supporting L2 acquisition and scientific literacy for ELLs include the use of cognates and schematic and pictorial representations (Dixon-Krauss, 1996 p. 14, 51-53; Ellis, 1994; Facella, Rampino & Shea, 2005). As a result of all these teaching and scaffolding strategies, learners in general and ELLs in particular become familiar with the language, terms and concepts of scientific inquiry, eventually internalizing knowledge.

Tharp and Gallimore (1988) provide a model that helps track the progression of learners' performance. Organized as a continuum consisting of four stages, this model can help gauge learners' performance (or learning) level. For instance, stage I, found in the ZPD, identifies learners who require assistance from more capable others, such as experts, parents, teachers, coaches and peers to perform or “learn” a task. Stage II, also found in the ZPD, identifies learners who do not need assistance from others to perform. Rather, learners rely on their own knowledge, assisting themselves independently. Stage III, known as the 'internalization, automatization, fossilization stage” identifies learners who have internalized or fossilized knowledge. Stage IV, or the de-automization stage, refers to learners who revisit performances and prior knowledge to supplement, expand, further clarify or reconnect to their corpus of knowledge. In revisiting prior knowledge, learners in stage IV return to the ZPD (stages I or II), again requiring the assistance or others or of themselves. An example may help illustrate the application of this model. Let's say a person wanted to learn a new language. At first, more knowledgeable peers, such as a teacher, can help this person learn how to speak the language. During stage I, appropriate and effective scaffolding techniques are crucial because the learner's prior knowledge of language and/or affective domains can affect the depth of knowledge the learner is capable of handling at any particular time. With effective scaffolding techniques the learner can begin speaking independently (stage II). The novice speaker may listen to a language tape or practice speaking by him or herself. When the speaker can carry on conversations with others and without further assistance, language has been internalized, automitized and fossilized. However, if after some time the learner attempts to advance his or her knowledge of idioms (considered difficult in language learning), then the learner would require the assistance of others, teachers or peers for instance, to learn and revisit the appropriate language and/or expressions that accompany such understanding. At this point, the learner has de-automitized and has regressed to stage I or II.

Learners can be located at any point within the stages of the performance continuum. For instance, stage I may include novice and not so novice learners who still require assistance of others. Stage II may include learners who can perform parts of a task independently, but require assistance from others on some other parts. It is important to note here that internalized knowledge of a task or concept does not necessarily indicate “correct” knowledge. Misconceptions can also be internalized but hopefully de-automitized at some later point. Also, teachers or more knowledgeable others can only assist in learning and thus teaching can only occur in stages I or II or at the ZPD. A learner’s ZPD must be first identified in order to implement effective scaffolding strategies. The challenge for educators is to correctly identify the knowledge and skills each learner possesses so that they may build on those; devising and using appropriate scaffolding techniques and assisting learner's progress in the continuum.

Methodological Framework

Qualitative data analysis

This exploratory study aimed to gain an understanding of the learning strategies that Latino ELLs find most effective in a physical science setting as a result of their participation in an after-school program. To gauge the effects of this after-school intervention – that is, the potential change of students’ knowledge of physical science concepts partially as a result of their participation in LASPS – and potential effective curricular and instructional strategies for ELLs in the science classroom, both qualitative and quantitative data were obtained and analyzed. The qualitative research design permitted this researcher to draw from the richness of both types of data as well as the strengths of each type of analysis.

In this study, the qualitative research was best for data collection because this study was an attempt to answer multiple questions that are not readily given to one type of approach. The first two questions of this study attempted to investigate students' change in content knowledge as a result of an intervention and quantitative data collection methods were also used to help inform the study. Quantitative data collection methods usually include closed-ended information such as those found in performance assessments (for instance, a pre- and post-test were used to answer these two questions). Central to the multiple benefits and appropriateness of pre- and posttest data collection was the expediency of data collection and analysis given the time constraints of this study. In addition, this method provided quantitative research strengths, such as enhancing the validity and generalizability of the study as well as that of the assessment instrument itself (Johnson & Onwuegbuzie, 2004). The pre- and posttest instruments used in this study may be useful tools for future science teachers teaching ELLs. It is important to note that social constructivist ideologies, such as that put forward by Vygotsky, oppose performance testing because such tests assess learners' problem solving ability in a contextual vacuum. Since true problem solving processes are virtually impossible without social interaction in general and without the assistance of individuals of a higher ZPD, isolated testing would be thus contrary to basic human nature (Vygotsky, 1978, p. 88). However, in this study, the pre- and posttests were designed to provide students with models and demonstrations relevant to the test questions to help them draw from the tools used in science investigations and problem generations and solutions. For both pre- and posttests, students used available lab kits during the test period to answer questions. For the posttest, participants who participated in the study also drew from cognitive and kinesthetic memories of, as well as constructed knowledge from, supervised hands-on group activities. Thus, while tests can be interpreted as a departure from the theoretical basis for the study, this necessary quantitative component was designed with a Vygotskian constructivist framework.

Questions 3 and 4 of this study regarding students' ideas about effective curricular and instructional practices are best answered using qualitative data collection methods. Participant observation (PO), interviews and students' written products provide and present participants' ideas and opinions – as well as evidence of these ideas and opinions – and their moment-to-moment interactions and ongoing construction of meaning. With these data collection techniques, participants' ideas of most effective learning practices are fully explored and described from their point of view – as participant experiences embedded in the local context of a classroom (Johnson & Onwuegbuzie, 2004).

This study employed a concurrent embedded qualitative research design. Qualitative methods were used as the central data collection tool and quantitative data, in the form of pre- and posttests assessments, were used to enhance and help clarify results (Creswell & Clark, 2006; Greene, Caracelli, & Graham, 1989 p.259; Johnson & Onwuegbuzie, 2004, p. 22). The term 'concurrent' refers here to the fact that both kinds of data were collected at the same time during this study.

Qualitative Research

This study is essentially one of interactions between people. Moreover, the researcher is a person who acts as the primary observational and analytical lens of the study. Both of these human-centered, fundamental factors define the nature of this research study. While this study is one that falls under the rubric of social science, it is the focus on pedagogy and culture that provides an additional perspective that crosses different social science and humanities disciplines. In addition, the researcher-as-lens approach brings up issues of interpretation and social-historical context. Thus, we frame this study as a qualitative research study, especially as defined by Denzin and Lincoln (1994). The basic approach here is to understand human interactions as phenomena in their natural setting and context while, at the same time, to derive meanings which will lead to an improvement in the way students are taught the various subject matters deemed important for them to know. In this case, the focus is on Latino ELLs and their science knowledge acquisition in the contextual space of the science classroom.

Case studies.

The study's aim requires a focus on the participants and their interactions *in situ*, which is to say that, from an epistemological perspective, in the natural context in which the interactions occur. Meanings, both inherent (in the sense of those envisioned by teachers and students) and derived (in the sense of a researcher who has set out to understand a problem in pedagogy) are best drawn when the moment-to-moment goings-on in the classroom environment are left to unfold on their own. In this qualitative study, the case study approach was thus most appropriate. As a research strategy, the case study is preferred when the interest in some social phenomenon – be it an individual, a group of individuals, a program or initiative, and so on – is an in-depth, holistic understanding that preserves the meaning and context in which the phenomenon is observed (Flyvbjerg, 2006; Hodkinson & Hodkinson, 2001; Stake, 1994). An advantage of the case study approach is its applicability to both qualitative and quantitative data and analysis (Lipset, Trow, & Coleman, 2004, p. 113).

Case study typologies.

Viewing this approach through the prisms of the various case study typologies in the existing literature serves to articulate and clarify its basic orientation and nature. Let us first consider Stake's (1994) typology, which defines case studies as either extrinsic or intrinsic. The case studies proposed in this study cannot be considered to be intrinsic in nature because we do not have a specific interest in these particular research participants, this particular enrichment program, this particular school, and so on. Rather, the extrinsic case study permits us to consider the set and setting of our study (a local high school) as a prototype of similarly situated high schools with a new and small but growing Latino student population.

On the other hand, we can view our case studies as instrumental in nature (however loosely) because we did not know what science knowledge Latino ELLs in a city high school science classroom possessed and which pedagogical and curricular strategies worked best in order for them to learn science. If we had known, we would have observed and recorded that discourse and situated the research findings within some larger context (ELLs not being served by current bilingual strategy, etc.) without having to articulate the nature of the study's typicality.

In addition, we can view this case study approach as collective because multiple cases are studied. The proposed after-school program can be considered one case study and each participating student can be considered as an individual case study. Using the typology proposed by Yin (1989), we can make further helpful distinctions. Our case study approach can be seen as an exploratory case study approach because there is no prior knowledge or literature on the kind of teaching strategies secondary low performing Latino ELLs find to be most helpful in learning science.

Data led to two different levels of analysis. One level of analysis addressed the main unit, the "case", and another addressed the subunits, embedded in the "overall case" (Lipset, Trow, & Coleman, 2004, p.113). For instance, evidence collected in this study about the effectiveness of bilingual and science teaching strategies in a proposed after-school program were considered the main unit of analysis. However, data regarding participants' ideas about effective teaching strategies acted as subunits or units embedded in the main case. Thus, this study is one with an embedded multiple-case design, with data from subunits informing the main unit of analysis.

Limitations of case studies.

In case studies, research environments are open and not controlled; thus, they do not lend themselves to numerical representations limiting generalizability (in the conventional sense) to other populations (Hodkinson & Hodkinson, 2001). In other words, case studies cannot be used to generalize knowledge about some larger population based on the data collected. On the other hand, by observing something in one of the cases that may run counter to other hypotheses or established concepts, a case study can be very informative (Flyvbjerg, 2006). Case studies rely heavily on multiple sources of evidence to establish construct validity (Yin, 1989). Therefore, case study data are time-consuming to collect and analyze. Typically, case study analyses require researchers' skills and knowledge to design, conduct and administer multiple data collection instruments (Hodkinson & Hodkinson, 2001; Yin, 1989).

"The strength of case study data collection is the opportunity to use many different sources of evidence" (Yin, 1989, p. 96). The purpose of the case study approach is to gather as much complete and in-depth information about the case of interest. Yin (1989) recommends the use of multiple sources of evidence to develop converging lines of inquiry, thus increasing construct validity and reliability. According to Yin (1989) and Berg (1998), data triangulation – or the combinations of different kinds of data (Denzin, 1978 as cited in Patton, 1980) provide multiple measures of the same phenomenon. Triangulation attempts to prevent threats to validity identified in each data collection strategy (Fielding & Fielding as cited in Berg, 1998). For instance, strategies such as participant observation are limited by the perception of the evaluator-observer and interviews are limited by personal bias (Patton, 1980). In this study, focus group interviews, participant observation and documents were used as multiple sources of evidence for the case study approach.

Interviews.

Interviews are conversations between researcher and participant(s) with the purpose of gathering information about phenomena that is difficult to observe directly (Berg, 1998; Patton, 1980). Interviews can be conducted through face-to-face, postal or electronic mail and telephone communications and may vary in frequency and duration (Fontana & Frey, 1994). Interviews may be structured, semistructured or unstructured (deMarrais, 2004; Fontana & Frey, 1994). In this study, both standardized open-ended or semistructured interviews and unstructured interviews (in the case of participant observation and focus group interviews) were used. Questioning participants on predetermined topics and issues characterized semistructured interviews, however, the researcher, for the purpose of clarification, devised further questions. Semistructured interviews limit "naturalness of speech due to standardization of wording in interview questions" (Patton, 1980). In contrast and unique to unstructured interviews (Fontana & Frey, 1994) or informal conversational interviews (Patton, 1980) is the researchers' ability to formulate and ask questions while in the immediate context. Interview questions emerge from observations and are not predetermined. This strategy can be challenging to the researcher because the researcher has to formulate questions (if at all) "on the spot," thus adding pressure for researchers' keenness and quick ability to respond to the situation. Data collection and analysis can be an additional burden to the researcher due to the quantity and management of data. The interview as a data collection strategy has limitations. Participants can only report their perceptions of what has happened. Perceptions of both participant and researcher can be subject to personal bias and can be influenced by anger, anxiety, ability to recall events, emotional state and even politics (Patton, 1980).

This study employed focus group interviews or group interviewing. A focus group interview is a specific kind of interviewing addressing a small group of individuals regarding specific questions about a topic (Denzin & Lincoln, 1994, p. 365). Focus group interviews permit participants to share ideas and opinions about a specific topic in a more permissive, non-threatening environment (Krueger, 1988, p. 18; Krueger, & Casey, 2000). During group discussions, individuals may shift conversations, exchanging views, opinions and ideas. Glesne and Peshkin (1992) suggest that focus group interviewing may prove useful for younger participants because it encourages students to talk, especially when among peers.

As a research methodology, the focus group interview is pertinent to this study for two main reasons. First, the participants in this study are young individuals who may be more willing to talk about a topic when stimulated by group discussion. Secondly, focus interviews permit researchers to gather general background information about a specific topic of interest and stimulate and generate new ideas and concepts. In this study, students' ideas about the benefits of particular teaching strategies are sought out to gather general information about what works best for low performing ELLs when learning science.

Vignettes are qualitative tools used for eliciting opinions, beliefs and attitudes from participants. Finch (1987) describes vignettes as "short stories about hypothetical characters in specified circumstances, to whose situation the interviewee is invited to respond" (Finch, 1987, p.105). Hazel (1995) recommends using vignettes with young participants to stimulate discussions, especially regarding abstract or complex topics. The vignette used in this study, as part of the first focus interview, described a scenario of a teacher who was trying out different teaching methods for a sheltered science class (see appendix A). Participants read the vignette and discussed their ideas about the specific teaching methods described in the vignette. Semi-structured interview questions were employed throughout the group discussion and the discussion was audiotaped (see Appendix A). Participants were able to carry on discussions and answer questions in English or Spanish. Two other focus interviews were completed throughout the program. The two other focus interviews dug deeper into the reasons why students chose each particular strategy. However, the third interview addressed the effectiveness of the after-school program, querying more about their experiences in the program for evaluative purposes.

Participant observation.

Participant observation is a research strategy by which the researcher participates and documents his/her observations about ongoing events pertaining to the study/participant (Preissle & Grant, 2004). Participant observation strengthens the ability of the researcher to understand the emic perspective because they have the opportunity to live and perceive reality from the viewpoint of the participant (Patton, 1980). A continuum ranging from complete participant as observer, the observer as participant and the complete observer identifies/categorizes the degree to which a researcher participates in the "field" (Adler & Adler, 1994; Dewalt & Dewalt, 2002). Field notes are the traditional form of collecting data in participant observation (Emerson, Fretz, & Shaw, 1995). Participant observation as a data collection strategy has various limitations. Participants may react in atypical ways when they know they are being observed, limiting the researcher's observation of the "usual" and most common events (Patton, 1980). However, prolonged engagement and extended time may help participants feel more comfortable with the participant observation process and participants may return to the typical ways of doing things.

In addition, participant observation primarily focuses on participants' actions and interactions (Patton, 1980). Participant observation together with interviews has the potential to provide a clearer picture of internal and external behaviors. Participant observation forces researchers to rely more readily on inferences that can be strongly influenced by researcher bias (Adler & Adler, 1994). In this study, participant observation was used to document students' discussions during lessons. To ensure accuracy of data, two tape recorders were used and placed among student groups during five lessons.

Archiving and documentation.

Public and private archives are physical data that help researchers gain historical insights and can also serve as evidence of participants' experiences (Suzuki, Ahluwalia, Arora, & Mattis, 2007, p.315). For instance, web links can provide actuarial records such as standardized assessment records and prior science and mathematical courses (Berg, 1998; Yin, 1989). In this study, participants' demographic data and academic histories were acquired and provided insights about students' cultural and academic backgrounds. Demographic data was gathered with the use of an application form, and a demographic/evaluative survey, which was administered at the end of LASPS.

Research Design

Inception of the after-school program.

An invitation about a grant opportunity aimed at working with Latino students was offered at the State University. With the goal of increasing the enrollment of Latinos in universities, especially at the State University, the Hispanic Scholarship Fund (HSF) announced grants of up to $10,000 to educators and programs working with the Latino public school population in the vicinity of the university. The HSF grant specified certain city area high schools where the grant could be applied, the City High School being one of them. This unique grant opportunity had the potential to fund a bilingual after-school program specifically aimed at Latino science learners. Such an academic program would benefit gatekeepers and the Latino community alike. For instance, The State University and the HSF would increase their Latino outreach efforts for college matriculation, which is currently abysmal. Furthermore, such a program would establish a more positive relationship between the local schools and the university. So far, the perception is that the university holds a parasitic relationship with the local school district, due in part to the university's eagerness to use local schools as teaching and data collecting grounds. Similarly, the local school district would benefit from a no-cost after-school enrichment program specifically aimed at Latino high schoolers. No such program has been offered in the district. Moreover, the school district can increase awareness of academic programs that potentially work for the Latino student body. The Latino community is the fastest growing population in the county and efforts to address their academic needs are rapidly increasing. With the advent of the after-school program, the participating school would also benefit by increasing the Latino students' knowledge base (through extended exposure to science teaching). Lastly, Latino participants would benefit from a bilingual science program. Such a program would immerse Latino participants in a truly bilingual program (perhaps for the first time in their academic life), increase their knowledge base of science, science-related careers and college admissions.

A proposal was submitted to the HSF grant to conduct a Latino After-school Physical Science program (or LASPS for short) for Latino students at City High School. LASPS was awarded partial funding specifically aimed for science supplies, college trips and snacks. Specific parameters for LASPS were addressed as specified by HSF, the research study and the school's participating teacher.

First, the HSF specified that Latino students be the primary recipients of any program or services offered by grant applicants. Thus, for the after-school program a good number of Latino students were required as participants in the program. Since the aim of the program was to help all science students who are Latinos, an equal mixture of Latinos who were fluent in English and Latino Spanish-speaking ELLs was preferred. It is important to note here that Latinos can be inclusive or exclusive of ELLs. Non-bilingual Latinos and other non-Latino students could have participated in the program but were informed that the proposed after-school program would be conducted bilingually.

Secondly, for research and implementation purposes 15 student-participants were considered ideal for the program. Factors such as the ratio of student to teacher and availability of resources would have presented issues limiting the kind of outreach the program was designed for. Also, for qualitative data collection purposes, a higher number of students would have potentially limited the quality of the data.

Thirdly, the range of physical science topics and activities that could be addressed in 18 instructional periods were considered as a limiting parameter. Length of lessons and activities, resources, and availability for field trips depended on time and financial resources available.

Mr. Phil, City High participating teacher, agreed with the proposed parameters. We went on to discuss the topics in physical science that he deemed the most important for students to learn and revisit given the time frame of the program. Mr. Phil identified four areas in physical science where students experience the most difficulty. Mr. Phil recommended that LASPS cover the areas of motion, light reflection and refraction, mechanical advantage and electricity. Over the next few months following the initial agreement, Mr. Phil and I discussed the lessons for the program. He remained open about the proposed laboratory experiences that were offered by LASPS. However, for the topic of mechanical advantage, Mr. Phil specifically asked that the students construct a Rube Goldberg contraption. He felt that this hands-on experience was appropriate for the program. He explained that the proposed enrichment program would have the time and the resources to build a contraption, but most importantly, students would really enjoy building one. He said that the contraption would help solidify concepts related to simple machines and mechanical advantage. Project was approved under IRB # 2010-10127. Date of application was November 3, 2009.

LASPS design.

The design of LASPS was two-fold. On one hand, the instructional design for LASPS was key because we had to maximize participants' knowledge base and experiences with science in a short period of time. On the other, the design of the program was pivotal in that it shaped and informed data collection for this study. In the next section, program design and implementation regarding instruction is introduced, then a discussion of research considerations and data collection is addressed.

Physical science considerations for LASPS.

With the aim of enriching physical science concepts among the participants, Mr. Phil and I agreed on selected physical science topics. Mr. Phil selected topics that he deemed important to develop further and to supplement regular classroom instruction. Mr. Phil requested that all lessons taught in LASPS focus only on the physics content of the course rather than a mixture of physics and chemistry. The rationale behind Mr. Phil’s decision about focusing particularly on the physics portion of the physical science curriculum is based on two main points. The 8^{th} grade physical science curricula in this school district emphasizes chemistry, thus students experience more chemistry and chemistry laboratory exercises prior to entering physical science at the high school level. Secondly, materials for chemistry activities are readily abundant, thereby facilitating chemistry lab experiences to occur more often during regular classes. Topics suggested by Mr. Phil included force and motion, light reflection and refraction, potential and gravitational energy, electricity and mechanical advantage. As far as science teaching strategies, we agreed that hands- on lab activities should include a combination of new science classroom technology (Logger Pro Sensors) and online computer programs, in addition to regular physical science classroom resources (cars, weights, chronometers and so on). Selecting approaches to teaching the course was left entirely up to me, partly because I have more experience with bilingual teaching, and partly because of the research design.

The role of language in teaching LASPS.

In addition to constructivist recommended teaching strategies such as appropriate scaffolding (i.e., journaling and inquiry-based learning), this study employed bilingual teaching strategies. The role of language was thus an important consideration. Vygotsky claims that we (humans) learn through the use of cultural tools. Social language can be seen as a cultural tool used as the medium through which knowledge is interchanged. Language, as it was used in this bilingual program as well as my unique qualities (i.e., bilingual, similar in culture to students, and my teaching expertise) had the potential to give insights as to how language (in this case, the English language) adds or detracts from knowledge acquisition. It is important to state at this point that the aim of this study was not specifically to studying the role of language in learning (English, academic or science languages included). However, any knowledge about language use moves researchers and educators, me included, closer to understanding the role that language can play in learning science.

Before considering measuring the role of language, operationalizing the term “language” in this particular context would be most useful. For this study, language is taken to refer to academic language or the language used in a school setting. Furthermore, academic language is teased into two domains: the use of the English language as a way to learn science and the science language as a way to speak and express knowledge and understanding of science. When referring to the English language as a social and academic tool to learning, one must consider which aspects of the English language we could potentially measure quantitatively or qualitatively in a classroom setting. To quantitatively measure the of use of the English language in an academic setting, I consider the four basic language arts skills of reading, writing, listening and speaking to determine proficiency in a language. Each skill is then subdivided into various sub skills that experts in the field use to indicate mastery within each skill. For instance, in the writing skill, experts would examine syntax, grammar and so on. In addition to the four language skills that are most readily measured, cultural language is another component of language that may confound or enrich the measure of students’ basic skills in the English language. Cultural language here refers to the language used by the students to communicate ideas about the world and derived from the social interchange that happens every day, whether it be the language used at home and reciprocated in the school or the language used to communicate among peers. Measuring these specific language skills is beyond the scope of this study. What was possible for me to assess was participants’ fluency of listening, speaking, reading and writing skills in the English and Spanish languages (when used) as it was used in the classroom and in this program. The significance of examining the role of the English language in academic settings is important for any teacher. After all, it is the language of communication in US schools. More importantly, studying the relationship of the “social” language used by the Latinos and Latino ELLs in LASPS can potentially provide clues to how these students communicate scientific thinking.

Science language is its own language with specific modes, symbols and ways of expressions (Lemke, 1990). In this study, science language refers to the specific vocabulary and ways of expressing knowledge and understanding of physical science. It is also inclusive of mathematical language and its forms since many concepts in physical science are summarized and shared with the scientific community in mathematical expressions. Furthermore, both the science language I use to teach physical science and the science language students use to communicate their science knowledge are important. This semiotic exchange in communication between teacher and student and students among themselves set the stage for how relationships are constructed, how science is discussed and knowledge is interchanged. However, the aim of this study was not to gain specific insights about how science language is used as means to communicate concepts and ideas. What was possible in this study was to examine how both a veteran Latina teacher and high school Latino science learners express physical science language, and how these expressions may have led to conceptual understanding. Examining these modes of communication can potentially lead to adapting more effective curricular and teaching methodologies for Latinos in physical science courses.

Program implementation.

The following section provides a description of participants of this study. The study site, City High, is described first and includes a brief description of science curricular tracks and requirements for the successful completion of high school science credits. Student-participants are described next and include participants' characteristics and their academic preparation. Participants' descriptions were gathered using a demographic questionnaire, a program application form, attendance records for the program and participant observation. Lastly, data gathered through participant observation were used to describe participating instructors in regards to their prior professional experiences. Pseudonyms were used to identify all participants.

Participants.

City and school setting. This local southeastern suburban high school is located amidst a college town, home to a "Research 1" state university. As of 2011, the small city hosting the local school is mostly populated by Whites (61.9 %), Blacks or African Americans (26.6%) and Latinos (10.4%) (U. S. Census Bureau, 2010). In 2009, 36.3 % of individuals were living below poverty level compared to 16.6% statewide (U. S. Census Bureau, 2011).

The student body population of the city's public school system is composed of African Americans (52 %), Whites (19 %), Latinos (22 %), and Asians (2 %) (School District, 2011). In 2010, three out of 21 district schools did not meet Academic Yearly Progress (AYP) goals (School District, 2011), including the participating school in this study. About 79 % of students qualify for free or reduced lunch (School District, 2011).

As of this writing, City High School did not meet AYP for the past 5 years and it is under a Needs Improvement Plan as mandated by the NCLB Act. Sixty-six percent of its students are considered "economically disadvantaged" and 3.2 % of its student body is classified as English Language Learners (State Department of Education, 2010). The graduation rate for this school is 70.4 %, with a 69.2 % graduation rate for Latinos and 60.5 % graduation rate for ELLs compared to 86.9 % graduation rate for Whites (The Governor's Office of Student Achievement, 2009-2010 Report Card, 2010).

As a requirement for graduation, all students in the state are required to obtain passing scores on two exit exams: the End of Course Test (EOCT) and the State High School Graduation

Test (SHSGT). Both, the EOCT and the SHSGT assess students' knowledge in mathematics, social studies, science and language arts. The science portions of the tests assess students' mastery of the characteristics of science and content knowledge in physical science and biology (State Department of Education, 2008c; U.S. Department of Education, 2005). Students who do not obtain passing scores on both exams are given the opportunity to attend review courses and retake the tests (as many times as necessary) until a passing score is achieved. Review courses are scheduled during regular school hours. Students also have the opportunity to voluntarily attend the school's after-school program where the students may receive tutoring in all subjects.

The science program at City High requires that all entering 9^{th} graders enroll in a physical science course during the first semester in secondary school. Physical science takes place in the fall semester and lasts about five months. The physical science class takes place every day and lasts 90 minutes in a Block schedule. Students are exposed to a variety of physical science topics covering inorganic chemistry, matter, energy transformations, Newton's laws, and electricity. Students receive lectures that are combined with PowerPoint presentations, demonstrations, and inquiry activities. Inquiry activities include traditional laboratory exercises as well as online interactive lessons. Materials for inquiry activities are often limited or nonexistent. Multiple assessments are administered throughout the course, with multiple choice-type exams dominating the majority of the assessments. A final exam concludes the course.

In regard to mathematics, mathematics academic tracks at this school require all 9th graders to complete pre-algebra, algebra or Euclidean geometry courses. Upon successful completion of these courses, students would continue algebra, informal geometry or Euclidean geometry or second year algebra (Flowchart for students entering high school before 2008).

ELLs who do not obtain passing scores on any of the four domains (reading, writing, listening and speaking) of the WIDA-ACCESS Proficiency Test are eligible to receive bilingual education in the form of an immersion program. ELLs attend English monolingual classes but are "pulled out" during regular school hours to receive one period of English as a second language (ESOL). One semester prior to this study, City High offered ELLs "sheltered science" instruction in physical science and biology. Sheltered instruction consists of courses taught by a teacher who has received special training in educating ELLs. As a result of these bilingual approaches, Spanish-speaking ELLs usually travel as a cohort -- thus creating a small bilingual community among the school's student body population.

Participating Latino science learners. Participants for this program included Spanish-speaking Latino secondary students attending City High and who were interested in participating in LASPS. Participants attending LASPS were one of three kinds of students. Some participants were ninth graders currently enrolled in physical science; some students were 10th, 11th, and 12th graders seeking to advance their knowledge in physical science as preparation for exit exams; and other students sought to gain advanced knowledge and skills of physical science for personal growth.

Recruitment efforts initially attracted a total of 15 Latino students (9 females and 6 males). Participants in LASPS were currently enrolled in grades 9-12 and included a variety of dominant L1 bilinguals (or ELLs), dominant L2 bilinguals and balanced bilinguals. Student participation in LASPS varied as competing agendas (i.e., attending sports and other tutoring sessions, jobs and family duties) affected full participation in the program. This study focuses on six participants, Dominic, Pablo, Gabby, Elena, Juan and Mario, who attended the program consistently. However, data about participants who attended the program intermittently are also included to emphasize key findings. None of the participants were enrolled in advanced academic tracks.

Dominic was a shy 9th grade 14 year-old male. Dominic had successfully completed physical science and the physical science EOCT. During the semester of program implementation, Dominic was not enrolled in any science course. At first glance, Dominic did not appear Latino. Dominic's appearance was very "Justin Bieber," with his hair combed to the side, and wearing a cleanly fitted shirt. I approached him once and asked him if he spoke Spanish. He confirmed being a United States-born Mexican and that he spoke Spanish mostly at home. Demographic and participant observation data also supported his assertions. Dominic is a dominant L2 bilingual who began speaking English at the age of 5. Dominic identified having high levels of proficiency regarding speaking and listening skills in the Spanish language. However, he did not feel confident with reading and writing in Spanish. Dominic was always in the company of Pablo.

Pablo was a tall and outspoken 16 year-old 10th grader. Pablo had successfully completed physical science and the physical science EOCT. During the semester of program implementation, Pablo was enrolled in an environmental science course. Demographic and PO data identified Pablo as a balanced bilingual. Pablo is a fluent Spanish speaker who began learning English in school at the age of 5. Pablo considers himself fluent in speaking, listening, reading and writing in Spanish. Pablo was born in Texas and identifies with the Tex-Mex community. Dominic and Pablo were inseparable during their participation in LASPS.

Gabby was a bright and independent 16 year-old who was born in Mexico. Gabby had successfully completed physical science and the physical science EOCT. During the semester of program implementation, Gabby was enrolled in 10th grade college-prep biology. She was also enrolled in a French language course. Gabby traveled back and forward between Mexico and the United States. Gabby attended elementary school in Mexico for one year. She learned how to speak English at the age of 9. Demographic and PO data indicated that Gabby was a dominant L1 bilingual. Gabby identified having fluent skills in reading, writing, speaking and listening in the Spanish language. During her participation in LASPS, Gabby was always in the company of Elena and Juan.

Elena was a quiet 16 year-old female introvert enrolled in the 10^{th} grade. Elena did not successfully achieve in her prior physical science course or in the physical science EOCT. During the semester of program implementation, Elena was attending a physical science course focused on reviewing key physical science concepts. Elena is of Mexican descent and was born on the west coast of the United States. Elena first spoke Spanish at home and then began learning English at school at the age of 5. Demographic and participant observation data indicated that Elena is a dominant L2 bilingual. Elena felt more competent with the English language than the Spanish language. Elena can communicate effectively in Spanish but is unable to read and write in Spanish.

Juan was a bright and intelligent 17 year-old male who was in the 10^{th} grade. Juan had successfully completed both, the HS physical science course and the physical science EOCT. He was enrolled in a college-prep biology course. Like Gabby, he was also learning French. Juan was born in Nicaragua. He was an elementary school student in Nicaragua for 3 years. Juan began learning English at the age of 10. Juan considers himself fully fluent in the Spanish language. He reads, writes and speaks Spanish. Juan's dual Spanish-English language fluency classifies him as a balanced bilingual.

Mario was a quiet 14-year old male completing the 9^{th} grade. Mario was completing the required physical science course. Demographic and participant observation data indicated that Mario was a dominant L2 bilingual. Mario was able to speak in Spanish but his reading and writing skills in Spanish were very low. His journal writings indicated that Mario had low reading and writing proficiencies in the English language as well. Mario's intermittent attendance in LASPS made it difficult to get a clear idea of his academic strengths.

Instructors. There were a total of 5 instructors in LASPS. Dr. Watkins and Mr. Phil acted as supervisors and supportive instructors to the course. Student-teachers Carlos and Rachel acted as supportive instructors. I was the principal instructor for LASPS. Below is a description of each of our background and instructional roles in the program.

Currently, I hold a bachelor and master degree in science education. As a science teacher, I taught numerous courses at the high school level. During my first teaching assignment that lasted 7 years in an impoverished Black/Latino Bronx high school, I taught general science, physical science, biology, earth science and environmental science bilingually. I also conducted numerous enrichment opportunities for my students. I led science clubs, taught after-school enrichment programs that immersed students in zoological studies (at the local Bronx Zoo) and taught an after-school program that introduced students to conducting authentic science research. Also, 2 of my students entered national science competitions. To supplement my teaching, my students always had the opportunity to attend field trips. Every teaching year, I conducted numerous field trips to the American Museum of Natural History (NY) to conduct lessons and research activities. During four summers (1993-1997), I chaperoned students from the high school who attended summer school at a private southern high school. In addition, I was the science teacher for the program. I designed and taught my own science course that immersed students in numerous hands-on, minds on activities. For example, students conducted the popular study of the effect of light on plant growth, from beginning to end. Students designed, hypothesized, experimented, collected data and concluded results for this project. In addition, every teaching day that lasted between 5 and 7 hours, science lessons immersed students in laboratory experiences all day long since resources and time were not limiting factors. Science experiences ranged from determining vitamin C content in vegetables to finding fossil remains at the nearby mountains. At this school, I was also a school director (lasting 5 years). I oversaw academic programs for a student cohort of 300 students.

My second teaching position, lasting one year, was at an impoverished, predominantly Latino/Dominican upper Manhattan High School. While in this position, I taught earth science, traveled to the American Museum of Natural History as a field trip and conducted the first science fair to be held in this school in many years. Academic conditions at this school were so denigrating that I decided to advance my teaching degree by enrolling in a science education PhD program.

As a graduate student, I have held numerous graduate assistant positions. For the past 6 years, I have worked, on different assignments, with professional development. Generally, I have worked to develop in-service teachers' awareness, and pedagogical skills about Latinos and ELL learners. I have also helped develop science assessments and conducted teacher workshops on science inquiry frameworks and academic language. As a student-teacher supervisor, I have worked with numerous preservice science teachers. I supervised student-teachers when teaching science lessons, evaluated lesson plans and activities and helped coach science teaching. On numerous occasions, I have taught lectures and conducted activities for pre-service teacher courses regarding the academic needs of Latinos, ELLs in particular. As a result of my interactions with pre-service science teachers, I recruited two university students to participate in the LASPS program, once it had commenced.

At the time, student-teacher Carlos was completing the first preservice science teaching course. This course consisted of observing veteran science teachers as they taught in the classrooms. I met Carlos in this course. Before transferring to the science education department, Carlos was a full time Biology major, with one published manuscript in this area. Carlos is of Cuban descent. He grew up in Miami, Fla., and recalls ties to his Latino family. He naturally gravitated toward me during the course, perhaps because of our similar Latino background or closeness in age (as he once described being an older, more mature student than the rest). I invited him to the LASPS program. I told him that though LASPS was not biology oriented, it would be wise to learn more about teaching physical science. It is common to find beginning science teachers teaching physical science in high school. In addition to benefiting from observing physical science teaching methodologies, I explained to him that he could also experience bilingual teaching. Furthermore, he could also set foot inside City High as a potential location to conduct his internship course in the next semester and as a future employment opportunity. He was very enthusiastic about participating in the program. He also considered LASPS as an opportunity to gather information addressing a course requirement that he had to meet about multicultural classrooms. He agreed to come on a regular basis. He also suggested that a classmate of his join LASPS to fulfill a similar course requirement. Student-teacher Rachel, a second year science education major, was welcomed to the LASPS program too.

Rachel is a White, young female interested in learning how to teach secondary level Latino students. For a while, Rachel lived in the Western coast of the United States where she socialized with Spanish-speaking Latinos. For Rachel, LASPS presented an opportunity to deepen her understanding of Latino science learners. Throughout LASPS, Rachel enthusiastically welcomed LASPS participants and remained committed to the teaching and learning with the students.

The participating teacher, Mr. Phil, has been the school's "sheltered science" instructor from 2007-2009. Mr. Phil grew up in a bilingual household where English and French were spoken consistently, but Mr. Phil himself is not fluent in French. Mr. Phil earned his bachelor's degree in civil engineering and has worked as an environmental engineering consultant for seven years. He has been a science teacher for 10 years and has taught physical science and biology both in "sheltered science" and regular classrooms at the current school. Mr. Phil has received training in the WIDA standards and some training in Sheltered Instruction Observation Protocol or SIOP. Both WIDA standards and SIOP offer instructional methods to teachers specifically teaching ELLs. Mr. Phil is certified as an instructor for English for Speakers of Other Languages (ESOL), and also holds a National Board certification to teach physics. Because Mr. Phil has taught "sheltered classrooms" for two years, Latino students in the school are very friendly and appreciate Mr. Phil. Mr. Phil's physical presence during LASPS was required by state law. He often acted as a supporting instructor. Mr. Phil's support was mainly in assisting participants with individual tutoring and maintaining records for the program.

Dr. Watkins, principal investigator for the study, also provided a supportive role in LASPS. Dr. Watkins is a chemist by training and science education professor at the State University. Her research interests lie in field of multicultural education. Her multiple roles included devising and maintaining LASPS records (including budget management), setting field trip experiences and coordinating the culminating social event. In the LASPS classroom, she often assisted individual participants when completing worksheets and projects. Dr. Watkins also served as the principal focus group interviewer. Her directorship and mentorship helped LASPS run smoothly.

The enrichment program. Recruitment efforts began a week prior to the beginning of LASPS. At the school level, a morning announcement advertised LASPS for the entire week. LASPS flyers were distributed to science and ESOL teachers to read and distribute to students. Two days prior to the beginning of LASPS, a display table was set up outside students' lunchroom containing a tri-fold and describing the LASPS program in both English and Spanish. Along with the colored LASPS descriptions were displays of small models of electrical circuits, classroom cars, a multimeter, science probes and a Derby race car. I stood behind the table, explaining the purpose of the program and distributing flyers and consent forms.

LASPS took place after regular school hours (that is, during after school hours) twice a week for 15 weeks during the spring 2010 semester. Each lesson lasted for about 1.5 hours. Participating students read, journaled, reviewed pertinent vocabulary and conducted science inquiry activities that supplemented classroom lessons. In addition, participants designed and executed a science project. Lessons for the program expanded topics covered during regular classes and included force and motion, light reflection and refraction, gravitational and potential energies, electricity and mechanical advantage. Lessons were taught by myself (the researcher) and were conducted in English and Spanish. Lessons included short lectures and structured hands-on activities. Participants used worksheets that supplemented and guided the lessons. Participants also used a journaling notebook to document ideas about what worked well for them in learning science. Occasionally, participants used journals to document observations, and to draw charts and designs of their projects. Participants wrote in their journals for 5 minutes prior to the end of each lesson. To promote additive bilingualism, participants were given the opportunity to write in Spanish or English (Reyes & Vallone, 2008, p. 103). The semi-guided inquiry project, the Rube Goldberg contraption, was designed and completed by participants in about 4 lessons. The semester long, open-inquiry culminating project consisted of participants' design of a wooden car. At the end of the course, each of the cars was weighed and tested for speed and acceleration in a final class competition. Participants controlled for weight, speed and air resistance. Table 4 outlines topics covered in the program, number of lessons devoted to each topic and the kinds of activities conducted during each unit. Lessons were not static but dynamic. Prior taught concepts were reviewed at the beginning of each lesson and reinforced with additional practices. Furthermore, ongoing projects expanded over several lessons.

Table 4

Physical Science Units, Number of Lessons Devoted to Each Topic and Activity Covered During the Enrichment Program.

Unit	Number of lessons	Science Activities
1. Force and motion	7	Structured lab experiences with speed, velocity, acceleration, Newton's Laws, work and power
2. Energy	1	Discussions and interpretations of diagrams and charts
3. Light Reflection and Refraction	2	Reviewing states of matter, mediums, surface, reading, extrapolating information and observing light reflection and refraction in a glass water tank
4. Simple Machines and Mechanical Advantage	1	Computerized models of simple machines and Rube Goldberg Contraptions Project: Rube Goldberg Contraptions
5. Electricity	4	Structured lab experiences: Designing and building electrical circuits

Participants also visited the State University on field trips on two different occasions. The first field trip placed participants in a physics lab at the university. In this field trip, participants attended a physics lecture about electricity, electrical conductivity and the use of the Van de Graaff generator. They also participated in a lab on waves. Later on during the day, participants toured a lab with an electron microscope. There, participants listened to a short lecture on the use of the electron microscope in the study of rocks. They also witnessed its application in rock and element identification.

The second field trip to the university placed participants in a food science lab. Participants participated in a short lecture on chocolate and conducted a laboratory exercise on chocolate preparation. This lab exercise was scientifically oriented rather than just a culinary experience. At the conclusion of the exercise, participants enjoyed the chocolate variations that they created. Participants also toured labs and listened to additional lectures on food science. The culminating activity on this field trip had participants eating “dots ice cream” created right in front of their eyes.

At the conclusion of the LASPS program, participants and their parents, convened for an award ceremony rewarding the participants for their participation in the program. Participants were also awarded certificates for their Derby car designs. The award ceremony was held in a local hotel restaurant. School and university personnel attended the ceremony.

Pre- and posttest assessments.

Participants' content knowledge was assessed using pre- and posttests. Both an initial pretest and, in conclusion, a posttest – were administered to participants to gain an understanding of the change in physical science knowledge they constructed (partly, at least) as a result of their participation in the program. The physical science test was developed with the cooperation of

Mr. Phil. The test was written in both Spanish and English and consisted of 21 questions with both multiple choice questions and problem solving short answer essays. Multiple-choice questions were randomly selected from five New York Board of Regents Physics exams (available online). Regents Physics examination questions were representative of the knowledge and skills that a student should be able to answer after completing a secondary level physics or physical science course (see Appendix B).

To answer test questions, participants had the opportunity to work at each of four lab stations with materials and set-ups specifically geared to support and answer each question. Lab station #1 displayed a fish tank filled with water with the back portion covered in black construction paper. A laser-pen was shone on the water and used to indicate the path of a light beam. Participants used this set-up to answer 4 questions regarding light reflection and refraction. Lab station #2 displayed a pendulum. Participants answered 1 multiple-choice question regarding potential and kinetic energy. Lab station #3 contained two circuit boards, one with a parallel circuit and one with a series circuit. Participants had the opportunity to use this set up to answer 7 questions regarding electric field strength, circuits and electrical resistance. Lab station #4 contained two wooden cars with the capacity to hold different kinds of weights. In addition, an area was marked so that students had the opportunity to investigate the cars' speed and acceleration. Participants answered 7 questions regarding acceleration and motion-related forces. The posttest included a Rube Goldberg contraption to help participants answer questions regarding mechanical advantage.

To increase content-related evidence of validity, the pre- and posttest was given to a physics expert (physics college professor) and a current high school physical science teacher. Each expert judged each question and provided suggestions and recommendations about the test.

To increase the reliability of the test, judges provided answers to each question. An answer key was devised from judge's responses. This researcher scored pre- and posttests.

Data Analysis

A good qualitative research study is one that is integrated; that is, from the outset, data collection and analysis are being done at the same time. Huberman and Miles (1994) discuss the advantages of "interim analysis" in qualitative research whereby researchers can modify questions and redirect their foci a second time around as new or more data are collected. Ezzy (2002) adds to this discussion by suggesting that researchers' preconceived theories and ideas lead to questions of what is important, and the researcher takes cues from the environment (Ezzy, 2002, p. 63).

Preliminary analysis of the data began with a discussion of the data as they were being collected (Ezzy, 2002, p. 65). Ezzy (2002) explains that data discussions (a) stimulate ideas about its meaning and significance (b) give rise to the elaboration of issues that may arise, thus providing depth of complexity and quality of analysis to the research, (c) prompt researchers to examine personal values and theoretical orientations, (d) provide opportunities to explore and test theories and interpretations, and (e) consider problems and planning of the methodology. In this study, discussions about data occurred with dissertation committee members, participating instructors, other more knowledgeable peers, and through a personal reflection journal.

Immediately after focus group interviews were conducted, I first met with the interviewer and then with Mr. Phil separately to discuss preliminary interpretations of participants' statements and ideas. Interviews were transcribed at the end of LASPS. Preliminary coding was noted as these took place and later codes were placed along transcription margins.

Participant observations were also transcribed at the end of the program. Rudimentary coding schemes were noted to "encourage a detailed reflection on the issues of the research" (Ezzy, 2002, p. 70). Thematic analysis permitted data to be coded and categorized thematically (Ezzy, 2002, p. 86). First, through open coding, both focus group interviews and field note transcripts were read line-by-line and were coded for hunches and ideas (Emerson, Fretz & Shaw, 1995). The purpose of open coding is exploratory and opens lines of inquiry (Berg, 1998). Strauss (1987) suggests asking the data a specific and consistent set of questions. Emerson, Fretz and Shaw (1995), along with Strauss (1987), stress writing theoretical memos to further clarify and connect themes and categories (Strauss, 1987), using focused coding or coding frames (Berg, 1998). In this study, theoretical memos were noted in my researcher's journal. A visual representation (in the form of a schematic diagram) was used as a display to make meaning of data transcripts, theoretical memos, public and private archives (Huberman & Miles, 1994). The diagram also facilitated data saturation and triangulation because data were continuously sorted, contrasted and compared.

Analysis using qualitative methods.

This study looked at the performance of participants who took pre and posttests in an effort to measure any change in physical science content knowledge as the result of their participation in LASPS. Furthermore, this study looked at teaching strategies beneficial to learning. The concurrent embedded case study approach as used in this study had two basic procedures. During stage 1, qualitative and quantitative data were analyzed separately. Qualitative data consisted of:

1. 18 lesson worksheets
2. Participants' journal entries (one entry for every lesson participants attended)

3. Participant observation throughout LASPS (Five lessons were audiotaped)
4. 3 Focus group interviews
5. LASPS demographic questionnaires
6. LASPS registration forms
7. Researcher's journal

First, the previously coded participant observation was examined for patterns. Once patterns were identified, I referred to lesson worksheets, focus interviews, LASPS demographic questionnaire, registration form and participant and researcher's journals to substantiate the patterns found. Emergent themes were noted.

Quantitative data consisted of pre- and posttests. Using test responses provided by expert judges, this researcher scored both tests. An analytic comparison of participants' responses to test questions was made. First, pre test data were analyzed by looking for patterns that were consistent across all responses. Similarly, posttest data were analyzed using the same procedure. Once both tests were analyzed independently, patterns common to both tests were then binned to form emergent themes.

During the second stage, qualitative and quantitative data sets were merged. The concurrent embedded design was implemented in the following manner. First, a visual representation was designed and preliminary themes in data from participation observation were placed at the center of the diagram. Other sources of data were placed in a clock-wise configuration. A pattern that was noted in data from participant observation was then compared to patterns noted in focus interviews, participant and researcher's journals, questionnaires and pre and posttests. Concurrently, completed lesson worksheets and participants' journal entries were matched and contrasted with relevant questions on the pre and posttest to identify patterns.

For example, on the lesson on electricity I compared participants' responses in pre-posttest questions, participants' completed lesson worksheets and journal entries in regards to electricity. This process allowed me to identify (a) participants' content knowledge regarding electricity (using both pre and posttest and participants' completed worksheets), and (b) participants' reflections on electricity. Furthermore, some participants used their journals to identify effective teaching and learning strategies regarding the topic of electricity. Collectively, pre and posttest responses, completed lesson worksheets and participant's journal reflections helped further identify and refine patterns. Finally, I looked for any correspondence between learning strategies and performance on the posttest.

Biases.

I kept a journal to write reflections before and after observations and through data analysis. Discussions concerning personal biases were carried out with competent others and aided with reflections about personal subjectivities (Feldman, Bell, & Berger, 2003, p.43; Glesne, 2006, p. 38) and keeping personal biases in check. A thick and rich description of the participants through quotes and excerpts from the data is presented. Readers can therefore infer their own interpretations from the data, thus increasing the trustworthiness of the accounts (Emerson, Fretz & Shaw, 1995).

Summary

In this section I summarized research methods and program design and implementation. This exploratory embedded case study employed a qualitative design, with quantitative data supporting qualitative data. Quantitative data collection employed the use of pre- and posttest examinations. Qualitative data collection involved focus interviews, participant observation, documentation and archives and participants' artifacts. LASPS acted as an intervention to teach and measure secondary level Latinos' knowledge of physical science. Furthermore, LASPS provided the opportunity to explore effective teaching strategies in a bilingual classroom setting. Initially, 15 Latinos enrolled in LASPS. This study focused on the 6 Latino bilinguals whose participation was consistent throughout the program. Multiple instructors taught LASPS. LASPS activities included constructivist teaching and learning strategies. At the conclusion of the program, supervisors and administrators, instructors and student-teachers, and the City High Latino community gathered to celebrate the implementation and administration of LASPS.

CHAPTER IV

DATA ANALYSIS AND FINDINGS

Overview

The aim of this study was twofold. On one hand, this study sought to identify and explain science knowledge change in secondary level Latino students as the result of their participation in a targeted bilingual physical science after-school program. On the other, this study sought to explore secondary level Latino physical science learners' preferred science teaching and learning strategies, as they were practiced in an after- school enrichment program. Both qualitative and quantitative data were collected to inform this study with quantitative data supplementing qualitative data. In the following sections, qualitative and quantitative results are presented and discussed. Quantitative data were collected using pre- and posttest examinations. Qualitative data were collected using an after-school registration form, a demographic/evaluative questionnaire, journal entries, focus interviews and participant observation. First, emergent themes relating to participants' ideas and perspectives about bilingual teaching strategies are presented and discussed. Then, three science lessons are presented highlighting constructivist-driven teaching strategies, their effectiveness and challenges. Findings are embedded in lessons, teaching moments and teaching excerpts as opportunities for discussions arise. Lastly, participants' ideas and perspectives on effective teaching strategies, as taught in an after-school program, are presented and discussed.

Before beginning a presentation of findings, it is important to discuss the context in which teaching and learning occurred during LASPS sessions. First, instructors and participants met as a group. Participants received an orientation about the goals of the lesson. After a mini lecture on the lesson's topic, participants worked on completing lesson worksheets. Participants worked in pairs. First, participants were provided with the opportunity to answer questions independently. Then, instructors sat next to student groups and provided individualized tutoring. During these tutoring/mentoring moments, instructors asked assessment and assisting questions to probe students' prior knowledge. Once participants shared relevant experiences, instructors used these experiences to connect to the science concepts addressed in the lesson. Often, participants joined in to the different discussions that were occurring. On many occasions, prior experiences that were common to all of us, as Latinos, were further shared and discussed as a group. During these instances I led the discussions and provided opportunities for both, participants and other instructors to share opinions, ideas, perspectives and knowledge of the subject at hand.

After participants completed lesson worksheets, instructors and participants gathered as a group and discussed responses to lesson worksheets. Group discussions centered on clarifying and exploring possible science misconceptions. After lesson worksheets were completed, participants conducted science inquiry activities. At all times during LASPS sessions, instructors provided guidance and explanations to the learning challenges presented by the lessons. Again, participants received individualized tutoring from instructors. While participants worked on science inquiry activities, instructors helped and guided science learning. Often, lesson-relevant discussions between instructors and participants carried on for long periods of time. The goal here was to use any relevant knowledge participants possessed about the lesson topic and connect it to the lesson in a meaningful way. Lessons and group discussions were always dynamic and often expanded over the course of the program. The following section integrates the complexities of these social interactions and are shared in the emergent themes.

Emergent Themes

Theme 1: Bilingual teaching strategies supported bilingualism and comprehension of science among the participants.

Numerous strategies were used to conduct LASPS bilingually. The following section uses data from interviews, participant writing journals and participant observation to provide the context in which bilingual teaching occurred in the classroom as well as participants' responses to the different strategies. Transcription data on this section include Spanish statements and their corresponding English translations are denoted within parentheses. Additional researcher comments are identified in brackets. Asterisks represent inaudible statements.

Subtheme 1: Breaking down words and Spanish-English cognates supported bilingualism. Participants were exposed to various bilingual teaching and learning strategies such as exploring the etymology of words and Spanish-English cognates. Participants often referred to these strategies as "breaking down words." On many occasions, these teaching strategies helped participants bridge scientific language and everyday language. Participants enjoyed the opportunity to learn a word in a new form. All participants expressed that all the bilingual teaching strategies used in LASPS helped them understand the Spanish and English languages better (within a science context), learn science, and helped them identify better with the Latino culture. For instance, when referring to these bilingual teaching strategies, Gabby wrote in her journal that, "Also is helpful the explanation of words in both English and Spanish this helps in case we had a problem with one word." Like Gabby, Elena also found that the breaking down of terms such as translating them from English to Spanish was helpful. Elena wrote in her journal that, "Breaking down the definition of the word term. And translating some words in Spanish.

This helps me understand better." Pablo also wrote in his journal, "I learned better because you spoke in both languages, and you explained it really good." For Mario, in addition to helping learn science better, using Spanish in the classroom helped him identify better with his Latin culture. *Mario:* "I like you explained and showed us how to do in spanish." The following excerpt from the first focus interview helps illustrate his enthusiasm for his Latin-Mexican culture.

Interviewer: OK. ...but why is it that you want it [lessons] in both English and Spanish?

Mario: Those are my two languages. *Porque yo soy guero.* (Because I am Mexican.)

The following teaching moment, as recorded in audiotaped participant observation, illustrate how bilingual teaching strategies were enacted in the classrooms. On one occasion, the English cognate for the term *vecino* was discussed. The following excerpt illustrates how this learning strategy was applied in the lesson.

Researcher: I also want to point out one word that I placed in here [student worksheet] because most of you may not have known that word in English. At the end of number a, I placed a new word. Is anybody familiar with this word, vicinity?

Pablo: Vicinity

R: What is the Spanish equivalent of that word?

Pablo: Vis, vis something.

Dominic: Vicinidad

R: Uhu. *Tu vecino*

Dominic: Oooh

Pablo: Oooh

R: So vicinity is neighbor?

R: That is right. I thought I brought that word in for you, instead of using proximity. *Tu vecino o la persona al lado. Algo al lado de ti.* (Your neighbor or someone next to you. Something next to you.)

Pablo: You are my vicinity.

R: You are in my vicinity.

Pablo: You are in my vicinity. Get out!

Subtheme 2: Spanish translated statements supported science comprehension. Participants were also provided with numerous opportunities to read science-related statements in English and Spanish. On some occasions, participants read out loud to the class or to themselves, and at other times they used the Spanish statements for understanding purposes. The following excerpt from audiotaped PO provides teaching moments about how "reading Spanish statements and translating verbal statements into Spanish" were enacted in the classroom.

R: Could you read out loud.

Pablo: Study the following diagrams below, a ball is placed on top of the hill and then released. In Spanish too?

R: Si tu quieres.(If you like.)

Pablo: Estudia el diagrama debajo una bola es puesta en parte [skips la] *mas alta de una loma y despues corre hacia bajo.*

Participant statements regarding the Spanish translation of the pretest gave evidence that this particular bilingual strategy benefited and supported their understanding of English, testing, and science. For instance, in her journal entry Gabby stated that,

> …it was very helpful to have 2 copies one in Spanish and one in English. It was helpful because if you didn't understand one thing in one language you have the other one to rely

> on. Also it helped me learn words in Spanish that I didn’t know when I compared the two tests.

In his journal entry Pablo also added that,

> I liked that we had a Spanish and english exam because we get to practice Spanish and english at school to. I think it is easier in english but I think that this experience will help me learn how to do my work in Spanish too and that way an do it in both languages.

Paula, our Spanish-only speaker, wrote in her journal that, “*El examen estava un poco dificil pero le entendia porque lei en español, en realidad ni siquiera abri el examen en ingles, q asta se me perdio el papel.”* (The test was a bit hard, but I understood it because I read it in Spanish. The reality is that I didn’t even open the English exam. I even lost the paper.)

Pre- and posttests data also supported “the Spanish translation statements” as effective bilingual teaching and learning strategies in testing conditions. Participants used Spanish translations efficaciously during both pre- and posttest administrations. However, more participants read questions in Spanish in the pretest than they did in posttest. Furthermore, more participants referred to the Spanish version of the test in the areas where they had felt less knowledgeable, the areas of light reflection and refraction and mechanical advantage in particular. These findings indicate that when bilingual students experience difficulty with a concept, they may rely more on their native language for conceptual understanding and answering test questions. These data suggest that these bilingual students felt that they benefited from reading examinations in their native language.

Along with participants' assertions about the benefits of bilingual translations, the following teaching moment illustrates how the translations of written statements in participants' worksheet from English into Spanish language were instrumental in meaning making and conceptual understanding. Without the use of the written Spanish translations Gabby would have been lost in translation, language translation in particular, as she tried to make sense of new concepts in science.

In a third lesson on electrical circuits, participants were provided with a worksheet aimed at reviewing prior knowledge and developing further knowledge about series and parallel electrical circuits. To gather participants' prior knowledge of circuits, a review of the basic terms was used to define electrical circuits. First, participants were asked to identify all the parts of a simple circuit, such as the switch, bulb and batteries. Secondly, participants were asked to provide the formula and the unit used to calculate current. The next 3 sets of questions were aimed at getting participants to identify parallel and series circuits and to select a circuit that could turn on a light bulb. Participants were presented with the diagrams below and 3 statements questioning their understanding of current.

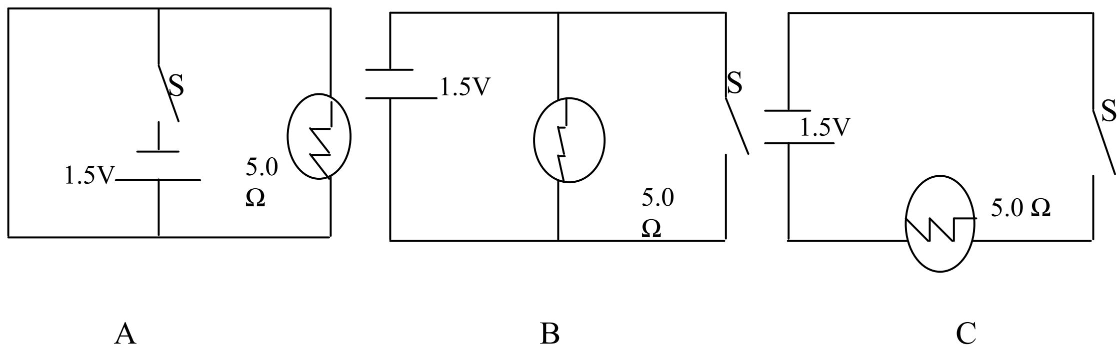

Figure1. Schematic diagrams of three electrical circuits presented as references to answer worksheet statements regarding series and parallel circuits.

Worksheet statements were worded as follows:

Use the schematic diagrams above to answer the following questions.

4. Which schematic diagram represents a series circuit?

5. Which schematic diagrams represent parallel circuits?

6. A 5.0 – ohm lamp requires 0.20 ampere of current to operate. In which circuit (s) would the lamp operate when the switch S is closed? *Una lampara de 5.0 –ohm requiere 0.20 ampere de corriente para operar. ¿En cúal circuito prenderá la lampara si cerramos el switch S?*

Gabby's worksheet indicated that she identified the diagrams correctly: diagram C as a series circuit and diagrams A and B as parallel circuits. The following excerpts from audiotaped participant observation illustrate Gabby's response to statement # 6 regarding the identification of a working circuit.

R: We are back to (statement) #6. A 5.0 – ohm lamp -the lamp, you see the bulb there, requires 0.20 amperes of current to operate. In which circuit (s) would the lamp operate when the switch S is closed?

Gabby: I say is B.

R: Why?

Gabby: Because even if you turn off the switch, energy...

R: Well, what is the difference between B and C?

Juan: B and C?

R: If you close the switch...

Gabby: That the switch is right next to the battery.

R: Oh, you are saying that the location of the battery and the switch has something to do with the current?

Gabby: Yes, because, right here...

Pablo: It takes longer.

Gabby: If you turn it off, it will still go like that.

When referring to electrical circuits, there is the fundamental knowledge about how electrical switches work. When the switch is closed, electrons will flow and a current will turn on a device connected to the circuit, such as the light bulb in this example. When the switch is opened, there is no electron flow and thus any device attached to the circuit will not turn on. Thus, a closed switch turns on a light bulb, and an open switch turns off a light bulb. The use of the term “closed” in statement #6 may have been a source of confusion for participants. For instance, a student might confuse a closed switch with lights off and an open switch with lights on.

It is possible that students, such as Gabby, interpret the term “close” in the phrase “when the switch S is closed?” as indicating the location of the switch on the circuit as in “close or nearby” the battery. It is evident in Gabby and Pablo’s responses that they associated the distance of the switch to the battery with the flow of electrons, Gabby: "That the switch is right next to the battery" and Pablo: "It takes longer (for the current to travel)." Gabby's worksheet showed that she traced the current of electricity on the left side of diagram B, skipping the right side of the diagram where the switch is located. For Gabby, the flow of electrons from the battery to the light bulb will occur regardless of the location of the switch and regardless if it is on or off. It is important to note here that when referring to electrical circuits, there is a distinction between the terms "open and closed" switches and "on or off" switches. When referring to switches in electrical circuits, the terms "open and closed" are appropriate because they refer to metal connectors that either open or close the flow of electrons in a circuit. The terms "on and off" are often used when referring to light switches that are installed in sockets, even though English speakers may interchange "open and closed" and "on and off" in this example.

In the Spanish language, however, similar terms are not interchangeable. The verb *prender* has various definitions that include "to turn on, to switch on, to light, to ignite" among others. The verb *apagar* refers to the action of turning off, switching off or to put out something. Los *interruptores en la pared se prenden o se apagan, no se abren y se cierran.* (Wall switches turn on and off, they do not open and close). For the Spanish speaker, it is much clearer to make the distinction between the terms *prendido y apagado* (on and off) and *abierto y cerrado* (open and closed) because when something is *abierto* (opened), it refers to something that is being opened or exposed, and in this case, dangerous if it were. Because our conversation occurred in English, notice that Gabby responds using the terms "on and off," like any other novice learner: "if you turn it off (the switch), it will still go like that," even though the terms on and off were never used in the discussion. Upon my insistence, Gabby decided to try to understand what the statement was asking. The following excerpt illustrates her approach.

R: Yeah, but take a look at c.

Gabby: But c, it goes like that and it doesn't close.

R: Gabby...Gabby, you were doing good. What happened to c? If I close the switch...

Gabby: C? It doesn't matter. Wait, what?

[Gabby reads statement #6 in Spanish to herself.]

R: Ok, a 5 ohm lamp...

Gabby: Oh, cuando el circuito prende, da la luz. (Oh, when the circuit turns on, it gives light). Oh sorry, I thought you meant which will turn off.

R: Oh, you read it in Spanish, and then it made sense?

Gabby: Yeah

R: Oh. Interesting.

Gabby: Oh, umm, I don't know. I am lost.

After Gabby reads the Spanish translation, statement #6 makes more sense to her. The term “prende” (to turn on) is clearly identified. She has also made the connection between “prender” y “dar luz” (to turn on and give light), and now the role of the switch in the circuit becomes more apparent. Gabby’s following statement indicates that she did not understand what was being asked in the English version of statement #6: “Oh sorry, I thought you meant which will turn off.” After this clarification to herself, she realized that she does not have the knowledge to answer the question. Immediately after Gabby makes the statement in Spanish and declares her lack of knowledge on circuits, Juan begins to read the Spanish statement, quietly and to himself, as if on cue. In the following excerpt, it is evident that Juan also experiences confusion with the term “closed” and reads the term in Spanish a couple of times. Also notice that Pablo confuses the terms “turn on” with “turn off.”

Juan: In Background (IB) [reads to himself] *Una lampara de 5.0 –ohm requiere 0.20 ampere de corriente para operar. ¿En cúal circuito prenderá la lampara si cerramos? ¿Si cerramos? ¿Si cerramos?*

R: Pablo, can you read number 6? In English or Spanish, whichever one you like.

Pablo: I don't know which one I like though. Ok. Wait, number 6. A 5.0 – ohm lamp requires 0.20 ampere of current to operate. In which circuit (s) would the lamp operate when the switch S is closed? *Una lampara de 5.0 –ohm requiere 0.20 ampere de corriente para operar. En cual cir*... what's that? How do you pronounce that in Spanish?

R: circuito

Pablo: circuito prendera la lampara si cerramos el switch S?

Juan: A, A, A

R: Now, look at the 3 diagrams. If you close switch S...

Gabby: All of them.

Pablo: All of them.

Juan: Which one will turn on?

Pablo: All of them will turn off.

Gabby: All of them.

In this teaching scenario it became evident in the case of Gabby that the Spanish translation was crucial in understanding what was being asked in a question. Juan also struggled with understanding what was meant with the term closed. He read the statement in Spanish, repeating the phrase "*si cerramos.*" For Gabby, Juan, and Pablo, the science vocabulary was missing in both their English and Spanish languages. Pre- and posttest data regarding this topic showed that participants experienced difficulty with answering an almost identical question as the one discussed above. Posttest data showed that only Dominic and Elena answered this question correctly. Gabby, Juan, Pablo, Mario, and Manuel answered this question incorrectly. Teaching moments like these, give evidence of the language struggles that science students experience, English Language Learners in particular.

Not all participants identified Spanish translations as a helpful strategy for learning science. Some Latino learners opted for the English versions because they reported not understanding Spanish sufficiently to make use of it. Rebecca's journal entry stated: "the test I preferred the English. I understood it more." Manuel also reasoned that the English-only version of the test was better for him because of his limited knowledge of Spanish. In his journal entry Pablo wrote that, "Today was pretty cool, the test was a little bit hard. I barely can speak spanish, and the english section was better, then spanish."

In the first focus interview, participants were asked to identify bilingual strategies that either worked or did not work for them in learning science. Elena agreed that all the bilingual strategies that she had experienced in the LASPS program were helpful for her in learning science. However, she identified written and oral Spanish translations as the least helpful learning strategy for her because of her limited knowledge of the Spanish language. Elena elaborates her response to the question "Which bilingual teaching strategy helped you the least in learning science?"

Elena: For me, [when the teacher is] speaking in English and Spanish, both in English and Spanish is not the best idea because since I've been going on speaking mostly English and some of the Spanish words I don't understand...

Elena: [and] ...translating words into Spanish.

I: Ok. That is not beneficial to you because you have a limited, ah, ah...

Elena: Knowledge.

I: Limited understanding of Spanish. You could say knowledge.

It is important to note here that Elena's journal entries, group and individual discussions as recorded on audiotaped participant observation gave evidence that Elena valued and appreciated the use of the Spanish language as a means of communication. Evidence of Elena's appreciation for the Spanish language is presented later on, especially in her conversations with Gabby.

Data on bilingual teaching strategies supported the use of Spanish-English cognates, breaking down words and Spanish translations in learning science. However, individual participants valued these strategies differently. For Gabby and Juan, for instance, reading Spanish translations further supported their conceptual understanding. For Elena, on the other hand, bilingual translations were not as useful as breaking down words. In addition to helping participants make meaning of science, bilingual teaching strategies were also used to supplement science teaching. Science teaching strategies, described in the next section, highlight participants' struggles with learning science and its associated language.

Theme 2: Science teaching provides insights into the complexities within the triangulation of languages, learning, and constructing knowledge in science.

The following section presents teaching strategies specific to science learning. Three science lessons are introduced as they were taught in LASPS. While all lessons discussed in this section emphasize the role of language, scaffolding strategies and specific learning strategies, each lesson presentation has been designed to highlight a specific theme. The lesson on light reflection and refraction and the calculation on speed focuses on how different languages play a role in learning science. The lesson on potential energy elaborates on the results of specific scaffolding strategies as they were used in the lesson. The lesson on mechanical advantage focuses on participant-identified learning strategies, group and open-ended inquiry, in particular. To introduce each lesson, a brief discussion of the topic is presented. Teaching moments in the form of excerpts from transcribed data are then introduced and interpreted. At the end of data presentation, a summary of themes is presented.

Subtheme 1: The role of language is instrumental in understanding science. LASPS lessons illustrate how language intersections, between Spanish and English languages, everyday language, and mathematical and science language, interfere with participants' conceptual understanding. Participants get "lost in translation" as they struggle to make meaning. First, they struggle with making meaning in linguistic translations such as with English terms that have different meanings in Spanish, and second with cultural and content related language such as everyday terms that have different meanings in science, and finally with everyday mathematical words that have specific meanings in science. The following teaching moments reveal the importance of language (in all its dimensions) in learning and understanding science. The lessons also illustrate how participants navigate the different languages in this particular instructional setting.

Brief introduction to light ray behavior: reflection. Light rays are reflected once they hit a surface. Some of the light rays will be absorbed by the medium that they hit. Reflection occurs when the light rays bounce off the surface. Light rays will reflect or bounce off at the same angle from where they came in relative to the normal (the angle of incidence equals the angle of reflection). The normal is an imaginary line that protrudes perpendicularly to the surface. Figure 2 illustrates how an incoming light ray is reflected off an even surface.

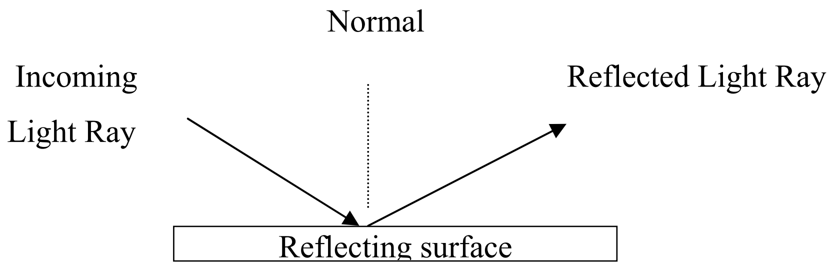

Figure 2. Schematic diagram on light ray reflection off an even surface.

Light rays are reflected in different directions when the surfaces are uneven. Figure 3 illustrates how incoming light rays are reflected off an uneven surface.

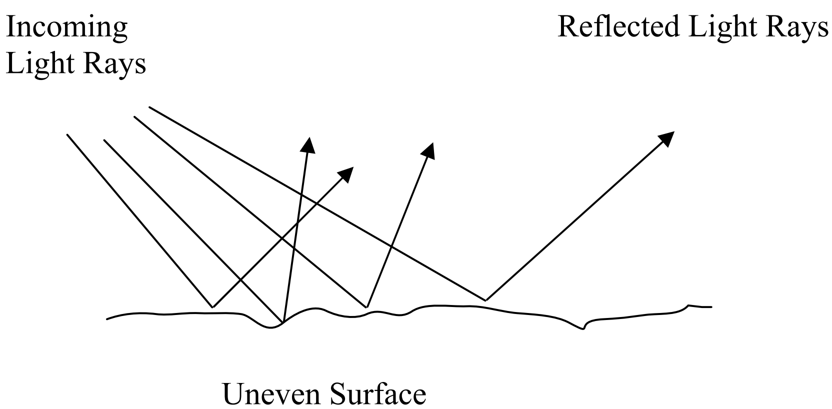

Figure 3. Schematic diagram on light ray reflection off an uneven surface.

Brief introduction to light ray behavior: refraction. As light rays travel through different mediums, they change speed. Light rays slow down and change direction when they enter a denser medium, such as from air to water, and the light ray is bent toward the normal (Diagram D). When light rays travel from a denser medium to a less dense medium, such as from glass to air, they speed up and bend away from the normal (Diagram E).

Diagram D

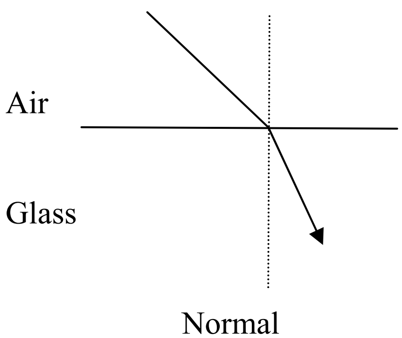

Diagram E

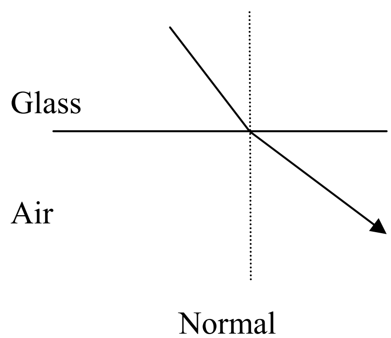

Figure 4. Schematic diagrams on light ray refraction through glass and air.

The concept of light reflection and refraction is applicable and used in our everyday lives. Ophthalmologists and optometrists have made use of this knowledge to study the eye organ and to make eyeglasses. In modern day, the knowledge of light behavior is applied in telecommunications, laser use and general surgical procedures, among others. The National Science Education Standards require that fourth graders know that “Light travels in a straight line until it strikes an object. Light can also be reflected by a mirror, refracted by a lens, or absorbed by an object” (p.107). By eighth grade, students should know that “light interacts with matter of transmission (including refraction), absorption, or scattering (including reflection)” (p. 155). The science State Performance Standards do not specifically require physical science students to understand light behavior, other than how waves generally behave. Thus, physical science standardized exams do not test this knowledge. As a result, physical science teachers may or may not discuss this topic.

Investigating the dimensions on teaching and learning of the lessons on light reflection and refraction. The topic of light reflection and refraction was discussed on 3 separate lessons. Prior to the lessons, participants who completed the pretest were exposed to a light and water tank display that coincided with the question of light reflection and refraction. This particular pre/posttest question on light reflection and refraction was copied from the New York Physics exam. During the lessons on behavior of light rays as they travel through different mediums, participants were provided with diagrams depicting a water tank filled with water. A light source was also placed near the tank. Participants were first asked to trace light rays that left a nearby light source (the lamp in the diagram) as the light rays were reflected in water with even and uneven surfaces. Participants were then asked to trace a beam of light as it refracted through liquid, then solid, then air. Participants' worksheets included a number of the following diagrams.

Diagram F: Even Surface Diagram G: Uneven Surface

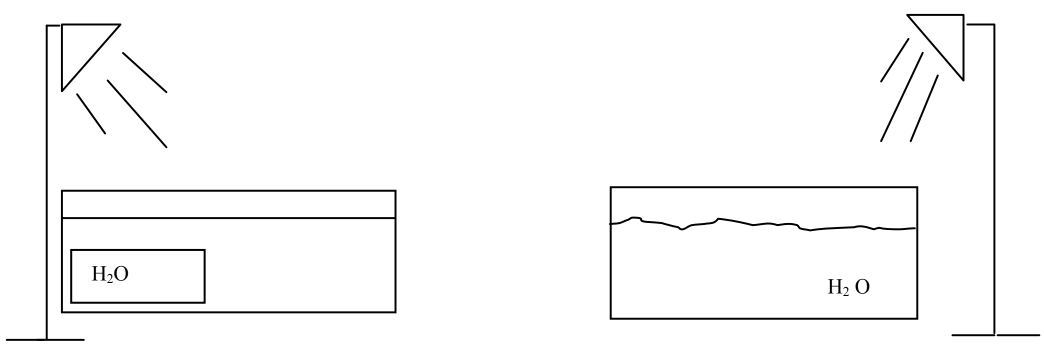

Figure 5. Schematic diagrams on light ray refraction through glass and air in lesson worksheets.

Worksheet exercises on reflection included statements #1and #2 and read like this: "The diagram below illustrates a lamp shining a bright light into a glass water tank filled with water. Use this diagram (diagram F) and trace a beam of light from the lamp to the surface of the water to show how light rays are reflected in an even surface.” The second exercises read similarly but asked participants to show how light rays are reflected from an uneven surface (using diagram G). The Spanish translation was a bit clearer and included the terms trazar (trace) and dibujar (draw). It read like this: *Usa el diagrama debajo para trazar y dibujar como un rayo de luz se refleja en una superficie desigual/igual.* For refraction exercises, two statements also translated in Spanish were presented to the participants. The first statement read like this: The diagram below illustrates a lamp shining a bright light into a glass water tank filled with water (diagram F). Exercise C asked participants to show how light is refracted. Exercise D asked the participants to use a more magnified diagram of the water tank to trace a beam of light as it travels from the light source through the different mediums: air, water, glass, and out of the water tank. The following teaching moments, as recorded on audiotape, present the discussions between participants and instructors that occurred in the second lesson on light reflection and refraction. To gather participants' prior knowledge on the topic, participants were first handed a worksheet and asked to answer the questions without using the textbook. Then, participants were gathered as a group for a class discussion. Five instructors were present, however, only 3 of the instructors worked one-on-one with the participants.

R: Ok, guys, let's see if we can complete this in about half an hour so that we can work on our projects. This sheet has to do with what we learned last week. If you need some help here, there are 3 adults to help you but I would like for you to try. Everybody, just look at your sheets and see what you can do before you even check the book.

Gabby: You just have to draw how it bends?

R: Well, coming from the light source, how would it reflect from the water?

Gabby: Reflect?

R: Reflect from the surface of the water. Now Gabby, that is not the surface of the water you know.

Pablo: Es cierto? You mean the surface? Doesn't it go all the way to the…

R: No, you do your own and we'll talk about it.

Gabby experiences difficulty with the term “reflect.” Instead, Gabby substitutes the term “reflect” with “bend.” Also, Gabby did identify the surface of the water correctly. The term surface is a term that, in my teaching experience, many science students have difficulty understanding.

R: [Back to Gabby] First of all, you did identify what was the water surface, right? The instructions say coming from the light source. Can you identify the light source? Good. Now follow the rays of the light source. And it hits that.What do you think happens once it hits it?

Gabby: It hits it, reflects.

R: Good. So show that.

Gabby: I just did it.

R: That's the way it will reflect? Ok, that's fine, I am not going to correct yet or say anything. It's coming from the light source and it's going to hit the water.

The following diagrams show uncorrected responses made by 3 participants to statements #1 regarding light reflection in uneven surfaces.

Gabby's response to light ray reflection in an uneven surface.

Pablo's response to light ray reflection in an uneven surface.

Dominic's response to light ray reflection in an uneven surface.

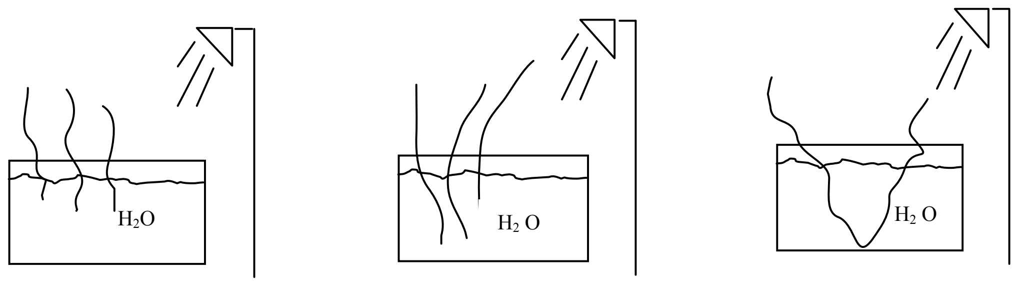

Figure 6. Schematic diagrams representing participants' responses to worksheet statements on light reflection.

Gabby and Pablo's drawing illustrate that they did not identify the lamp as the light source. Rather, from their drawing, it can be speculated that for Gabby and Pablo, the light is coming from other light sources, such as the lights in the room, or possibly the sun. Dominic identified the light source correctly, and may have some understanding about light reflection since he drew a light beam that bounced off the bottom of the water tank. Gabby, Pablo and Dominic are not familiar enough with the term ray, and thus, cannot draw a straight line. All 3 diagrams indicate that the participants did not identify the surface of the water correctly. The following excerpt gives additional evidence of Pablo's lack of understanding about the term surface.

Pablo: Is that how you do it? [Addressing Student-teacher Carlos] Or does it go straight from the surface?

Student-teacher Carlos: What do you think about that?

Pablo: I don't know.

Student-teacher Carlos: What type of surface does that have?

Pablo: Water.

Student-teacher Carlos: I know. But what type of surface? There are a lot of surfaces. Is it calm? straight? Or how is the light going to bounce off the water, surface of the water?

Pablo: Messed up.

Student-teacher Carlos: OK.

R: Show the rays.

Student-teacher Carlos: Show me.

Pablo: I don't know.

Student-teacher Carlos: Show me how the rays get all messed up. And as Gabby said, it is in the book. Show me.

Student-teacher Carlos: Is going straight up.

Pablo: You said it. It's going to go messed up.

Student-teacher Rachel: If it is a smooth surface?

Student-teacher Carlos: So, coming from the surface, off the surface.

Pablo: I know.

Student-teacher Rachel: So?

Student-teacher Rachel: Even if it's really, really, you know the water is messed up and choppy, then is it all going to still come off the same surfaces. So is it going to reflect the same surface?

Student-teacher Carlos: Is it all going off one ray? or

Pablo: No, it bounces off different places, I guess. I don't know. It was in the book. I, we learned this last week.

Gabby: Pablo? Do you want to see something?

Pablo: No, no, no. I remember this. Leave me alone. No, uhhhh.

Pablo: I am going to try it. This is the point of this. The point is not to look in the book.

Pablo articulates light reflection using the terms used by Student-teacher Carlos. At first, Pablo states that the light rays will get "messed up," then he uses the term to bounce off the surface. Once Pablo determines that his instructors will wait for him to respond, he becomes more determined and attempts to complete the diagram on his own. He uses the textbook, and corrects his drawing to show light rays coming from a light source instead of lines, and draws the rays bouncing off the surface of the water. Pablo's science terms changed to suit the discussion. The following excerpt illustrates that after this knowledge interchange between him, the textbook and the instructors, Pablo changes his everyday language to science language. Also notice that Dominic experiences less difficulty with the concept of reflection than Pablo and Gabby.

Student-teacher Rachel [Addressing Dominic]: Different angles?

Dominic: Yeah, the rays probably...

Student-teacher Rachel: Perfect. Nice, good job.

Student-teacher Rachel: Explained it.

Student-teacher Rachel [Addressing Pablo]: But can you explain why?

Pablo: Cause, ahmm, it's uneven, the surface.

Student-teacher Rachel: Uhu

Pablo: So, uhm

Student-teacher Rachel: So it's going to reflect different angles, right?

Pablo: Isn't it 'cause the surface is uneven, has like curves, whatever. So the curves, so the curves of the water is like that, the rays are going to hit at different places right? So it's going to go to different places, not go to the same place.

Student-teacher Carlos: How about when it' s perfectly flat?

Pablo: It's going to go to the same place.

Student-teacher Rachel: But what happens, though…

Pablo: If the thing comes in like this, it's going to go out like that.

Student-teacher Carlos: The same angle? Less angle?

Pablo: The same angle it came in.

Student-teacher Carlos: So, show me that in the bottom one.

Pablo: Well, yeah.

Participants continued to complete the statements in the worksheet independently. This time, participants attempted to answer the statement on light refraction.

Pablo: If it's refracted, is going to bend in like that, right?

R: Let's stop at c and then we can review.

Pablo: Oh, you mean c?

R: B.

Dominic: Is that right? the bottom one?

Pablo: No, it's wrong

Pablo: Is this supposed to be the refracted one? Ms. R? What is this one for? [Referring to the diagram on the sheet.]

Student-teacher Carlos: Different from air to water to glass and now the water tank. From air to water.

R: You like that diagram better?

Pablo: No, it's the same. It looks the same to me, well kind of...

R: One of them shows the thickness of the glass.

Pablo: Oh yeah, now I see. Yeah, you are right. Here is the diagram for refraction.

R (IB): Pero lee mi hija. ¿Tu terminaste la tercera? (Read my child. Did you finish the third one?)

Pablo: I don't get the point of this.

Pablo experiences frustration. Pablo does not understand what the statement is asking because he is unfamiliar with the terms trace and light beam. Furthermore, he struggles with the concepts of mediums and refraction. The following excerpt shows an attempt by the instructors to help Pablo understand what he is being asked to do.

R: Ok. The last question, D, is asking you to use this diagram in order for you to trace a beam of light as it travels from the lamp through the different mediums. So it's traveling from the air. Do we agree that is traveling through the air?

Pablo: Yes.

R: Light goes through the water, then it goes through the glass and out of the tank. What do you think? Just trace a beam of light as it goes through these different mediums.

Pablo: So we are suppose to draw it?

R: A line.

Pablo: Draw a line. That's it?

R: A line that represents light as it goes through each one of the mediums.

Student-teacher Rachel [Addressing Dominic]: That is a water tank so that's glass.

Dominic: Like that, something like that? Is that what you are saying? I don't know.

R: That's why it is good to review right now. Let's review.

Pablo: Let's NOT review.

Gabby's response to light ray refraction in the water tank.

Pablo's response to light ray refraction in the water tank.

Dominic's response to light ray refraction in the water tank.

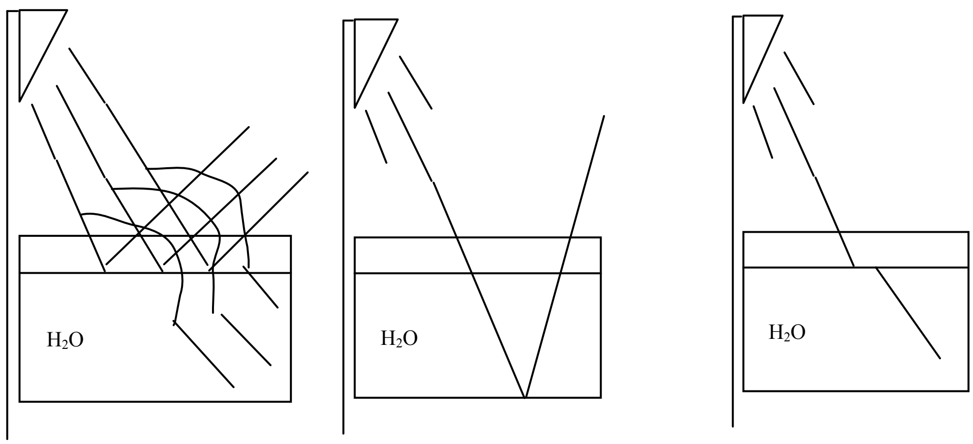

Figure 7. Schematic diagrams representing participants’ responses to worksheet statements on light refraction.

From participants' responses to the statements, it is evident that the participants have limited understanding of light refraction. Participants' diagrams showed that, this far, the participants have correctly identified the lamp as the light source. Gabby and Dominic have also identified refraction as a different concept than reflection. Pablo and Dominic attempted to redraw the diagrams in the textbook and though incorrect, their diagrams indicated more application of the concept of refraction than Gabby's drawing. Participants' drawings also indicated that the participants were not clear about the term medium as it is used in this context. Notice that the worksheet statement provided a hint as to which mediums were being discussed in the examples. Specifically, statement D stated “different mediums: air, water, glass and out of the water tank.” Participants' lack of understanding regarding mediums, molecule arrangement in these, and the mediums' respective densities, impeded participants from recognizing the effect that each medium has on the speed of light. Also, participants experienced difficulty with interpreting the worksheet graphs. The following audiotaped classroom discussions illustrate participants' understanding of light reflection and refraction, when discussed as a class.

R: Let's review the questions. Turn to the first page [of the worksheet]. Ok. Let's see what this looks like. At the same time, I want you to look at page 407 [book].

Look at page 407, top figure 12.19. Just take a look at this diagram. Look at the first one. Gabby, what does it say? The first one?

The diagram on page 407 shows diagrams A and B illustrated earlier and reads: “Light rays reflected from a rough surface area are reflected in many directions.” Notice Gabby's choice of words as she reads the statement under the diagram.

Gabby: Light, re.. light rays reflect from a rough surface are, hold on. Light rays reflected from a rough surface are reflected in a mirror image.

Gabby associates reflection with mirrors, probably because her first experience with the term reflection originated with the concept of a mirror image. It was difficult for Gabby to interpret light reflecting or “bending” from a clear and liquid substance and to see a mirror image in clear water.

R: So, now let's go back to A [in worksheet]. Um, does your diagram show that it goes in every direction?

Gabby: Yes. [Quietly]

Pablo: Sure.

R: The light is coming and then it bounces off. It can't be like here and then the light is going to be here. Where is that light coming from?

Gabby: What chu mean?

R: Here, look at the diagram.

Pablo: Look. It goes away **** that is

Gabby: OHHHHH, I get it.

Gabby: So we all have it wrong?

R: No.

Pablo: Aha [confirming.]

R: How about you Dominic? Did you get that?

Student-teacher Carlos: He did. He explained it to me.

R: Is Ok, I just need you to remember that [addressing Gabby who is showing signs of frustration]. It is the same ray of light that is being reflected. Because if you did this, where is this light coming from? Gabby?

R: Ok. And they go in different directions because the rough, the surfaces are uneven. And no, it's always a straight line by the way. Light travels in straight lines. Always.

R: Alright. With the next diagram, um, I was asking you to show the lights that are being reflected on an even surface. If it is being reflected on an even surface what would that look like?

Gabby: It is going to go straight up.

R: Straight up.

Gabby: Go on the same thing.

R: Right at the surface. We don't have wiggly lines for these. Right?

Student-teacher Carlos feels compelled to clarify the concept of light reflection and provides an example of a pool game. Pablo responds well to Carlos, whom he identifies with culturally. The following excerpt shows how Pablo "gets" how light rays exit at the same angle as they enter in an even surface.

Student-teacher Carlos: Do you guys like pool?

IB: Yeah.

Pablo: Yo, you *******

Student-teacher Carlos: Same thing like pool. You know when you hit it, let's say you hit this way, the ball is going to bank off whatever the same way, the same angle you hit it with.

Pablo: If you know that, you can pretty much win the game.

Student-teacher Rachel: And right here it says that the angle of incidence equals the angle of reflection.

Pablo: Hey, that's a good way to make me know this stuff. Cool.

R: [Addressing other students]: Awesome. And that is what? What is that called? Reflected. And when you look at a mirror that's what happens too. The light is reflected back at you.

Pablo: Uh/Uh [Confirming]

At the end of this discussion, all participants' worksheets had corrected drawings indicating how light rays are reflected.

The topic of light reflection appeared to hit a cord for Elena and me. On a follow-up discussion on a subsequent lesson, Elena approached me and asked me why was it that her mother covered mirrors with bed sheets when there were lightning episodes during a thunderstorm. I remembered my own upbringing and asking the same question to my mother. I remember my mother explaining that she covered the mirrors because evil spirits lurk during lightning and thunder. For my mother, superstition helped protect her family from the possibility of lightning reflecting off mirrors. Similarly, it is common practice in some cultures around the world to either cover mirrors or remove them from the wall during lightning events. Elena’s curiosity about the covering of mirrors during lightning episodes allowed me to draw from our common experiences and helped me connect and address the common misconception that mirrors attract lightning. Mirrors, I explained to Elena, are able to reflect light. I continued to explain to Elena that mirrors have even surfaces and when light strikes them, the angle of incoming light rays will equal of the angle of light ray reflection. Thus, covering an exposed mirror from lightning may help prevent the reflection of lightning rays. In this teaching moment, prior cultural experiences that Elena and I shared helped in the co-construction of science knowledge.

However, light refraction proved to be more challenging to teach. Notice how assessment questions assist with reviewing prior and relevant knowledge associated with light refraction.

R: Alright, let's try D.

R: So, we are looking at a tank full of water and it's made out of glass. And I tell you there is a lamp there with light. So, I ask you to just trace a beam of light as it travels through, from the light source, through the different mediums, air, water and glass. Now, let's discuss this a little bit. The states of matter. Who remembers what are the four states of matter?

At first, participants experienced difficulty with identifying the states of matter. After a brief review, participants identified the 4 states of matter. Participants were then asked to identify the mediums in the diagram. In our discussion, participants agreed that air represented a gas, water represented a liquid, and for this discussion, glass was considered a solid. Participants were then asked to identify in which of these 3 mediums the molecules were more spread apart (less dense). Participants responded:

R: Now, where are the molecules most spread apart in these 3 mediums? In air, water or glass? Where are the molecules more spread out?

IB: Water, gas, liquid?

Pablo: Wait, no. In a solid, like is a solid thing so they are stuck together, and gas is spread out.

Dominic: (IB) Plasma?

R: Ok, it's so spread out that we can walk through it. Everyday, every minute. You can walk through the molecules of air right now. That's the way you should remember it. The molecules in the air are really, really spread out. So, if the solid is really, really tight, such as this table, [knocking on the table to show tightness of solids] right?, you can't go through it because the molecules are so tight. And the air, you can walk through. What would the liquid be?

Elena: In between.

R: Right. So they are settled, right in between. Now, let's think about the light. When the light travels through the air what do you think is going to happen? Is it going to go faster or slower? Or what do you think is going to happen?

Elena: Slow

R: If it travels though gas, she says it is going slow. Gabby, what do you think? If light travels through gas, what do you think is its speed?

Gabby: Didn't you say the molecules are moving fast?

Student-teacher Carlos addresses participants' responses and mobilized them to conduct an impromptu activity on molecule arrangement in the three different states of matter, gas, liquid and solid. He asked the participants to stand up and had Dominic walk through the participants, as if he were a light ray, when the participants are spread apart [representing the gas state], when they are closer [representing the liquid state] and when they are close or shoulder-to-shoulder [representing the solid state]. At each point, he asked the participants to identify the speed of light. Participants responded and explained that in gas, Dominic traveled faster than in liquid, than in a solid. After the demonstration, participants were asked to identify the speed of light as it traveled through the different mediums. The following dialogue illustrates participants' understanding after the demonstration. Notice how Gabby's knowledge of light reflection and refraction is exposed.

R: Did you understand this example? Alright, now the light is going to travel from one medium- from air, from you know, gas, through liquid, through solid. Now, what do you think is going to happen to the speed of light as it moves through it? Let's see, if you trace something, if you trace a beam of light now that you know a little better, can you trace that light beam? And what do you think is going to happen? As it goes- it leaves from the light source, it is traveling through air and it hits water.

Gabby: I thought you meant like absorb it -reflected and refracted

Student-teacher Carlos: Part of it is.

R: It is. Remember, I just said that light will change its speed as it goes from one medium to another. Is your diagram showing that it is slowing in speed?

Pablo: So you are supposed to like make it? I don't know.

R: Yeah, right. Ok. Let's review this. Let's see if this reminds you of something. 412. Let's take a look at the picture on 412 with the lawnmower. What happens to the lawnmower as it changes from concrete to grass?

Pablo: It changes the angle, whatever.

R: It changes its direction right? See that. What do you think is going to happen once the light comes through the air and hits the water? It will bend. Good. And when it bends what do we call that?

Gabby and Elena: Reflection.

IB: Refraction.

R: Refraction, alright.

Pablo: Yeah.

R: Now take a look at these two diagrams that we did review last week. Ok. When it went from air through glass, which is a denser medium, look at the way that the light turned. Do you see it in red? What happens to the light as it went through?

Gabby: It bended and moved out.

R: It bended and also towards what is called the normal. If you draw an imaginary line it would go this way. What happens when it goes from glass through air?

Gabby: It went away from the normal.

R: Very good. Now let's think about your diagrams again and see if you can draw a path of a beam of light as it travels through the three mediums. You need another ink?

Pablo: Oh, I don't.

Gabby traces the light rays refracting incorrectly in her diagram. This is the diagram Gabby draws:

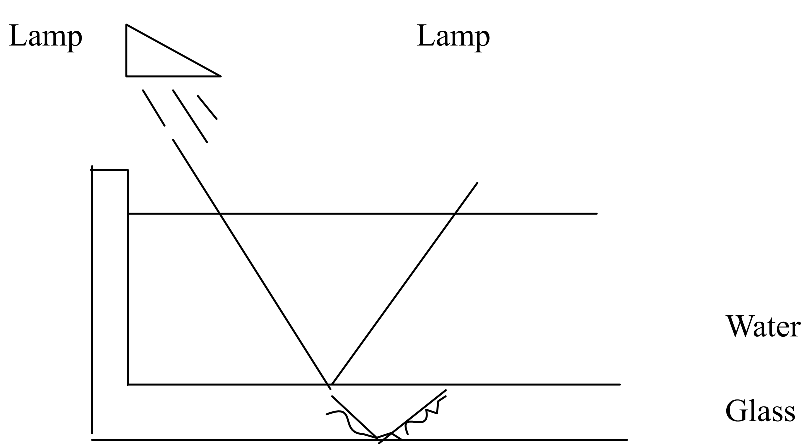

Figure 8. Schematic diagrams representing Gabby's response to worksheet statements on light reflection.

Gabby's drawing is indicative of her lack of understanding regarding light bending, specially as light enters from air to water. Participants, Gabby and Elena in particular, use the term bend to indicate that the light rays change directions and thus it is difficult for them to articulate what happens to the light when it is reflected and refracted. It is important to note here, that the textbook, the instructors and the statements on the worksheet did not use the term bend when referring to light reflection because light “bounces off” a surface. For physical science learners in general, the phrase “to bounce off” takes on a different meaning in this context. For Latinos and English speaking students alike, the term bounce is often associated with the bouncing of balls off a hard surface such as the floor or a wall. As a result of this term switch, it is difficult for physical science students, Latinos in particular, to describe and imagine light rays bouncing off a liquid. Thus, when the participants try to describe and draw how light is reflected, the term bend that they employ distorts their understanding and they get lost in translation.

Together with her problems with understanding the term refraction (bending), Gabby's drawing also indicates that she cannot interpret the diagram as it is presented in this exercise. Gabby cannot differentiate between air and water in this diagram. However, her crossed out rays in the glass portion of the diagram indicate that Gabby has identified glass as a different medium. After identifying Gabby's confusion with the term bend and her lack of proper interpretation of the diagram, I use Spanish to explain the concept of refraction with the intention to further scaffold her learning and remove the language barrier as a reason for misunderstanding. The following excerpts present the dialogue between Gabby and me.

R: Gabby, *¿qué le pasa a la luz? Pero, mi- te estoy diciendo que la luz se dobla cuando cambia…* (Gabby, what happens to the light?- But... I am telling you that light bends when it changes...)

Gabby: I know. *La luz se dobla.****** (Light bends)

R: This is air, this is liquid…

Gabby: Aha

R: When it goes straight… You are saying it goes straight down. (Her diagram shows a straight line and does not show bending of light).

Gabby: No. When it goes through air ******

R: I am asking you what happens to the light as it goes from air through water. It does not go in a straight path, look (referring to the diagram in the textbook). Does this go on a straight path? OK. So, remember, does it bend? What do you think? This is heavier, it is going to refract.

R: Do we agree that this is air?

Gabby: Uhu. She laughs- what is wrong with it?

R: Ok. Let's do this. Now, if everyone else is fine, you can move on to the next one, which is just working out formulas. [Other students work on the formula for speed.]

R: [I am working just with Gabby]- *La luz viaja en lineas rectas.* (Light travels in straight lines). The first thing you need to know is that light is going to leave the lamp like that, right. Are with me so far? It' snow hitting another medium, which is water. Do you agree? Ok. What…

Gabby: What do you mean is hitting water? ****

R: Let's **** that's why I give you this diagram, look. This is glass container, ok, and there is water inside it. Do you remember the one we used on the test? The light is going to go through here. You would think it ****** that the light will travel through the air, through the water and then through the glass.

Gabby: Oh yeah *****

R: ****** what do you think you have then?

Gabby: [Inaudible]

R: I want the light to go through. I am not asking you ***** As the light goes through this... Ok. In order to do that, the lamp is shining light and it hits this medium. A medium is just a different material. Once it hits this medium (water), the light will go through it because this water and the molecules are a little bit much closer. OK *** the light will slow down. Remember when we did that exercise? [Referring to Student-teacher Carlos' demonstration about the molecules being tighter in liquids than in solids.]

Gabby: Uhu.

R: So, what do you think is going to happen once the light hits this?

Gabby: Is going to bend.

R: It's going to bend. You have to decide whether it is going to bend in this direction or that direction.

R: What I am trying to show you is that when light travels from air through water through solid- every time, it changes direction.

R: This is one example, you ask yourself, which way is it going to bend? Ok. Why is this important to know?

Gabby: 'cause

R: Let me show this example [referring to the book and a picture of a fish. The light distorts the position of the fish]. Let's say you wanted to fish. Let's say you wanted to fish, alright. Because the light bends, it makes the fish look much higher than it is and it is just an illusion. Let's say you wanted to get something from the bottom of a lake, how would you do that? It will appear to be closer. And even at a different angle, do you see that? They did exactly what you did. Do you understand this example? Ok, I am going to give you another one.

Student-teacher Carlos and Pablo had also worked on the light refraction exercise. Their conversation took place at the same time I tutored Gabby. Pablo needed less assistance than Gabby, because Pablo identified refraction as light bending when it enters the different mediums. However, student-teacher Carlos met a different challenge when scaffolding Pablo about the direction of the light once it hits the different mediums. The following excerpts show their interactions.

Student-teacher Carlos: Too long...

Pablo: The middle one?

Student-teacher Carlos: The left.

Pablo: The left.

Student-teacher Carlos: *** goes through air again.

Pablo: It bend again.

Student-teacher Carlos: It won't bend backwards.

Pablo: This one?

Student-teacher Carlos: It won't bend backwards.

Pablo: It would go straight, and this will bend in air right?

Student-teacher Carlos: It never bends backwards.

Pablo: What? So, it has to keep going straight the whole time.

Student-teacher Carlos: So, it is going from something that is real dense to something that is not.

Pablo: There is nothing there.

Student-teacher Carlos: Glass.

Student-teacher Rachel: Look at my picture right here.

Pablo: Like that?

Student-teacher Carlos: Yeah.

Pablo: Ok. I did it.

Pablo completed the diagram. He traced light ray refraction through the different mediums correctly. Pablo was also the only participant in the class that completed the diagram correctly. On the follow up lesson, Gabby used her diagram to illustrate light reflection in even and uneven surfaces correctly. However, for the refraction exercise, Gabby illustrated internal reflection and light bending occurring only at the glass portion of the diagram.

Data gathered from participant observation, as presented in the above teaching moments, provided evidence that the participants experienced difficulty when learning the concept of light reflecting and refracting. Furthermore, pre- and posttest data support these findings. For example, pretest data showed that all participants completed this question on light refraction incorrectly. Posttest results showed that only Pablo and Dominic answered the question on light refraction correctly. Language use, in particular, played an important role in understanding the nuances of concept building among these physical science learners. For instance, everyday English language terms such as bend and bouncing off took on a particular meaning in the science classroom. The use of these particular terms in this context impeded some of the participants' ways of articulating the concept of light reflection. Scientific language such as the terms and phrases used in these lessons (for example, medium, light source, surface and molecule arrangement) also impeded participants' articulation and understanding of the concept of light reflection and refraction. Thus, using and identifying language as a learning tool is paramount if we are to develop scientific literacy among students.

Participant observation also provided evidence that the teaching and learning methods applied in these lessons provided sufficient scaffolding for concept building in the area of light reflection for some students. More specifically, participants' more knowledgeable peers, student-teachers Carlos and Rachel, provided the necessary scaffolding to move participants (at least Pablo and Dominic) to stage II of the learner's performance continuum (or LPC), as suggested in participants' responses in the posttest. At first, teaching provided performance assistance and included assessment and assisting questions, cognitive structuring (Type I: explanation and Type II: cognitive activity), language use and diagram interpretation in this particular context. Then, participants performed independently, without further assistance, and correctly identified and described the concept of light reflection.

The concept of light refraction was more challenging to teach because it was difficult to gauge participants' ZPD at the time of the lesson. Participants whose knowledge base included exposure or understanding of the prior concepts necessary to articulate light refraction (mediums, molecule arrangement, density), appeared to cross the line between stage I and II of the LPC. However, for those participants who lacked knowledge about mediums, their molecule arrangements and density, the teaching methods used as scaffolding tools in this lesson were inappropriate and/or insufficient and were unable to help bring these particular participants to stage II, or independent learning.

Subtheme 2: The mathematical term "per" confused participants. The following section describes teaching moments that occurred immediately after the lesson on light reflection and refraction. This portion of the lesson was designed to review the concept of speed and momentum, its formulas and their interpretations.

Background on formulaic expressions. Along with conceptual understanding, physical science students are expected to express scientific knowledge through the proper application of formulas. Formulas are statements, usually written and expressed in the form of equations, about a fact, rule, principle, or other logical relation. Formulas are short sentences that help consolidate bits and pieces of knowledge and are used for calculating quantities. They are often expressed as the product of a number and a physical unit (established by the International System of Units or *le Systéme Internationale d'Unités* or SI unit for short). The American System uses a different unit system (such as miles, pounds and gallons), and is commonly used in commercial and everyday language and in disciplinary areas outside of science.

Formulas are valid when all the terms in the formula have the same dimension. Every term in a formula has the potential to be converted to contain an identical unit. For instance, the SI unit for time is seconds but if a variable in a problem is given in hours, it can easily be converted to seconds. Formulas are applicable in a wide range of situations and some are particular sentences for solving specific problems. The following example may help illustrate the function of a formula. When calculating the walking speed of a human, we use the formula for speed: Speed equals distance (or displacement) divided by time or $v=d/t$.

This formula summarizes the variables necessary to calculate the speed of a human walker. If I want to determine the speed of a walker, then I must know the distance the walker walked and the time it took them to cover that distance. If I then divide the distance by the time it took them to walk certain meters, then I can easily calculate the speed at which he/she walked. Two things are important when using a formula in science to calculate a term or a variable. One must know some of the variables in the formula (in this case, distance and time) and one must remain consistent with the SI unit (in this case, distance is measured in meters and time in seconds).

Formulas represent the mathematical language of science. As an established scientific language, formulas help ease communication by standardizing measurements and data calculations in the scientific community. Furthermore, as a scientific literate community (limited as it is), we often express ourselves in this language. Consider the way we talk about weight. We often talk about how many pounds we have gained or lost. We talk about how fast we were driving, or how many milligrams of sodium we consume. Whether we use the SI or American system of units, we often summarize these ideas quickly by responding with a number and an unit (10 pounds, 55 miles per hour and 200 mg). Thus, understanding and applying formulas is an important skill that every student should know.

The National Science Education Standards as well as the State Performance Standards require that all science students know how to use and manipulate formulas, and their accompanying SI units. Physical science students are required to know some fundamental chemistry and physics formulas. The physics portion of physical science course, require that students know how to calculate speed, acceleration, weight, force, work, and mechanical advantage. Standardized exams such as the CRCT and EOCT also test this knowledge. For instance, a question from a physical science EOCT asked students to determine the speed of an object. The question was stated as follows, "In order to determine the speed of an object, what measurements must be made? a. distance and direction b. distance and mass c. time, distance and volume d. distance and time."

In another EOCT question, physical science students were asked to identify the SI unit for specific measurement. The question was stated as follows,

> The International System of Units (SI) is a standardized system of measurement used to express fundamental quantities in metric units. Which of the following metric units are used to measure the fundamental quantities of length, mass, and time, respectively, in the SI system? a. liter, gram, second b. foot, pound, second c. meter, kilogram, second d.

meter, ounce, second.

How the topic of formulas is taught depends on various factors. Factors such as time, resources, teachers' expertise, students' familiarity with mathematical formulas and their interpretations as well as students' prior knowledge of SI units may help or hinder the depth of knowledge that a student experiences. For instance, a physical science teacher may just conduct a lecture on the formula for speed and conduct some sample calculations for students to practice. Another teacher may conduct multiple laboratory hands-on exercises where students calculate the speed of a car. Some teachers may also drill on formulas and their corresponding SI units. The LASP program was designed to supplement this particular area of knowledge. More specifically, the LASPS program used the practice of cross-multiplying variables to isolate and calculate a term extensively during formulaic calculations.

Investigating the dimensions on teaching and learning of the lesson on the concept of speed and its calculation. During the beginning lessons in LASPS, participants conducted numerous laboratory exercises on motion. These lab exercises, including lectures and class discussions focused on reviewing, applying the concepts of speed, velocity, momentum, acceleration, Newton's laws of motion, work, power and energy. The first lab, asked participants to calculate their walking speed using Logger Pro computerized programs. In another lab, participants also calculated the speed and velocity of cars that carried different weights. LASPS worksheets asked participants to calculate speed, velocity, momentum and acceleration using formulas and SI units. In total, participants participated in 7 lectures and discussions on the topic of motion and conducted 7 different hands-on experiences related to the topic. Participants also attended a field trip focused on physics practices. In this field trip, participants were exposed to topics on electricity, electrical field strength, wave behavior and astronomy. At the beginning of the program, participants were also handed a wooden 3” x 5” block to design into a car. The car was to be designed for speed and acceleration. While lessons on motion were conducted, numerous references were made to the design of the car. The aim was to have participants consider motion, speed and acceleration, in the design of their cars.

Teaching, reviewing and applying the concept of motion was challenging. The need to develop the skill of formulaic calculations and interpretations in the participants became evident after every lesson when participants experienced difficulty in understanding, manipulating and expressing formulas and their corresponding SI units. Furthermore, participants experienced difficulty with translating and applying mathematical language in the physical science context. The following teaching moments, as recorded on audiotape, highlight some of the issues associated with concept development, scientific literacy and problem solving, in LASPS participants.

On the seventh lesson, participants were asked to revisit the concept of speed and its calculation. Participants ' worksheet asked them to recall the formula for speed and to manipulate the formula to calculate for distance. The questions were stated as follows:

Statement #1: “What is the formula for calculating the speed of a moving object?”

Statement #2: “If you wanted to use the formula for speed to find the distance that it takes an object to travel a certain speed and time, how would you rearrange the formula to isolate distance? Show your work.”

Student-teachers Carlos and Rachel helped individual participants answer the statements. To answer statement 1, Carlos and Rachel attempted to have the participants arrive at the formula for speed through the use of the SI units, meters per seconds or miles per hour (the American unit). The following excerpts illustrate the challenges, and participants' frustrations, that Carlos and Rachel met when teaching formulas and their corresponding SI units. Notice that both Carlos and Rachel use assessment questions first, then assisting questions next.

Student-teacher Carlos: What is speed measured in?

Pablo: Seconds, time.

Dominic: Meters per second.

Pablo: Miles per hour.

Student-teacher Carlos*:* So, what's the formula for that?

Pablo: Something times something.

Student-teacher Carlos: Miles per hour.

Pablo: Divide it.

Student-teacher Carlos: By what?

Pablo: By something.

Dominic: Meters per second.

At first, Pablo did correctly identify the SI unit for speed and only referred to the variable of time. Once Pablo identified the American unit for speed (miles per hour), he did not identify the term “per” as a mathematical term for division. Dominic on the other hand, identified the correct formula for speed. Later on in the discussion, it is evident that like Pablo, Dominic also expressed his lack of understanding for the term “per” as in meters per seconds. For both Pablo and Dominic, the term “per” is lost in translation between the mathematical and science language. Carlos attempts to bring meaning to the phase “miles per hour” and questions participants' understanding about each of the terms.

Student-teacher Carlos: Let's stick to miles per hour. You guys are familiar with that. So, how does that look like? Miles-per-hour.

Pablo: I don't know!

Student-teacher Carlos: You have a start there. So speed equals miles-per-hour. So what is miles?

Pablo: Miles?

Student-teacher Carlos: What is that? What is that a measure of? What is it a measure of? What is meters? What are you measuring?

Pablo: Distance.

Student-teacher Carlos: Distance, right.

Pablo: And hours. Oh wait, divide them. So divided by 10.

Student-teacher Carlos: And what does that equal?

Pablo: The speed, velocity.

Student-teacher Carlos: Good.

Pablo: Miles divided by time equals, right?

Student-teacher Carlos: It does not matter, is the same thing.

Pablo: I know, but it looks better this way.

Student-teacher Carlos: And it looks better if you keep the dividing sign when you put it. ***** at the end of the distance.

Pablo: Oh yeah, I forgot about that.

Student-teacher Carlos: Make sure you state that velocity equals distance divided by time. That way you can look back at it.

Pablo: And say, what the hell is this, alright.

Student-teacher Carlos: You better write that.

Pablo's worksheet indicated that he identified and wrote the correct formula for calculating speed. Pablo continued and read the next question on the worksheet. Carlos identified the terms that are "given" or accounted for in the formula and asked Pablo to manipulate the formula for speed. It is important to note here that participants were asked to calculate speed and not velocity. For Carlos, these two terms are interchangeable in this lesson. Even though the terms are related, velocity indicates speed and direction. Carlos' misuse of the term speed may have reinforced the confusion between the terms for speed and velocity among the participants. Furthermore, the formula for speed includes the term velocity as in $v = d/t$, and may have also served as a source of confusion for Carlos as well when explaining the concept of speed. Similarly, as evident in Carlos' and Rachel's discussions, they reinforced the use of the American unit 'miles per hour' rather than the SI unit (meters per second or kilometers per hour) in their teaching. The LASPS program is Carlos and Rachel's first exposure to teaching and they are not aware yet of the learning repercussions that may result from their lack of clarity. However, Carlos and Rachel's intent is to bridge everyday language with scientific language for the participants. After Pablo read the next statement, he identified what statement #2 was asking and stated:

Pablo: So I am trying to find distance.

Student-teacher Carlos: Yeap. You are given velocity, time, so how do you go about finding distance?

Pablo wrote the equation down on the worksheet and read it out loud, "velocity equals distance divided by time."

Student-teacher Carlos: So you start out like this, showing all your work.

Pablo: So you isolate this.

Student-teacher Carlos: Ok. So how do you get rid of this side? [How do you get rid of the variable "time" in v=d/t].

Pablo: Divide? [Hesitates] You multiply? I don't know?

Carlos identified Pablo's confusion with manipulating the formula. More specifically, Pablo did not know how to cross-multiply the terms in the equation. Carlos provided an assisting question meant to activate Pablo's understanding about the process of cross-multiplying.

Student-teacher Carlos: What are you doing here?

Pablo: Dividing.

Student-teacher Carlos: Ok. So what do you do to get it on the other side? [of the equation]

Pablo: Divide.

Student-teacher Carlos: Whatever you do to this side, if it's here. One way is to do the opposite.

Pablo: Multiply. [Cross-multiply the terms]

Student-teacher Carlos: Yeah. So equals. Put a little arrow.

Student-teacher Carlos: It did not show that you ****

Pablo: What do you mean?

Student-teacher Carlos: You are looking for speed.

Pablo: You multiply.

Student-teacher Carlos: Yeah, that's it.

Pablo: That's it!

Pablo: What were you saying?

Carlos provided cognitive structuring in the form of cognitive activity so that Pablo could organize his mental processes about the steps involved in formulaic rearrangements.

Student-teacher Carlos: Let's say you wanted to get time by itself.

Pablo: I start with velocity equals distance divided by time.

Student-teacher Carlos: And you want to get time by itself.

Pablo: Time by itself.

Student-teacher Carlos: Uhu [Confirming]

Pablo: You would multiply distance.

Student-teacher Carlos: What's...

Pablo: I don't know!

Student-teacher Carlos: I can't give ****

Pablo: I am going to do it like you did, the other way.

Student-teacher Carlos: Ok.

Student-teacher Carlos: But this is on top right?

Pablo: So, Okeyyyyy. I don't know.

Student-teacher Carlos: So if it's multiplying right here, right? How do you get rid of it?

Pablo: Divide.

Student-teacher Carlos: Yeah.

Pablo: So it'll be distance over velocity.

Student-teacher Carlos: No. Whatever you do on one side you got to do the other. That's why you have to show your work. So you are trying to get distance, right over here, right? So you put a d down here so these cancel, you see?

Pablo: Yeah

Student-teacher Carlos: You divide so...

Student-teacher Carlos: So now you have velocity equals = ****

Pablo answered the question correctly. The following statement illustrates Pablo's answer to statement #2:

$$V = \frac{d}{t} \qquad t \times v = d$$

Pablo's corrected response to the question provided sufficient evidence for Carlos that Pablo can, at the very least, manipulate the formula for speed to isolate distance. Student-teacher Carlos walked away from Pablo to help Student-teacher Rachel who was having difficulty explaining to Dominic the concept and formula for speed. Rachel also attempted to have Dominic derive the formula for speed by using what Dominic already knew. Dominic knew that speed is measured in meters per second, or the American terms “miles per hour” as Carlos had restated earlier in the discussion. Notice Dominic's lack of understanding of the term “per.” Rachel tried to clarify the use of the term “per” in the formula for speed.

Student-teacher Rachel: Ok, but per hour. What would you do in order to figure out how many miles you are going per hour? Would you multiply them or divide them?

Dominic: Divide?

Student-teacher Rachel: Good job! So you just put miles on top.

Dominic: Oh wait! Divide them.

Student-teacher Rachel: Divide right? That is what you told me. But you already have it all together. So you are going to have to- let's just scratch that one out. [She chuckles.] Alright, so you know, you know, the amount of miles that you traveled. That goes on top right?

Dominic: Uhuh [confirming].

Student-teacher Rachel: So, put miles there, then you are going to divide by time and miles.

Dominic: Miles per hour? or just ****

Student-teacher Rachel: Miles, because the “per” is saying that it is dividing, right? Miles divided by time which is in hours, right? [A pause] Yeah, so ****

Dominic: Oh, it is like this.

Student-teacher Rachel: Yeah. But that's the same thing you know. Dividing, there is a division sign you can do it either way. So, miles-per-hour?

Dominic: I got to write that. *****

Student-teacher Rachel: So, you want to do it like he did. Just, you know how people would measure it in meters per second or miles per hour? So, you just know that distance is on the top and time is on the bottom. So it may be easier for you to remember distance over time. Right! Good job. Nice.

Dominic read the next question, statement #2.

Student-teacher Rachel: Ok. So, you are looking for distance, right? So, the distance you would travel at a certain speed and time. So. Ok. So you know that speed equals distance over time. Ok. So you are getting the speed and you want to know the distance. What would you do to get the distance by itself? To go away from it, what would you do?

Dominic: You multiply.

Student-teacher Rachel: Yeah [happily]. So, you do time times... you get distance. Does that make sense?

Dominic: A little.

Student-teacher Rachel: You are just going to have to rearrange the formula because you know you want distance on this side by itself. So, if you are dividing over here, you are going to multiply time by the speed in order to get the distance. So, say you wanted, say you wanted, say you were given 12, yeah...

Dominic: You would multiply distance.

Student-teacher Rachel: Just because you know it.

Dominic: What *****

Rachel has assessed Dominic’s understanding of formula interpretation and manipulation. Rachel determined that Dominic's statement in response to her question “Does that make sense?” at which Dominic replied “a little” was indicative of Dominic's limited understanding about formula manipulation. Rachel called on her more knowledgeable peer, Carlos, to explain the concept of formula manipulation to Dominic.

Student-teacher Rachel: I explained it to him but he is saying he is having trouble understanding it.

Student-teacher Carlos: Dominic. So miles per hour, right?

Dominic: Yeah.

Student-teacher Rachel: It's miles on top for every hour. So, if you are going at 60 miles per hour you go 60 miles per hour right? Is how fast you are going. So velocity, speed equals... What is miles? What is that a measurement of?

Dominic: Seconds? No. Hours. No.

Student-teacher Carlos: So do you measure miles in hours?

Dominic: Umm, distance.

Student-teacher Carlos: Distance, right. And what are hours a measurement of?

Dominic: Seconds, time.

In addition to assessment and assisting questions, Carlos employed the use of cognitive structuring in the form of an explanation (Type I) to scaffold Dominic's understanding when he reinstates what statement #2 is implying.

Student-teacher Carlos: Time. So how fast you are going depends on how much distance you cover divided by the time it takes to cover that.

Student-teacher Rachel: He understands that, I guess. Is just getting it. If you are given, if you are given the time and the speed and but you are looking for distance, you would multiply those two because you want distance to be by itself on this side, right?

Student-teacher Carlos: Remember the conversion factors?

Student-teacher Rachel: Yeah.

Student-teacher Carlos: Remember we did the opposite to get it.

Dominic: Oh yeah, yeah, yeah.

Student-teacher Carlos: So time is on the bottom. You got to multiply by time on top. So you put time there, this cancels out. So it gives you the same thing here. So you have time and you are left with distance. Time times speed = distance. You get that?

Dominic: Kind of.

Student-teacher Carlos: Let's do...

Dominic: It's confusing but true...

Student-teacher Carlos: Is just practice. You just got to practice that. It's something you will use all the time.

Student-teacher Rachel: Definitely. Because...

Based on Dominic's response to the question “You get that?” at which Dominic answers “kind of,” Carlos and Rachel realized that the teaching strategies that they have used to scaffold Dominic's learning were not sufficient. Carlos took on a different approach to teaching and presented an everyday example to help Dominic connect spontaneous knowledge with scientific knowledge. Carlos presented an example where his knowledge of unit conversions helped him calculate how many cubic feet [of wood] were necessary for him to purchase to complete his project. Also notice Rachel's attempt to justify the importance of mathematics in our everyday lives.

Student-teacher Carlos: Because, I had inches... I need something with so many inches tall and so many feet wide and long and I need it in cubic feet I have to convert inches to feet and then multiply them all together to get cubic feet. And that was something I used this weekend. Not for homework but for something for life.

Student-teacher Rachel: Math is used everyday in our lives.

Student-teacher Carlos: Math is just a language that science uses to talk to each other.

Student-teacher Rachel: Ok

Student-teacher Carlos: So give him another one. Try to have...try to get time by itself. Dominic, try to get time by itself.

Dominic: Ok.

For this lesson, there were no further discussions on calculating speed. Other lessons in LASPS focused on reviewing different formulaic manipulations, including the one for speed. Associated knowledge regarding speed was more visible in participants' design of wooden cars. The ongoing project of the car design reinforced the concept of speed and velocity. When designing the car models, participants accounted for the force of friction and gravity as an influence on speed. They designed cars with smooth surfaces to resist air friction as it traveled down the ramp. Furthermore, most car designs included flat tops and low height to increase speed. Participants also added weights at the bottom of their cars to increase the car's momentum. While the car design project did not involve participants applying and manipulating the formula for speed, the project exposed participants to the different variables, including its associated language, that affect speed.

Participants' journal entries for the lessons on light reflection and refraction and the calculation of speed and momentum revealed that scaffolding strategies helped Elena bridge everyday language with science language. For example, Elena explained the concept of refraction and used the term bend correctly. In her journal entry Elena wrote:

> Today I learned about light, how light is, why is it visible and invisible. The colors that we can only see which are red, yellow, orange, green, blue, violet and ultraviolet. And how and why the light reflects and refracts. Refracts is went light bends, Reflects when light comes back, you see the same thing.

Dominic's journal entry also revealed that he was able to apply science language in the correct context. Notice that Dominic did not shy away from using the term medium. Dominic's journal entry states: “Today I learned momentum is calculated p = mv. And we also went over solid, liquid, solid and plasma. And also how light travels through different mediums.”

Regarding the concepts of light reflection and refraction, Dominic and Elena's journal entries suggested that they might have crossed the dividing line between Stage I and II in the LPC. Both participants were able to summarize the concept independently. However, Pablo's journal entry revealed that the scaffolding strategies used to help him move to ZPD Stage II were insufficient. Pablo was not able to distinguish between surface and medium. Furthermore, Pablo identified plasma as a surface in which light can refract. In his journal entry, Pablo wrote his definition for light reflection and refraction and it read: “I learned about reflecting and refracting and how it bends when it goes through the different surfaces like liquid, solid, gas and plasma. And I learned why it does it that way.”

Gabby, on the other hand, avoided writing in her journal about conceptual learning.

Rather, Gabby commented on the teaching strategies that helped her learn in this lesson. Gabby wrote in her journal: “I like how we worked by ourselves, even though is helpful when ya'll help us. I like it when ya'll just show us our mistakes and we fix it on our own. It is also helpful to review everything.” On her prior journal entry, and in addition to helpful learning strategies, Gabby specified what she learned. Gabby wrote:

> Today we learned about the different say that can happen to light. Those things are reflect, absorve and refract. It helped to look at all the different diagrams of how it works. Also not only look at the diagram but talk about other examples of everyday life of how light works and how we use it. I also think is very helpful when we talk in small groups where everybody gives their opinion.

Gabby's journal entry also gave evidence that along with group discussions, the worksheet diagrams were useful scaffolding tools in her learning of this topic.

Multiple-choice questions on pre and posttests assessed participants' knowledge of light refraction (question #1), calculating acceleration (question #2) and graph interpretation on the relationship of velocity and time (question # 14). Table 5 summarizes pre and posttest results, indicating participants who answered questions correctly regarding the topics of light refraction, calculating acceleration and the relationship between velocity and time.

Table 5

Participants who Answered Questions Correctly on Pre and Posttests Regarding Light Reflection and Refraction, Calculating Acceleration and The Relationship Between Velocity and Time.

	Light Reflection and Refraction		Calculating Acceleration		Relationship Between Velocity and Time	
Participants	Pre-test	Post-test	Pre-test	Post-test	Pre-test	Post-test
Dominic		X		X		
Elena				X		
Gabby			X			
Juan					X	
Manuel				X	X	
Mario				X		
Pablo		X	X			

Note. Manuel was absent during the lessons when these topics were discussed.

Evidence from posttest data, as well as lesson worksheets, suggest that Dominic and Pablo identified and interpreted graphs on light refraction correctly. Posttest data indicated that Dominic, Elena, Manuel and Mario calculated the average acceleration of a car correctly. None of the participants were able to translate their knowledge of the relationship between velocity and time in a graph during the posttest. It is important to note that question #14 asked participants' to interpret graph responses that were not discussed in LASPS.

Subtheme 3: Scaffolding strategies can help participants move through the Learners' Performance Continuum. Effective teaching can be experienced when learners cross between the different stages of the LPC. Scaffolding strategies are ways in which teachers can assist learners to cross over the different stages or navigate through them. LASPS lessons show participants' struggles and resistance with transitions among and between the stages of the LPC. The following lesson illustrates how assisting and assessment questions agitated learners' prior knowledge and challenged, at least one participant, to deautomitize fossilized concepts.

Brief introduction to potential energy. Potential energy (PE) refers to the energy that an object has stored. There are different kinds of PE, ex. mechanical, chemical. Mechanical PE refers to the potential and kinetic energy in a mechanical system. Energy associated with the motion or position of an object is referred to as mechanical energy. The school's physical science textbook defines potential energy as "the stored energy resulting from the relative positions of objects in a system." Furthermore, the school's physical science textbook defines gravitational PE as the energy that could potentially be used to do work and that results from an object's position above the ground. The physical science textbook chapter on potential energy does not define nor differentiate mechanical or chemical potential energy. It is important to note here, that while PE comes in many forms, in this discussion PE only refers to gravitational PE.

There are two important concepts necessary to define PE in an object. One concept refers to an objects' relative position to a point of reference (in physical science classrooms, the ground is usually the point of reference). The farther an object is from a point of reference, the higher the PE. The closer the object is to its point of reference, the lower the PE. The other concept refers to an object's state of being. PE is only measured in objects that are at rest with the potential to do work at some later point.

Often, teachers and textbooks discuss the concept of PE by presenting 1 of these three classic examples, with their accompanying diagrams:

1. The roller coaster. When the wagon is on top of the hill (it has the highest potential energy because the stored energy will be used as kinetic energy or energy of motion). When the wagon is at the bottom of the hill, it has the lowest PE or one equivalent to 0 (because of the wagon's relative position to the ground).
2. The ball on top of a hill. When the ball is on top of the hill, it has the highest PE (because it has energy stored and will be used as kinetic energy once it begins rolling). When the ball reaches the ground, PE = 0, because of the ball's relative position to the ground.
3. A pendulum. When the ball at the end of the pendulum is high, PE is high. When the ball reaches the bottom (or the center of the arc which is closest to the ground) PE = 0.

While convenient for short and brief discussions about PE, these diagrams and examples often limit the understanding of PE. For instance, students should have the opportunity to consider the different forces acting on a moving system. A roller coaster, for example, can either use the force of gravity to move down a hill, or a combination of electrical, magnetic and gravitational forces. While physical science curricula do not require students to know the interactions of these forces on a wagon (or a moving object), it is important that the students are aware and consider other existing and influencing forces acting on moving systems.

Secondly, students should know that in moving systems that do not use or use limited amounts of other forces (ex. electrical or magnetic), gravitational force is the main force acting on the moving systems presented in the diagrams. It is important that students understand the relationship between gravitational force and the position of an object. All objects around Earth, experience a gravitational pull toward Earth's core. The moving ball as well as the ball in a pendulum, experience equal gravitational force, relatively speaking, as compared to the Moon, which is much farther from the core of the Earth. When considering an objects' PE, gravitational force is measured by the location, elevation, or the distance of an object to a point of reference.

Thirdly, while the intention of these diagrams is to indicate that an objects' PE is dependent on its position, students may also connect an object's position to immediate movement, since in each of the scenarios, movement is about to occur. Whether implied or explicit, students should know and understand that the movement of an object in a moving system can occur at any time, present or future.

The relationship between PE and an object's location as presented in the classic classroom diagrams may seem explicit and logical. However, using diagrams that often refer to the ground as the point of reference, may limit the applicability of PE in other models, such as a moving system in space or objects underneath the ground.

Investigating the dimensions on teaching and learning of the lesson on potential energy. While conducting a lesson on potential energy, I was challenged by a participant's definition of PE ("PE is stored energy") and considered extending his definition. At first, to devise appropriate scaffolding techniques, participants' ZPD about PE was important to establish. At the beginning of the lesson, participants were presented with an example that applied the concept of PE and were asked to define PE using this example.

Participants were presented with an example of a notebook lying on top of the desk. After participants responded to the question of the notebook's PE, participants were challenged to apply their (limited) knowledge of PE in a different situation. They were presented with an example of a human cadaver, resting in a coffin and buried under the ground. In this situation, the participants were provided with a different point of reference for defining and interpreting PE. With this teaching strategy, the aim was to move participants' ZPD to a higher level, independent learning at the very least. Assisting and assessment questions led the discussion most of the time. The following conversations illustrate participants' explanations and exploration of the new situation.

R: Anybody? Can you tell me what potential energy is?

Juan: Is the energy with the point of rest?

R: At point of rest. If this notebook is sitting right here, does that have potential energy?

Gabby: Yeah

Juan: Yeah, is not moving.

R: Oh, ok.

Gabby: No, because their is no force pushing on it?

R: Huh? Is there any force put on this notebook right now?

Mario: Yes.

R: Some of you are saying yes.

Juan: Gravity, right?

R: Yes.

Juan: Is pushing down on it.

R: There is the pull of gravity.

Mario: An external force.

R: But some of you are saying this [notebook] has potential energy. Why?

Juan: Like a roller coaster, when it goes up to the top then it comes down, like on the top it has potential energy when it is coming back down it has kinetic energy.

R: Very good. You have those two concepts.

For Gabby, her more knowledgeable peers clarified that the force of gravity is acting on the object. Both Juan and Mario co-construct knowledge and correctly identified the force acting on the notebook. To define PE, Juan provided a clear and well -defined example, that of the wagon in a roller coaster. He explained that when the wagon is at rest it has PE and when motion begins, the wagon has KE. Notice that implied in Juan's explanation of the roller coaster is that the ground is the point of reference. Juan 's response provided some evidence regarding participants' prior knowledge of PE, Juan's prior knowledge in particular. After Juan's explanation of PE, participants were challenged to consider a different scenario. As an example of applying knowledge in a new situation, participants were presented with the example of a human buried cadaver so that they have the opportunity to consider a new point of reference and a potential moving system within a larger moving system. The following teaching scenario presents participants' responses to the challenge.

R: Now let me ask you something. *Un cadaver*, a cadaver [said it in English], does that have potential energy?

Mario: A what?

R: A cadaver.

R: Does a cadaver have potential energy?

Juan: Is not moving.

Mario: A corpse, there you go.

Juan: It has a point of rest also.

R: Is resting.

Student-teacher Carlos: [responding to Mario] ...is another word

R: The word in Spanish is *cadaver.*

Mario: But yeah, you are like cadaver, you say it like abra cadabra.

R: Is a new word for you... no, not abra cadabra, cadaver [I laugh, he laughs a bit]. That's the new word you learned today. Now can a cadaver...does a cadaver have potential energy?

Mario: Maybe.

R: Is resting.

Juan: Is not moving.

Mario: Is it on top of the ground? [Mario identifies a point of reference.]

R: Oh, you want to know if... Ok.

IB: No.

R: The cadaver is buried in a ...*un ataul*...(in a coffin).

Juan: Is underground right now.

R: Is underground right now and is buried in there. Does it have potential energy?

Juan: Is down there in its lowest point.

R: Yes, it is at its lowest point.

Juan: I say yes ‘cuz is not moving, is at a point of rest, umm. There is force pushing on it but is not moving so...my understanding of potential energy is it doesn't move.

R: That is why I'm trying to challenge you. If something is not moving, does that necessarily mean that it has potential energy?

Juan: Buried under the world, the world moves so...

R: So in that sense...

Juan: I guess.

The two concepts about PE were clear to Juan. The cadaver has a force acting on it and it is at rest. Regarding Juan's definition of PE, Juan's ZPD is at stage III or the fossilization/internalization/automization stage. Juan's knowledge about PE, however limited, has been internalized as the result of prior learning. It is not clear whether Juan considers other points of reference (such as the ground above the cadaver, which would yield a negative PE, nor the core of the Earth, which yields a positive PE).

The confirmation that the cadaver is resting at its lowest point under the ground led Juan to consider the cadaver as either a stationary or a moving system. Juan questioned whether the cadaver is in fact resting if the Earth is moving. Juan proposed that the cadaver is not stationary (resting) but rather some system that is part of larger moving system ["Buried under the world, the world moves so..."]. (Note- Juan is not aware that Earth's rotation is not considered when measuring objects' PE on Earth). Juan's statement suggests that he has moved to stage IV or the De-automatization stage of the LPC and reverts back to stage I where he now requests assistance from more capable others to understand the new piece to the puzzle. Without any resolution during this teaching moment, Juan's knowledge of PE, *descended* to Stage III where he feels comfortable and abruptly ends his explanation of the cadaver's PE. At a later point in the lesson, Juan ignores his newly found, non-fitting puzzle piece and opts for a more comfortable explanation. Gabby, on the other hand, still experiences difficulty identifying the force acting on the cadaver.

R: The world...you mean the Earth. The actual planet has potential energy. Does the cadaver have potential energy?

Juan: I say yes. I gave my explanation already.

Gabby: I don't think so.

R: Why not?

Gabby: ‘cuz there is no force acting on it.

R: So, in order for something to have potential energy it must have force...

Gabby: Acting on it. But it should be at rest. Like, it can't be moving, but it has to have force acting on it. ‘Cuz then it wouldn't be energy because it has no force.

Gabby considered the energy portion of the term “Potential Energy.” Gabby identified and defined energy as the force multiplied by distance. Gabby accounts for the distance variable by stating that the cadaver cannot move. Gabby ignores the force of gravity and without it, she reasons that the cadaver has no energy.

The discussion moved on to chemical and mechanical potential energy. In this discussion, participants were exposed to the concept of chemical energy, especially in regards to the cadaver, through the explanation of more capable others (LASPS instructors). Student-teacher Carlos, Juan, Gabby and I carried on a discussion and differentiated between the cadaver’s chemical and mechanical PE. Upon this clarification, Juan confirms that the cadaver, in its current position and using the ground above as its reference point for measuring PE, has chemical PE but does not have any mechanical PE. There were no further discussions about the cadaver. This is partly attributed to the disconnect and non-participation of other participants to the discussions on the cadaver. The example of the cadaver may have been above some of the participants’ ZPD, which led me to return my teaching to a more comfortable zone. However, the discussions on mechanical and chemical PE exposed other participants to other concepts such as considering other types of energies that act on the cadaver. These conversations led the lesson to another platform and scaffolded participants' higher order thinking. In the following conversations, participants define PE using a point of reference that they are familiar with.

R: Ohhhh, maybe I should clarify. Does it [cadaver] have any mechanical potential energy?

Juan: No, no.

R: But in order for you to define that, and I think this is a good example the way you put it before [referring to the roller coaster example Juan provided earlier]. Is, umm, is the energy that is stored in an object relative to its position. So, if it were at the top it would have more potential energy because it's going to move.

Juan: Even if it's at the bottom it has potential energy.

R: Yes. It's just less right?

Juan: ‘Cuz when a ball, when it hits the ground...

R: But less because of its relative position...umm. Alright, let me ask Mario. Because I think Juan got it. Mario, what is potential energy?

R: If you are on top of a hill, and you are about...

Mario: I have the most energy.

R: You have a lot of potential energy?

Mario: Yes.

R: Why?

Mario: Because you are at the top.

R: Because you are at the top and...

Mario: You have a...lots of energy and slow down****

R: Ok, good. So you have a lot of stored energy because of your position on the top. So when we define potential energy, we are defining the energy that is stored in you, ok, relative to where you are. What if you are at the bottom of the hill? Do you have potential energy?

Mario: No.

Juan: Yes.

Mario: You still have, double, kinetic.

Juan: Only when you are going down you have kinetic energy.

R: I am not saying kinetic, potential. Potential only.

Juan: When you are at the bottom also, if...depending on the position you are.

R: That is always true. Is always depending where you are. But if.....

Juan: Like a level. You have to have a level.

R: No more in front of it [No more downhill or at level with the ground] then you cannot [considering the ground as the reference point]. Then, it would be 0. If at level, it would be 0. Alright.

Mario: Is kind of like the graph.

R: What?

Mario: Is kind of like the graph but going down.

R: OK.

Mario: It has potential energy.

Mario co-constructed knowledge with his more "knowledgeable peer" Juan. Mario appeared to understand that at an elevation [from the ground], he has more PE. He also associated PE with KE. However, for Mario, once he stopped moving [when he reached the ground], he no longer had PE. Juan clarified this relationship. What is important here to note is that Mario associated PE with immediate motion and when there was no further motion, he considered an object (in this case, himself) with having no PE. It is possible that Mario's misconception could have emerged from the classic diagrams and models used by teachers and textbooks to explain PE. Mario does, however, provide an explanation and defended his understanding of PE with a more familiar model, that of a graph. His reiteration of a familiar model to explain PE indicated that Mario is at stage III where he has fossilized knowledge, however limited that is. Elena and Dominic stubbornly remained somewhat acquiescent by mimicking my definition of PE, rather than providing their own interpretations. It is possible however, that Elena has fossilized this knowledge and needs no further assistance.

R: Let's see. Elena, what is potential energy?

Elena: Energy stored in an object.

R: Relative to its position.

Elena: Well...

R: If it's at 0...

Elena: There is nothing.

R: It may, well, have chemical energy. So, for [statement] #3 can you write, describe what it is? Dominic, did you write it already?

Dominic: Uhuh [confirming].

R: What is potential energy?

Dominic: I put stored energy.

R: Relative to its position.

Juan: [Laughs deeply and slowly.]

Juan's behavioral expression [laughing deeply and slowly] can be indicative of his irritation with his peers' responses, because for him, this knowledge has been internalized and automatized. To Juan, it may appear that his peers require much more assistance from others. Also, notice that Juan has extended his definition of PE by incorporating the second concept associated from the definition of PE. Juan now included in his definition of PE the concept of relative position. He went on to argue, for himself and for his peers, that his limited understanding of PE is attributed to the manner in which his prior teachers presented this information. The following excerpt illustrates this point.

R: Ok. It's a good thing that we are reviewing that. Alright, let me draw a diagram and then explain it with kinetic energy.

Juan: My teacher only explained it like, stored energy and that's it when I was in 9th grade.

R: That is it! It's not just stored energy. It is stored energy but...

Juan: Yeah, I get it how it is, but, this is like, probably that is the way they are explaining to them now, so...

When asked to write about what helped them learn this lesson better, participants' journal entries regarding this topic provided feedback about the scaffolding strategies used in this lesson. Pablo wrote in this journal that, "We learned that potential energy is bigger at its highest point and kinetic at its lowest. Student teacher Carlos helped me because he speaked to me in normal language and didn't use all these complicated words." Gabby added in her journal entry that, "She [Student-teacher Rachel] help us when working in our worksheet and explained to us when potential energy is high kinetic energy is low and vice versa." Juan also identified using the worksheets as a useful tool to learn the concept of energy. Mario's journal entry expressed his newfound knowledge of the new word used in this lesson. Mario wrote in his journal that, "I learned what cadaver means and the formula for kinetic energy."

The pre- and posttest question on PE included a diagram of a pendulum and an actual model of a pendulum at the lab station (see test question #12 in appendix). Four multiple-choice graph-responses accompanied the pendulum diagram that visually aided in addressing the question on the relationship between PE and displacement (distance). Pre test data showed that 4 out of 7 participants (Juan, Pablo, Dominic and Manuel) answered this question correctly. Gabby, Elena and Mario answered this question incorrectly. However, posttest data showed that for the participants present during the lesson on PE, 5 out of 6 participants answered this question correctly with only Elena answering it incorrectly.

Subtheme 4: The use of scaffolding strategies using inquiry activities facilitates participants' understanding of science. Group-based inquiry activity is another form of scaffolding strategy that provides a medium through which learners can conduct investigations, apply knowledge and interact with materials, and exchange ideas with peers and more knowledgeable others. The semi-structured group-based inquiry activity on simple machines illustrates that group work supports knowledge acquisition (between peers and from more knowledgeable others), supports affective domains in learning (motivation, leadership and confidence) and sparks further interest in science and its applicability in everyday life. Lessons and activities on the Rube Goldberg contraption illustrate these points.

Background on simple machines and mechanical advantage. Machines are mechanical devices that facilitate work. Machines can be classified into two classes: simple machines such as a screw, a lever or a pulley, or a compound machine such as a pair of scissors, which combines two levers. Machines help ease work by doing one of three things. Machines can decrease the force needed to do work, such as using gardening shears so one can cut through thick branches without using as much force. Machines can decrease the distance required to do work, such as using a baseball bat to decrease the amount of distance that one's hands must move to hit a baseball at high speed. Machines can also keep the distance and the force the same but change the direction such as a single pulley that changes the direction but does not affect the amount of force needed to move an object.

Mechanical advantage refers to the ability of a machine to change the amount of force that was applied to it. Mechanical advantage is a dimensionless number that represents how much a machine multiplies the force or distance. To say that a machine has mechanical advantage, it means that the force applied to the machine is equal to the force available to the job. For example, a person can lift a 25 N crate using a simple pulley and the force required will be 25 N, thus the mechanical advantage is equal to 1. Simply put, the pulley has just helped with lifting the box and only the direction of the force has been changed (up or down). In this example, the input force equals the output force. A mechanical advantage higher than 1 means that the force that can be applied to the task is greater than then force than you put in, in other words, machines multiply the force you put in by the mechanical advantage. For example, suppose a pair of gardening loppers has a mechanical advantage of 7, and you applied a 5 N force to the handles to cut a branch. The force that will be applied to the branch you are trying to cut is 35 N. Also, the distance moved by your hands (at one end of the lopper) is 7 times the distance moved by the blades (at the other end of the loppers). Thus, a mechanical advantage greater than 1 increases the force and decreases the distance. A mechanical advantage less than 1 indicates that the distance is increased and the force is decreased. For example, suppose a baseball bat has a mechanical advantage of 0.5. A person trying to hit a baseball with a baseball bat moves her hands 3 feet in 1 second. The end of the bat will travel 6 feet in one second, twice as fast. However, if the person swings the bat with a force of 20 N, the force applied to the baseball will be 10 N. In this example, a mechanical advantage less than one, requires more force from the person but the distance that the bat extends decreases the distance that the hands move and increases the swing and speed of the bat at the other end.

Everyday knowledge of mechanical advantage is not so obvious, especially when machine retailers do not identify it for their consumers. However, human experience develops this knowledge. An example of a playground game may help illustrate this point. Consider placing a 60 pound child on one side of a playground seesaw. The 60 pound child will create an input force of 60 pounds on one end and will transfer an output force of 60 pounds on the other side of the seesaw. For the simple machine to work, a child weighing 60 pounds or more will be necessary to sit on the opposing side to cause a mechanical advantage greater than one (and the children will swing up and down). If the children weigh the same, the seesaw will be balanced and the mechanical advantage will be equal to 1, where input force equals output force. If the other child weighs less than 60 pounds, the machine has no mechanical advantage and thus the kids will not move. This example illustrates that while knowledge of mechanical advantage is not explicit, we can make sense of the concept from applying it in our everyday lives.

The National Science Education Standards do not require physical science students to develop an understanding of mechanical advantage. However, the State Performance Standards requires physical science students to calculate mechanical advantage using simple machines. Instructional challenges regarding resources, time commitments and students' mathematical skills may limit the application, calculation and understanding of mechanical advantage. Investigating the dimensions on teaching and learning of simple machines and mechanical advantage.

Two lessons on mechanical advantage were enacted to explain and develop participants' understandings regarding this topic. Furthermore, the Rube Goldberg contraption project presented participants with the opportunity to apply the concept of mechanical advantage and to review their knowledge of simple machines. Participants designed and constructed a simple Rube Goldberg contraption that lasted approximately 4 lessons. Participants were provided with a 3' x 4' wooden trifold and numerous simple machines to construct the contraption. Participants worked in groups of 2 or 3 students. A total of 3 contraptions were constructed and one was completed. Participants were not asked to calculate mechanical advantage for any portion of the contraption.

Posttest data indicated that the participants, all except for one, could not identify correctly the purpose of a mechanical advantage greater than 1 in a simple machine. Furthermore, when participants were asked to draw a diagram of a simple machine that could reduce the amount of force used to move a 25 kg box, of the participants who took the posttest, 3 out of 6 were able to correctly identify and draw a simple machine that could reduce the force needed to move the 25 kg box. Participants who answered this question incorrectly drew simple machines with mechanical advantage of 1, often depicting one pulley pulling the box upward. When asked to explain how the simple machine worked, only one participant was able to explain how the simple machine can provide you with a mechanical advantage.

Participants' journal entries reveal that the participants were able to recapitulate the concept of simple machines as a result of their participation in these lessons. Dominic's journal entry summarizes his understanding of simple machines and stated that, "Today I learned that simple machines can be used as a tool to construct work: some can be very complicated to construct." Pablo also added in his journal entry that, "Simple machines can be used to make complicated machines." In his journal entry, Mario wrote that he learned about mechanical advantage, but did not explain the concept. Gabby identified the simple machines that she used in her Rube Goldberg project. Gabby's journal entry stated that, "In our design, we are using various simple machines. We are using the inclined planes, a pulley and a screw. They all help our design a lot." Journal entries also showed the Rube Goldberg design for each participant.

Moreover, journal entries provided feedback about specific teaching/learning strategies that worked for participants in learning this concept. Elena wrote in her journal entry: "I learned about 6 pulleys. It was explained really well. And the activity in the computer helps me understand it more. Of how it locks and works."

Audiotaped discussions of participants as they constructed their Rube Goldberg contraption show their enthusiasm for the project. Along with construction and applying science concepts (identifying simple machines and mechanical advantage) came singing as well. The following excerpts show Pablo and Dominic's hands-on experience as they hammered away the wood.

Student-teacher Carlos: You need some bolts?

Dominic: Who me?

Student-teacher Carlos: Yeah.

Dominic: [Banging] ...Never mind.

Pablo: Let's watch. We are going to be ghetto fabulous. [They chuckle.]

Dominic: Say it again, uhm, Pablo...Spaghetti [singing] Spaghetti...

Student-teacher Carlos: So, what are you building right there?

Pablo: Right here?

Student-teacher Carlos: Yeah, what type of simple machine?

Pablo: This right here? Like an incline plane.

Student-teacher Carlos: So, what are you going to do now?

Pablo: Huh?

Student-teacher Carlos: What are you going to do now with that pulley?

Pablo: Find a way to put it around here.

Student-teacher Carlos: What type of pulley system is that?

Pablo: The normal one.

Student-teacher Carlos: First, second or third?

Pablo: First.

Dominic: Second.

Pablo: Is the first, you just pull it.

Dominic: Oh yeah, 'cuz of the strings.

Student-teacher Carlos: 'Cuz it's yeah. Just changes the direction, right? What does the second one do?

Dominic: It, umm, it has two strings, right?

R: *Ponlos hablar ciencias a estos muchachos. Dile*, tell them to explain what they are doing scientifically. (Focus these boys on talking science. Tell...)

Pablo: I know. He is asking us...an incline plane. So, the work is less, right?

Pablo: *Hay Dios mio.* [Dominic and Pablo chuckle.] I am going to speak Spanish from now on to see if the people on the tape can understand.

R: I am the only one who is going to listen to it.

Pablo: Man, *yo hablo puro español*, for real though. (I speak pure Spanish.)

Dominic: Who?

Pablo: Yo

Dominic: At home?

Pablo: *Aquí.* (Here)

Dominic: Oh

Pablo: Voy hablar puro español. (I will speak pure Spanish.)

Dominic: *Yo tambien.* (Me too.)

Pablo: *Orale. Ya no puedes hablar nada en ingles.* (You can only speak English.)

Dominic: *Orale.*

Pablo: *¿Qué dijistes?* (What did you say?)

Gabby and Elena were working on their own contraption on another side of the room.

Gabby: *Hecha la pelota haber como se va.* (Place the ball to see how it goes.)

Elena: *Esperate..oh ya se.* [ball rolling] (*Wait. Oh, now I know.)*

Gabby: Laughs

Elena: Holly shhhhhhh [laughs]

R: What happened? What happened?

Gabby: Nothing, it worked that's all.

Elena: No, it didn't, shhhhh.

Pablo: Holly shssss.

R: Isn't that what you wanted?

Gabby: Yeah.

Pablo: Yours is cool. I like yours.

Gabby: *Na mas agarra mas* string. (Go get some more string.)

Gabby: [Hammering] God damn it!

R: Where is it coming out? [The nail.]

Elena: Right here.

Gabby: Actually, what it is doing es *que se esta subiendo aca, este esta muy, muy* close to it. (Actually what is doing is that is going up here, it is too, too close to it.)

Pablo and Dominic continued hammering and singing as they worked on their contraption. Gabby and Elena redesigned and reconstructed their contraption. They included an inflated balloon that popped when a carefully placed nail punctured it. Gabby and Elena, as well as other participants, were very excited when their contraption worked.

Data from focus interviews revealed that participants valued working on hands-on projects. When asked what really worked for you in learning science, students reported that hands-on projects (guided and open-ended inquiry) were beneficial to their learning. Gabby stated that, "The projects and stuff helped a lot because it was something we did on our own." In response to the question of which LASPS experiences helped you learn understand science concepts during a focus interview, Dominic replied that both the Derby car and the Rube Goldberg experiences were helpful in learning science. Gabby added that she liked both projects because "it was something we did independently, and it was fun too. I learned about simple machines and how they work. It is not as easy as pushing a button, it's much harder than that." Pablo also supported Gabby's statement and added that building the Rube Goldberg project provided him with "hands- on training. It was machinie and fun too." Elena added that hands-on projects worked well for her because she enjoyed working in groups. Gabby, Pablo and Dominic agreed with her. Pablo added that working in groups is beneficial to his learning because "the people around you influence you to do what you do." Pablo identified Dominic and Student-teacher Carlos among the people who really influenced his learning.

The Derby car project was also identified as a helpful science learning experience. When asked what [science] concepts [the derby car] helped to reinforce, Pablo responded:

> The forces acting on the object. We had to learn about that because, like it helped you, 'cuz we had to learn what shape we wanted the car and...the forces that acted on it depended on the shape too. The friction, all that. And with the car we learned a lot, it helped us learn a lot about that.

Gabby wrote in her journal entry that she "liked a lot that she was working on her [car] design…is good that we solve the problems."

Theme 3: Latino bilingual learners can identify and articulate strategies that facilitate their personal learning and understanding of science.

During focus interviews, participants were asked about specific learning strategies that helped them learn science better. The following section presents participants' responses to these questions. In addition, participants' ideas of preferred learning strategies are presented. Although the categories below are not technically teaching strategies, (e.g., structured questions vs. worksheet) it is the means by which the participants identified and articulated where their learning was facilitated.

Subtheme 1: Worksheets. Participants identified worksheets to be helpful in their science learning. The following interview excerpts highlight the learning benefits of the worksheets used in LASPS.

I: I want to talk about the worksheets you had to do. At the beginning of every class meeting, you worked on worksheets that asked you to do various activities, such as read a graph, work out formulas or answer questions. Did these worksheets help you understand the concept? If so, why? If not, why not?

Pablo: It did, 'cuz like the worksheet that we just did a couple...it was about the...I forgot what u call it, uhmm...

Gabby: Current.

Pablo: Current and this circuit thingie, all that...

I: Aha, about parallel and ....

Pablo: Yeah, parallel and series circuit, that's what I am talking about, uhm. Like that helps a lot 'cuz they have little diagrams... drawings and stuff that you could actually look and understand. And then it has it like written down and teachers also explain it to you. And the worksheets help you, like 'cuz in your notebook you have to write out of your head and you have to keep writing and whatever. And you don't really want to but umm, the sheet it gives you, like when you read it, it helps you and gives you guidelines into what you are writing is good for you to learn. And is really good. *Y esta chido.*

I: Sometimes you had these worksheets that asked you to read a graph or at other times you had to work out formulas or answer questions. And I wanted to know which of these worksheets helped you and why they helped you and which worksheets didn't help you.

Dominic: I would say all of them helped.

I: Why?

Dominic: 'Cuz most of them I already knew and then I forgot. And then when I saw the paper, I didn't know what to do and then the teacher helped me to remember again, like refresh my memory again.

I: Now, with these worksheets you've done now and these experiences, do you actually think you understand the concept now vs. memorizing the concept? You know there is a difference.

Pablo: Yeah.

Elena: To me, I understand a little better because it broke it down to ways we could learn it much better. So, now I have a little idea of how it is done and how it is suppose to be.

IB: Awesome.

I: Aha. And you said this activity helped you to learn how to learn.

Elena: Yes.

Subtheme 2: Laboratory experiences. Participants identified laboratory exercises (structured inquiry) as helpful learning experiences. On her second journal entry, Elena wrote that "doing labs helped better. Was more descriptive, explaining better. Bilingual." Dominic's second and third journal entries also echoed Elena's. In response to "what helped you learn science better today?" Dominic wrote in his journal that, "The way I learn science is through experiences, by doing them. I learn by doing hands-on activities." Gabby added in her journal that, "It was helpful that we did labs with Mrs. R. being there helping us the whole time. It also helped the small group, and her telling us and explaining is easier to learn." On another entry she wrote: "I think it helps when they [instructors] give us time to think about what we are doing and how we are doing it." On numerous occasions Juan wrote in his journal that labs helped him learn better. The following two journal entries present Juan's preference for lab experiences as a helpful way to learn. Juan wrote in his journal that, "I think that labs are really important. The labs she [Mrs. R] did were fun and I enjoyed them and learned a lot." In another entry, Juan wrote in his journal that, "I like what we did today. First we did worksheets and then we did some labs. We connected different types of circuits (series circuits and parallel circuits). I learned a lot from it."

Subtheme 3: Field trips. Participants identified LASPS field trips as conducive to their learning. Journal entries suggest that field experiences complemented science learning and encouraged participants' science knowledge acquisition. During these experiences, participants' were exposed to science discussions from "more knowledgeable peers", experts in this case. Dominic, Mario, Gabby, Pablo and Elena wrote in their journals about their learning experiences as the result of their participation in the first field trip to the physics lab and the observatory at the State University. Dominic's journal entry stated that, "Today I learned that telescope can really look into space, and that Saturn moves position every year." Mario stated that he "liked when he saw the Van de Graaff Generator." Pablo echoed Mario's statement and added in his journal entry that he "learned a lot about different machines and how the Vender-graph generator causes static electricity." Gabby wrote that "The trip taught me a lot, especially how important is physics in the world. I learned this because of how he [the physicist] explained how old televisions worked." Elena shared her enthusiasm for the trip and wrote, "The observatory place was awesome." Participants' experiences in the field also supplemented lessons on electricity, because often, participants' would refer to the knowledge they had learned in the physics lab.

Subtheme 4: Journaling. Some participants' reported journaling as a helpful learning strategy when this practice is used as a user-friendly, non-graded activity. When questioned, participants' stated that journaling, as a way to learn and summarize knowledge was effective when the journals are structured and systematized. For instance, Juan explained in the second focus interview that his biology teacher used journaling as a way to guide reviews for tests. He found that the system of organization for journal entries (including pictures, diagrams and lesson summaries) was helpful in keeping track of notes and reviewing for exams. In response to journaling as a learning tool during our second focus interview Juan added that he "processes things better when he writes it." Elena also agreed with Juan that as a reviewing tool, journaling is helpful.

During focus interviews, participants' selected journaling as the least favorite and least helpful strategy for learning. Participants stated that journaling was tedious because it required writing and summarizing. “Writing down things makes me not want to learn,” stated Pablo during our second focus interview. However, participants provided 3 recommendations about using journaling as a learning tool. At first, Pablo recommended using computerized journaling rather than writing on paper. Dominic and Elena agreed with Pablo's recommendation. Gabby suggested that journaling ought to be assigned as a free-writing exercise rather than as a tool for summarizing concepts. Furthermore, she stated that language preference should be left to the student. Free writing “is like your thoughts. You don't have to be thinking about questions and stuff,” Gabby explained. In this respect, Gabby felt that reflective (free-writing) journals should not be used as a graded exercise because grading limits freedom of expression. When asked to explain why a teacher should not grade reflective writing, Gabby stated that “different kids have different opinions and if the teacher did not hold the same opinion, the teacher would grade the journal entry as a 0 just because she doesn't think the same.” Regarding language preference for reflective journaling, Gabby, Elena, Juan, Pablo and Dominic all prefer to have the choice to write in English, Spanish or “Spanglish” (the term that participants used).

It is important to note here that even though journals were not used as a formal assessment tool in this program, they provided insights about participants' science understandings on a daily basis. Collectively, participants' journal entries provided feedback about effective teaching and learning strategies.

Subtheme 5: Instructors. Participants identified the number of instructors and the characteristics of the instructors to be instrumental for learning science. When asked how the teachers helped you learn [science] concepts, Pablo stated that they [instructors] got one-on-one with you. “Individual, one student, and they explained it better,” added Elena. Dominic and Pablo felt that that Student-teacher Carlos was motivating because they felt a cultural connection with him. Pablo stated that, .”..he's been through what we've been through and then he is Hispanic, he is a guy and not much older than us. Mr. Carlos tries to communicate everyday, Ms. R. too and Ms. Rachel.” Dominic added that Mr. Carlos “pushed me to get the answer.” Juan stated that “the way teachers teached” was also beneficial to his learning. Juan added that “Sometimes she [Mrs. R.] would speak in Spanish, in a word that you probably would not know in English and it gives you a better definition.” Pablo added that “she [Mrs. R.] would get more like with one person too and just with that person she would help them.”

Audiotaped lessons also voiced participants' ideas about LASPS instructors, especially regarding student-teacher interactions. The following excerpt presents Pablo’s ideas about the program and the instructors.

Pablo: I like this class. I look forward to it because I don't like going home. This class is fun.

R: What is fun about it?

Pablo: There are a lot of things to do. Like you can learn stuff...We get to work with our hands. Ya'll don't talk to me like I am some kind of eighty year old guy or something...Ya'll wait for us. I don't know the other teachers, they say half of the students get it, they don't wait. They say get the information from another student. And then, the other student does not know or is not sure and explains it wrong. ...And then, if there are two dumb kids in one class and they are going slow, they start treating them like them too. Ya'll take your time and explain it right. You don't have to just go through and act like we already know it. Hope we already have it.

Subtheme 6: Participants' evaluative ideas about LASPS. Overall, participants were very satisfied with LASPS. Participants suggested that in a future similar program, it should remain bilingual, include a small number of Latino participants, and include a variety of science subjects and experiences, rather than just in physical science. In response to the question “Is there anything else you would share about this after-school program”, Manuel said “nothing except that it was cool.”

Summary

This section presented data regarding LASPS participants; their struggles and connections with physical science, their ideas about effective teaching and learning strategies and their experiences with the program. Collectively, data provided supporting evidence about what physical science knowledge secondary level Latino physical science learners possessed at the onset of LASPS and what kinds of science knowledge participants learned and experienced during their participation in LASPS. Furthermore, data supported findings regarding effective and not so effective teaching strategies specifically aimed at Latino high school students.

The data provided evidence about participants' limited physical science knowledge. Participants experienced difficulty in manifesting their understanding of the four physical science themes discussed in LASPS. Conceptual understanding of motion, light reflection and refraction, electricity and mechanical advantage was minimal. Participants' lack of science-related skills such as calculating, interpreting and manipulating formulas, reading and interpreting graphs and science statements exacerbated their inability to develop conceptual understanding. Pre and posttest data indicate that overall participants strengthened their conceptual physical science knowledge because they were able to answer more questions correctly in posttests than in pre tests. However, these findings should be taken *cum grano salis.* Participants' increased scores on posttests are a reflection of multidimentional processes, not exclusively as the result of the intervention.

Participants in LASPS identified all bilingual teaching strategies used in this program as helpful in learning science, with only journaling being the less preferred strategy among them. Bilingual teaching strategies supported bilingualism and biculturalism among participants. In addition to supporting language development (both the English and Spanish languages), data from PO indicate that bilingual translations were beneficial in understanding written and verbal statements about physical science.

Furthermore, participants' struggles with the different languages inherent to science were self-evident in both sets of data. Both pre- and posttest assessment data and qualitative data show that participants experienced difficulty navigating both everyday language and science language, and mathematical and science languages. In addition, participants' struggled with making meaning in both the English and Spanish languages. Repeatedly, participants found themselves lost in translation among and between these five languages.

Scaffolding strategies as used in LASPS were identified as beneficial in learning. Qualitative data provided evidence that assisting and assessment questions, cognitive structuring, inquiry and group based activities, increased exposure to a variety of more knowledgeable peers, worksheets, field trips, journaling and small teacher-to student-ratio scaffolded learning among participants. On different occasions, the combination of these strategies supported learners as they moved along the learner's performance continuum, with some participants moving from teacher-assisted learning to independent learning.

CHAPTER V

DISCUSSION OF FINDINGS AND IMPLICATIONS

Overview

In chapters 1, 2 and 3 of this study I provided an overview of the study, the theoretical frameworks and research methodology guiding this inquiry. In chapter 4, I introduced teaching and learning scenarios that explored and discussed science knowledge construction and teaching approaches in secondary level Spanish-English bilingual learners attending a science enrichment after-school program. In this chapter, I present a synthesis of what has been learned from this study, and suggest implications for research, for practitioners and for my own future work.

My goal for this study was to contribute effective teaching strategies for the physical science Latino bilingual learner (LBL). As a result of this study, I was able to gain a deeper understanding of some of the challenges secondary level LBLs face regarding the triangulation of the Spanish, English and science languages and their respective cultures. Findings from this study can better inform educators and practitioners about teaching and curricular approaches to address the linguistic and learning needs of high school Latino bilinguals in the physical science classroom specifically, and in academic settings more generally.

The following three research questions were posed in this study:

1. What science knowledge do secondary-level Spanish-speaking Latinos participating in an enrichment program possess about physical science at outset of the intervention?
2. What science content knowledge did the participants construct as a result of their participation in the enrichment program?

3. What are the curricular and instructional practices that secondary-level Latino bilinguals found beneficial in the construction of their science content knowledge?

To answer these questions, the Latino After-School Physical Science program (LASPS) was implemented during the spring of 2010 in a small-city high school located amidst a large public southeastern state university. Six secondary-level Latino students participated in LASPS. LASPS was taught bilingually and focused on four areas of physical science. These topics included motion, light reflection and refraction, electricity and mechanical advantage. Scaffolding teaching strategies, grounded in constructivist theory, dominated instruction and were used to both support and augment learning in the areas of language and science learning. To develop linguistic competencies that used students' linguistic capital, teaching strategies made use of Spanish-English cognates, bilingual translations (both written and oral) and journal writing. The main teaching strategies used to develop the culture of science involved hands-on structured, semi-structured and open-ended science inquiry activities. Brief lectures and lesson worksheets helped with opening and encouraging discussions among participants. Mathematical skills related to articulating physical science were also reinforced. Both quantitative and qualitative data collection methods were used in this study. Quantitative data consisted of pre- and posttest examinations during the program. Qualitative data consisted of three focus group interviews, and participants' artifacts such as lesson worksheets, journal entries and structured and open inquiry projects. Participant observation was used as a qualitative data collection method throughout the program.

As a researcher, this study provided me with a context for designing and completing a qualitative case study about physical science knowledge construction among secondary level LBLs. The design of this case study does not permit for transferability to an entire population of

Latino science learners. However, qualitative approaches in this study provided numerous opportunities to gain a deeper and richer understanding of how science knowledge is constructed in LBLs. Furthermore, qualitative approaches helped inform effective teaching strategies for LBLs in science classrooms.

Quantitative methods in this study, mainly the use of pre- and posttest assessments, helped support qualitative findings as they were intended. However, analysis of pre- and posttests presented numerous challenges. Issues associated with the low number of participants, the nature of the assessment, and participants' linguistic demands limited the effectiveness of this measure for getting a clearer picture of participants' science knowledge and its construction. Furthermore, I was limited in the kinds of claims I could make based on the pre- and posttest data because they were not sufficiently strong for making statistical claims nor claims about science content knowledge the participants possessed or gained as the result of their participation in LASPS. Nevertheless, results from pre and posttest examinations were informative in that they highlighted areas of participants' academic challenges and strengths especially in physical science.

In addition to the methodology of the study evolving over time, the conceptualization of language evolved as well. Initially the role of language was conceptualized as the cultural tool through which knowledge is interchanged (Vygotsky, 1978). Furthermore, from a Vygotskyian perspective, language is a social tool through which knowledge is co-constructed. However, as this study progressed, my thinking of the role in science learning also evolved. I learned some of the complexities of languages when they intersect the teaching, learning and doing of science.

In the following descriptions, the research questions are answered. Responses to questions are strongly supported by qualitative findings and are summarized using a synopsis of the findings that were more fully presented in chapter IV. Themes of the findings are further elaborated in the discussion section.

1. What science knowledge do secondary-level Spanish-speaking Latinos participating in an enrichment program possess about physical science at outset of the intervention?

Based on the findings for this study, all participants experienced difficulty expressing their conceptual understanding of the four major topics taught in LASPS: motion, light reflection and refraction, electricity and mechanical advantage. Pre test scores show that participants experienced the most difficulty in the areas of light reflection and refraction, and mechanical advantage. Participants had limited knowledge of basic mathematical, physical science and reading skills. For instance, both pretest data and field notes show that participants had difficulty with interpreting graphs and formulas (proportional reasoning), including unit conversions. Furthermore, participants could not interpret written physical science statements successfully, regardless of whether they were written in English or Spanish.

2. What science content knowledge did the participants construct as a result of their participation in the enrichment program?

Qualitative data indicated that participants gained a deeper of understanding of (a) forces acting on a moving object, such as friction and gravitational forces, (b) light behavior as it travels through different mediums, (c) electrical circuits, (d) simple machines and mechanical advantage, (e) proportional reasoning, or the manipulation of formulas and their units, and (f) the scientific method, research design, experimentation and drawing conclusions.

When looking at pre- and posttest responses as an indication of the physical science knowledge participants constructed as a result of their participation in LASPS evidence of learning was encouraging. Posttest responses showed an overall increase in scores for all participants. Scores did not highlight any particular area where participants consistently scored higher. Rather, test scores reflected individual gains in specific areas. It is noteworthy that more participants scored correctly in the areas of light reflection and refraction and electricity and some score gains were noted for the area of mechanical advantage.

3. What are the curricular and instructional practices that secondary-level Latino bilinguals found beneficial in the construction of their science content knowledge?

Participants identified the bilingual teaching strategies used in this study as effective learning strategies. All participants agreed that the use of cognates, breaking down words, Spanish translations, journaling and characteristics of teachers and their respective modes of instructions were beneficial to their learning. Participants identified group and independent inquiry activities, lesson worksheets and field trips as helpful science learning strategies. Journaling was the least favorite learning strategy among the participants.

Discussion

Helping construct scientific literacy in academic settings among secondary level LBLs involves at least two big challenges. For one, LBLs have to gain linguistic competencies in Spanish, English and the language of science, and then find ways to bring those developing competencies into congruence with each other (Moje, Collazo, Carrillo, & Marx, 2004). Secondly, bilingual learners have to bridge the cultures endemic to each of these distinct cultural constructs (Aikenhead, 2001; Bravo & Garcia, 2004; Lee, 2003; Moje et al., 2001). In other words, the bilingual learner is forced to triangulate the Spanish, English and science cultures simultaneously, in vivo and often in non-supportive, assimilationist learning environments (Garza & Crawford, 2005; Lipman, 1997, Nieto, 2004; Rosen, 1977). Linguistic and cultural demands often lead the learner to misinterpretations, especially when the learner has low proficiency levels in any of the three languages. Thus, teaching science and co-constructing scientific literacy among LBLs requires strategic teaching approaches that help syncretize three learning areas while supporting the social and linguistic capital that students bring with them.

At the onset of this study, I chose learning strategies that have worked for me in the past as a Latino bilingual learner. During this research process, I have come to realize that I will always be learning English as the result of the culture that I now identify with. However, I use and develop the Spanish language simultaneously when interacting in the English-speaking environment. In Spanish-speaking environments, I become the American1 ambassador bringing the English culture including the English language into Latin culture. In English speaking environments, I become the Spanish ambassador bringing the Spanish language and culture into the American culture. I found that the American[1] ambassador role is most important when explaining science phenomena since the Latinos around me explain the world differently. Indigenous knowledge, including pseudo science is very prevalent among the Latinos I interact with including the students I have taught. Thus, there is a self-imposed demand to bring Western science into my community and an impetus to engender scientific literacy among them. I am hopeful that increasing scientific literacy in the Latinos I interact with will help them make better and more informed decisions, and increase their participation in society, whether here in the United States or in their homeland. I am, however, most effective when I access and build upon Latino knowledge and experiences. Not only do I make use of those prior experiences and

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[1] The term American here refers to a heterogeneous population residing in the United States and identifying with the English culture inclusive of common beliefs and perspectives, and who use English as the main language of communication.

connect them to other ways of seeing the world, but also I recognize and value the knowledge my students already bring with them. At the very least, in this endeavor I am the trilingual and tricultural ambassador. I have come to see the value of co-constructing these specific abilities with LBLs who may face similar challenges, currently or in a near future.

As a secondary level science teacher, strategic teaching is important to help construct the knowledge and skills necessary to develop fluency in the languages of Spanish, English and science and their respective cultures. As a result of this study, I came to explore and better understand the complexities existing in the triangulation of the Spanish, English and science languages and their respective cultures among high school LBLs. In this section, I present these complexities, as they were manifest in my interactions with the project participants. Themes relating to bilingual teaching strategies are presented first, followed by themes relating to science teaching strategies. Each theme includes a brief discussion of the findings, followed by research implications, suggestions for practitioners and my future research interests.

Bilingual teaching strategies supported bilingualism, trilingualism and comprehension of science among the participants.

Studies report that when bilinguals are highly proficient in their native language or L1, linguistic and cognitive skills are transferred to the host language or L2 and ease L2 learning (Hammer & Blanc, 2003; Cummins, 1991). For instance, Medina, Marcello, Mishra, Shitala, (1994) found that proficient reading levels in L1 positively impact content area learning (Medina Jr., Marcello, Mishra, Shitala P., 1994). Common sense and my bilingual teaching experiences suggest that in science teaching, translating statements into L1 seem an appropriate teaching tool if the aim is to get students to derive meaning and conceptual understanding. Furthermore, additive bilingualism is thought to be enhanced when both languages are used in academic learning (Portes & Rambaut, 1996).

Literature to date recommends the use of cognates to enhance L1 and L2 vocabulary learning (Carlo, et.al, 2004; Bravo, Hiebert and Pearson, 2005) and metalinguistic awareness (Rico, 2004). Latinos benefit from the use of Spanish-English cognates especially in science, because science vocabulary is rich in Latin roots and Spanish-English cognates (Marco, Bravo, Elfrieda, Hiebert, and Pearson, 2005). No study to date reports on the effect of the use of cognates and breaking down words on secondary level science classrooms and academic achievement.

In this study, both participants and this researcher identified cognates and breaking down words as very useful learning strategies. The following teaching moment presents how Pablo made use of metacognitve skills by incorporating the newly learned cognate term in a sentence, on the spot.

R: What is the Spanish equivalent of that word [vicinity]?

Pablo: Vis, vis something.

Dominic: Vicinidad

R: Uhu. *Tu vecino*

Dominic: Oooh

Pablo: Oooh

R: That is right. I thought I brought that word in for you, instead of using proximity. *Tu vecino o la persona al lado. Algo al lado de ti.* (Your neighbor or someone next to you. Something next to you.)

Pablo: You are my vicinity.

R: You are in my vicinity.

Pablo: You are in my vicinity. Get out!

This finding is important because for Pablo and Dominic, the new cognate might be a term that they will be able to identify in the English language. Moreover, because Pablo and Dominic learned this term in a science context, it is possible that both participants will positively associate science, Spanish and English learning.

Similar effects can be speculated for Elena. However, Elena faces a different learning challenge. Elena does not read or write in Spanish. Though the introduction of cognates could potentially help her in linking Spanish and English languages together, it is also possible that this strategy can make both languages accessible to her. For Elena, the breaking down of words was more useful than learning cognates. It appeared that for Elena, who did not achieve successfully in the physical science End Of Course Test, the breaking down of words made science language accessible. On numerous occasions, Elena wrote in her journal that breaking down terms was beneficial to her learning. In one journal entry Elena wrote and defined the terms and other associated concepts regarding light reflection and refraction. This example gives evidence that the breaking down of terms supported the development of Elena's metacognitive skills.

However, there were also *oportuntidades perdidas* or missed opportunities in teaching that could have helped participants break down everyday language as it is used in science. At the crux of the matter were participants, such as Gabby and Pablo, who were lost in translation as they attempted to make meaning of everyday language in a specific science context. Terms such as "to bounce off " as it was used to refer to light reflection and "open and closed switches" as it was used when referring to electrical circuits confused the participants and marked areas where languages were incongruent. Experiences like these have negative repercussions. At the very least, these experiences have the potential to further widen the disconnect between the Spanish, English and science languages, resulting in disassociations especially with science learning. At the very worst, knowledge construction is impeded.

Similarly, participants experienced difficulty with specific mathematical language, proportional reasoning in particular, often used in physical science to express science understandings. Students experiencing difficulty with proportionality reasoning is not specific to bilingual learners (Akatugba & Wallace, 2010). This is still an area of cognition that challenges both mathematics and science educators alike. However, issues associated with the use of the International System of Units (SI) in proportional reasoning in physical science and among Latino bilinguals are important to understand for several reasons. First, knowledge about the units accompanying physical science proportions can lead to better reasoning, helping deconstruct the science knowledge embedded in abbreviated physics expressions such as formulas. Understanding the relationships between the units and the formulas is important for successful articulation of physics concepts. Secondly, Latinos in the US face an interpretation challenge regarding the use of the American System of units.

It can be speculated that consecutive Latino bilinguals who travel to Latin countries have an increased exposure to SI units since it is the language used in Latin countries to express measurable quantities. However, for Gabby and Juan whom have traveled to Mexico and Nicaragua respectively for long periods of time, using the SI units in the science classroom appeared to be challenging. This is due in part to the fact that everyday English language -outside of science- uses the American System of units rather than SI units. Thus, Latino bilinguals in the US who still have strong ties to their Spanish-speaking homelands, require special linguistic skills and cultural knowledge related to SI units to translate and navigate the American culture and science culture. For instance, a Latino bilingual must first convert the Spanish SI units to the

American System of Units to effectively communicate in the English-speaking American community, exclusive of science discourse. For example, they may have to describe their weight in pounds rather than in kilograms. Secondly, the bilingual learner must then revert back and translate the American System of units to SI units in science discourse (i.e., converting miles per hour to kilometers per hour). The juxtaposing of the science language and the everyday US language used to express measurements can serve as a source of confusion for students such as Gabby and Juan (assuming that they already have a clear understanding about what each unit represents). Linguistic demands such as those associated with the translations of units give evidence of the linguistic complexities bilingual students face when interacting in US culture generally, and in science classrooms in particular.

Research implications: Trilingualism. Literature suggests creating hybrid or third spaces in ELL classrooms so that learners can bridge the native, English and science languages (Calabrese-Barton and Tan, 2008; Moje et al, 2001). In addition to creating a positive learning environment, it also important to augment students' trilingual competencies by using teaching and learning strategies, such as Spanish-English cognates and breaking down words to support and further develop understanding. Positive word associations, such as those potentially constructed using cognates in the science classrooms, can enhance trilingualism in science learning. Further studies are thus recommended regarding curricular development that supports bringing the three languages and cultures together in a mutualistic relationship. Future research on the use of cognates with other language groups could be useful to the field of teaching. Further studies could also focus on how LBLs in the US navigate science language within their respective communities, home and abroad.

Implications for practitioners: Trilingualism. It is also important for practitioners to identify everyday language terms that have specific meanings in science. When teaching, this relationship can be very easily overlooked. It is much easier to concentrate in teaching the science concept than to consider the everyday language that can be used to explain it. Thus, a closer look into the everyday language that may serve as possible sources of confusion for bilingual Latinos in science learning is clearly warranted.

Science teachers in particular should draw upon learners' linguistic capital to increase metalinguistic awareness. In this effort, for every lesson or whenever possible, secondary level practitioners teaching bilingual or ELL Latino learners should identify and discuss cognates, their meanings and uses. This can be achieved by introducing and defining cognates during lessons that are pertinent to both science language and academic language. In addition, teachers can insert cognates into speech and written statements (including assessments) so that students practice and learn these words- how they are pronounced, used in a sentence and so on.

It is also very important for practitioners in bilingual classrooms to be clear about the kinds of everyday language they use including their respective curricula. This is equally true for monolingual teachers as well as bilingual teachers. At first, it may be difficult to gauge the specific terms that Latino bilinguals experience difficulty with. Practitioners can make use of class and group discussions to gather learners' definitions of the terms as they are used in Spanish and American subcultures. Practitioners can then define what the terms mean in the science context. In bilingual classrooms it is crucial that teachers and students agree on all terms especially because Latinos are a heterogeneous group and individual experiences vary. Visual representations may be very useful in this instance. Practitioners can use available online Spanish science textbooks written in Spanish-speaking countries to draw upon culturally-relevant examples for their curricula.

Implications for my future research: Trilingualism. Developing science curricula that (1) make use of Spanish-English cognates that enhance both science and academic language and (2) identifies science terms that may be a source of confusion for LBLs, came to be an important goal in the LASPS Project. First, as a bilingual educator, I am interested in developing trilingualism and multiculturalism (at the very least) in LBLs. Science curricula that target these linguistic and cultural intersections can help emergent trilingual ambassadors develop the knowledge and skills to better navigate within these cultures. Such curricula would be very useful for all teachers because they may serve as teaching resources often missing as classroom resources. Thus, what is pertinent here is to conduct studies that (1) identify age appropriate Spanish-English cognates for secondary level LBLs in the various science disciplines (2) identify Spanish-English cognates that support academic language (3) offer effective curricular methods that support metalinguistic awareness, and (4) explore science terms that may serve as potential sources of confusion for Latino science learners.

Translated materials.

In this study, I sought to understand the use of Spanish translated curricula, lesson worksheets and exams in particular, with the goal of investigating whether such teaching strategies are useful in constructing and assessing student's knowledge. More specifically, I sought to understand (1) if the written English language served as an impediment to interpreting and answering science questions and statements, and (2) how useful were Spanish translations in the construction and assessment of knowledge in high school LBLs.

LASPS participants were provided with two individual pre- and posttest examinations. One test was written exclusively in English and the other in Spanish. Participants were asked to use both exams to answer questions and to indicate in the English version of the test if they read the question in Spanish. Quantitative data led to two major findings regarding the use of translated versions of the test. The first finding indicates that more students read the pretest Spanish version than they did the posttest. The second finding indicates that for participants who used both tests, more participants referred to the Spanish version of the test in the areas where they felt less knowledgeable, the areas of light reflection and refraction and mechanical advantage in particular. The first finding indicates that when bilingual students experience difficulty with recalling prior knowledge, they rely more on their native language for reading and interpreting questions. The second finding indicates that when bilingual students experience difficulty with a concept, they rely more on their native language for conceptual understanding and answering test questions.

For bilingual examinations and lesson worksheets, Juan, Pablo, Gabby, Elena and Mario identified Spanish translations as very helpful in learning science. However, for different participants, Spanish translations addressed different learning issues. For Juan and Gabby, dominant L1 bilinguals, Spanish translations helped with reading and comprehending science statements. For instance, in a lesson on electrical circuits and after struggling with understanding what the English written statement was asking, Gabby resorted to the Spanish translation and it was then when she understood what was being asked. For Pablo, a balanced bilingual, reading the Spanish translations was more about learning science in Spanish, as if adding to his already existing science repertoire. For Mario, a dominant L2 bilingual, the Spanish translations were a cultural statement that supported his cultural heritage. "Those are my two languages. *Porque yo soy guero* (Because I am Mexican)" stated Mario as a response to the question regarding the effectiveness of Spanish translations as a teaching strategy. For Elena, a dominant L2 bilingual, the Spanish translations were no more than translations she could not read. These findings indicate that for the majority of the participants, Spanish translations were useful, for reasons ranging from improved comprehension to acknowledgement of bicultural identities. Furthermore, pre and posttest data indicated that 4 out of 5 participants used the Spanish test version and thus benefitted from reading examinations in their native language.

Research implications: Translated materials. Federal mandates require testing accommodations for ELLs that include extended time, use of dictionaries and reading translated instructions by a proctor. States such as New York, accommodate Spanish-speaking ELLs by providing Spanish versions of the NY science regents exams. Reports on testing accommodations for ELLs include the number of testing accommodations and the testing scores for ELLs (NAEP, 2011). No studies report on the effectiveness of translated science state -level standardized tests, nor on classroom tests on assessing science knowledge.

Findings from this study support the use of Spanish translated materials for HS LBLs. These findings however, have various technical, curricular and teaching implications. From the technical aspect, at the national and state levels, what remains to be understood is the kind of bilingual testing format that is most beneficial for bilinguals and assessing their knowledge. For instance, is it more feasible to provide two separate test versions, or one version that includes both languages. Classroom teachers face similar challenges in terms of resources. Often, finding translation e-programs or bilingual personnel capable of translating materials such as worksheets and examinations is difficult or altogether absent. Teachers are often left alone to devise curricular resources targeting LBLs and ELLs that draw on their cultural and linguistic capital. Often, local school districts de-prioritize the purchase of bilingual materials, citing budget constraints as the primary reason. Deprioritizing the purchase of bilingual resources that support both teachers and students is destructive to the education of the Latino society, bilingual learners included. Because the Latino population is the fastest growing population in US (Census, 2010), the demand for bilingual (and ELL) resources is high. A focus on local and national expenditure regarding the instruction and supporting curricula for LBLs is clearly warranted. With this information, budgets can be reallocated to further support this demand. Also, further studies are necessary to assess the kinds and quality of available bilingual curricula in an effort to create a national curricular bank. Additionally, state and local educational boards can be better informed about most effective bilingual curricula so that they may purchase or suggest these to practitioners. Further research is needed on the effectiveness of bilingual curricula in languages other than Spanish.

Implications for practitioners: Translated materials. Spanish translated textbooks are available, and teachers who are fortunate enough to possess them often distribute them among their bilingual and ELL learners. In practice however, it is not sufficient to just assign a Spanish translated version of a textbook to a bilingual learner. Students may not possess the knowledge to read them. Even if the learner does possess the Spanish literary skills, it is still difficult for them to interpret these textbooks, which are often direct translations of the English and may not make the same sense in Spanish (Gonzalez-Espada, 2001). Often, LBLs in US schools want to learn in the English language. This, however, presents a challenge for the practitioner especially because bilingual curricula are often limited. At the very least, the monolingual English teacher can make use of teachers' classroom resources and available e-materials, which often include Spanish translated assessments. In the absence of bilingual resources, the practitioner can use language that draws upon students' native language, such as the use of Spanish-English cognates. Also, the practitioner can help by breaking down the definition of words of both English and science terms. To increase metacognitive awareness in secondary level bilingual science learners, practitioners should expose LBLs to the language of both English and Spanish standardized exams (available online). The bilingual Spanish speaking high school science teacher should first consider including science statements that have meaning in the Spanish culture and then translate them to the English language. This strategy can help with making congruent and positive associations between the English, Spanish and science languages. With lesson worksheets and assessments, practitioners should include both the English and the Spanish translations; English statements should be presented first. This strategy has the potential for HS LBLs to access the Spanish language discreetly without the stigmatization associated with low L2 proficiency that is prevalent in assimilationist and subtractive schooling.

Implications for my future research: Translated materials. Upon the recommendation of committee members, I provided the participants with two versions of the pre- and posttests. This teaching strategy worked in this supportive bilingual environment partly because all participants were bilinguals and felt safe to exchange between the two versions of the test. However, administering two separate versions of the tests in monolingual high school classrooms may present a different story. To this end, I would like to conduct studies on the effect of (1) administering separate Spanish versions of the test to LBLS in monolingual HS science settings (2) administering assessments using consecutive English statements followed by its corresponding Spanish translation to LBLs compared to English versions alone, and (3) Spanish translations and understanding science concepts among LBLs.

Science teaching provides insights into the complexities within the triangulation of languages, learning, and constructing knowledge in science.

At the onset of this study, I envisioned a science program that enriched general scientific literacy among HS LBLs, and enriched physical science understandings in particular. I created a bilingual science-learning environment, where students felt comfortable with asking questions and expanding their curiosity about scientific ways of thinking and doing. To increase science learning in LBLs, I made use of effective science teaching strategies that included hands-on, guided and independent inquiry activities (Calderon, 2001, Hampton and Rodriguez, 2001; Lynch, et al., 2005). Furthermore, I emphasized mathematical skills necessary to express physical science knowledge. The intent here was to build critical thinkers and more able science students to prepare them for more rigorous tracks, eventually leading to post secondary education. However, similar to my own learning experiences during my early education, I found this student population relying on rote memorization at the expense of developing critical thinking. While motivated, determined, and applied students, participants in this study were deficient in basic science and mathematical skills. Basic science concepts were underdeveloped in these participants. Metacognitive learning skills fared no better.

Designing science learning experiences that addressed all these academic challenges was crucial. It was imperative to draw upon what the students already knew, not only as a place to start but to help reconstruct these learning deficiencies. Because prior physical science knowledge, and scientific ways of thinking and doing appeared deficient, scaffolding strategies that supported students' ZPD seemed important. The teaching challenge here was to further develop students' ZPD in regards to metacognition so that they may become independent learners (and less reliant on subtractive schooling) and to further develop fundamental physical science concepts, scientific ways of doing, and basic mathematical skills.

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Although the application of Vygotsky's contributions to learning in the ZPD was not an intentional part of this study, my own familiarity with his framework allowed me to consider some his perspectives on learning that may lend itself to future research in the area of science learning in bilingual contexts. Some of my considerations of learning in the ZPD are used in the data analysis and are presented in Chapter IV.

Lesson worksheets for developing science and academic language. A substantial finding in this study about lesson worksheets as used in LASPS is that not only did they support metalinguistic awareness among the students but they also supported metacognition. Lesson worksheets were developmentally constructed to draw on prior knowledge. Furthermore, application and synthesis of science concepts and ideas were used as a strategy to expand newly co-constructed knowledge. Lesson worksheets for LASPS were different than the curricular worksheets accompanying teachers' classroom resources and in two ways. First, lesson worksheets were adapted to review and master specific learning issues that were generally exhibited by participants. Secondly, lesson worksheets included translated statements, pictures and diagrams pertinent to statements to help develop understanding and interpretations of statements.

All participants identified lesson worksheets as helpful in learning science for a number of reasons. For instance, Pablo found worksheet diagrams very useful in learning. In response to how LASP worksheets were effective learning tools during a focus group interview, Pablo stated that worksheets "helps a lot 'cuz they have little diagrams...drawings and stuff that you could actually look and understand." Pablo's statement provides evidence that diagrams and illustrations in worksheets were helpful in interpreting statements, and helped scaffold learning through the use of visuals (Ashton, 1996; Dixon-Krauss, 1996a; Ellis, 1994; Facella, Rampino,

& Shea, 2005).

Elena and Pablo also identified worksheets as being an effective learning tools because worksheets structured learning. Regarding worksheets during a focus group interview, Elena stated that worksheets were helpful because they helped her break down science concepts "to ways we could learn it much better." Pablo also echoed Elena and stated that the worksheets "help you and gives you guidelines into what you are writing is good for you to learn. And is really good." As a teaching tool, the worksheets structured cognition, especially for Elena and Pablo.

As a curricular strategy, worksheets anchored the lessons and provided learning opportunities for me and for the students. As a teacher, I was able to gauge students' ZPD and constantly revised and developed lessons to teach right above the students' ZPD. This was important because in addition to building basic science and mathematical skills and science concepts for the learner, I also scaffolded academic language, science language in particular. Particular attention was placed on the kind of language I used to develop science vocabularies and ways of expressing science. Lesson worksheets also provided the opportunity for student participants and student teachers to interact and exchange knowledge. Student participants reported that what made the lesson worksheets work effectively was working with mentors and peers and getting the individualized attention to work science problems and solutions. At first, students were asked to work problems by themselves in small groups. Then, the instructors helped co-construct knowledge at or above students' ZPD through the use assessing and assisting questions. In a journal entry Gabby expressed that she found it helpful when the instructors "gave us time to think about what we were doing and how we were doing it." Gabby's statement about worksheets give evidence that worksheets supported the development of metacognition.

Furthermore, and most importantly, field notes illustrated that LASP worksheets served as the springboard for knowledge interchange and co-construction among participants and instructors.

Research implications: *Lesson Worksheets.* Literature reports that teachers often use lesson worksheets to "drill and kill" students and they do so as a response to time constraints and standardized testing pressures (Menken, 2006). The use of worksheets for these purposes are ineffective, limits students' learning (Menken, 2006) and demoralizes students (Banks, 1995; Constantino, 1994). Literature reports on methods that can be implemented in worksheets to develop both science and English language skills (Echevarria, Vogt and Short, 2004; Garcia, 2005, Fathman and Crowther, 2006). Current studies regarding the use of lesson worksheets to develop academic and science language in secondary level Latino bilinguals and ELLs are scant or non-existing. Thus, future studies that focus on the construction of curricular worksheets aimed at developing science and academic language for secondary level LBLs are necessary. Studies that identify effective curricula inclusive of lesson worksheets for secondary high school learners, especially bilingual learners, are also important. Such studies can help develop resources for science teachers, support effective teaching practices and further develop science and academic language knowledge, not just for the LBL but for all students.

Implications for practitioners: Lesson worksheets. Current and future practitioners can develop more appropriate lesson worksheets for LBLs. Lesson worksheets can include (1) questions that review prior knowledge (2) questions that ask learners to apply knowledge in new situations, and (3) questions that ask learners and analyze new found knowledge. Whenever possible, practitioners should include statements that evaluate knowledge. At first, the practitioner can help scaffold learning by providing examples of how to evaluate information. On successive worksheets, the practitioner can include more evaluative passages but include fill-in statements so that learners can interact with the passages. Assisting and assessing questions can be very useful here to provide the learner with further writing opportunities. Lastly, once learners demonstrate basic mastery of information evaluation procedures, open-ended questions can be introduced to learners and responses can then be shared with peers. At the beginning of the course, practitioners should provide the most scaffolding. An approach to scaffolding techniques can begin at first by introducing multiple-choice questions and few free response questions. Progressively, practitioners can move away from multiple-choice questions, only using them sparingly, and move to constructed response statements. This allows learners to elaborate responses, further developing the English language and science linguistic expressions. Lesson worksheets should conclude with relevant hands-on inquiry activities and their respective findings and concluding statements.

Implications for my future research: Lesson worksheets. To further understand how science teachers, bilingual science teachers in particular, are using and developing curricula for LBLs, I would like to conduct additional studies regarding the current use and development of lesson worksheets in science classrooms. I am particularly interested in studying curricular strategies inclusive of lesson worksheets in biology classrooms and those addressing LBLs. Biology classrooms are of most importance to me for two reasons. Biology is my area of expertise and biology contains more vocabulary inclusive of Spanish-English cognates and Latin derivatives as compared to physics and chemistry.

The use of scaffolding strategies using inquiry activities facilitates participants' understanding of science. Science inquiry activities are at the core of science learning. As a science teacher, I sought to provide participants in this study the opportunity to experience guided, semi-guided and independent inquiry activities. As part of every lesson, participants conducted structured inquiry relevant to the topic. The structured inquiry activities supplemented lessons and reinforced science and mathematical skills. For instance, participants questioned, measured, calculated, applied and synthesized science skills and knowledge. The Rube Goldberg contraption was a collaborative semi-structured inquiry activity reinforcing the concepts of simple machines and mechanical advantage (Schroeder, Scott, Tolson, Huang, & Lee, 2007). The Derby racecar design was an independent open-ended inquiry activity that reinforced Newton's laws of motion.

All participants identified inquiry activities as helpful science learning strategies. Participants enjoyed semi-structured and open-ended inquiry work the most. In addition to doing and talking science, semi-structured and open-ended work provided different venues for experimentation. Most importantly, both collaborative structured and independent open-ended inquiring activities reflected students' preferred ways of learning. Inquiring activities helped participants apply science knowledge and challenge preexisting knowledge. It also furthered opportunities to experiment and be decision makers. Participants experienced science as a practical endeavor, not just abstract knowledge. For Pablo, the Rube Goldberg contraption experience gave him the opportunity to "work with his hands" and it made science practical for him, similar to the experiences he shares with his dad (who is a manual laborer). For Pablo, this experience was more tuned to his cultural career expectations. He was comfortable. Science was not a foreign and abstract perspective that exists only in the science classroom. Most importantly, as the result of this experience with the Rube Goldberg contraption, both Pablo and his lab partner Dominic were able to further construct physical science knowledge. Field notes and posttest showed that both Pablo and Dominic were able to correctly identify simple machines and their respective mechanical advantages.

For Gabby and Elena, constructing the Rube Goldberg contraption was a motivating experience. Often, female students shy away from physics because they often perceive physics as male-oriented knowledge (Kessels and Hannover, 2008; Murphy and Whitelegg, 2006). However, constructing the Rube Goldberg contraption gave Gabby and Elena the opportunity for leadership. Both students designed, experimented, hammered, lifted objects, sawed and glued simple machines unto the contraption. Often, male students stopped by their workstations and complimented them in their work. Because Gabby and Elena were the first and only group to complete the uniquely designed contraption, their classmates and themselves admired their accomplishment. Participant observation indicated that Gabby preferred to be recognized for her scientific abilities, rather than as a female who was able to complete a project. This is very telling of Gabby's personality, her strengths and her values. The Rube Goldberg contraption also gave Gabby another unique perspective on machines, how they function and how science knowledge plays a role in our everyday lives. When referring to contraptions in a focus group interview, Gabby added that contraptions are complicated machines and that “is not as easy as pushing a button. It's much harder than that.” As a result of this learning experience, all participants became more scientifically literate regarding simple machines, contraptions and mechanical advantage.

The Derby racecar design project was also a successful learning experience. Throughout the program this project opened science discourse among all of the participants including instructors. We often found ourselves talking about the design, considering the different forces that act on the car and on the wheels. Elena, Gabby and Pablo took great care to design competitive models. Gabby and Elena worked for weeks, carving the car and considering its aesthetics. Gabby complained about the amount of time and hand pain she endured with carving and sanding the car. Elena involved her father in the project. She talked about how her father helped her with sanding and took her to hobby shops to gather other complementary materials. To design his car, Pablo drew on his prior carving experiences during Boy Scouts. In all, participants were motivated and committed. They also applied their science knowledge and expertise to the design. As a result of this experience, participants are more informed about car designs, especially about how car designs are influenced by knowledge of simple machines, mechanical advantage and motion-related forces. It is important to note that the participants brought the projects home to their families. It provided a unique opportunity for family members to interact and exchange knowledge. More importantly, participants were trilingual ambassadors in their family, using the Spanish and English languages to make science comprehensible and accessible to family members.

Research implications: Inquiry activities. The effectiveness of science inquiry activities for ELL science learners has been demonstrated in the research literature (Amaral, Garrison, & Klentschy, 2002; Bravo & Garcia, 2004; Cuevas, Lee, Hart, & Deaktor, 2005; Hampton & Rodriguez, 2001; Torres & Zeidler, 2002). However, future studies are necessary to understand the kinds of science experiences that are helping construct and support science inquiry in all students, particularly in LBLs. For instance, are science teachers teaching HS LBLs using open-ended inquiry? Are these open-ended science inquiries activities requiring the participation of family members? How are LBLs sharing science knowledge with their families and their peers? How are the bilingual learners serving as more knowledgeable agents in their communities? How is scientific literacy making its way beyond the science classroom? Findings from these studies can inform educators about how knowledge of scientific literacy is being constructed by LBLs and their respective communities. More importantly, what are the most effective methods to support inquiring minds?

Implications for practitioners: Inquiry activities. Often, science teachers lack time, resources and the knowledge to design appropriate curricula such as motivating semi-guided open-ended inquiry activities for secondary level science learners (Hollins & Guzman, 2005; Huang, 2004; Kanter & Konstantopoulos, 2010). To develop a culture of inquiry, a practitioner can provide experiences for the learner through structured-inquiry and can be short in duration. The idea here is that to help construct the knowledge and skills necessary to conduct science investigations through the scientific process with guidance from the teacher. A science inquiry worksheet can structure this learning process. The worksheet can include statements regarding study design, hypothesizing, experimentation and drawing conclusions, inclusive of science language. When students feel comfortable with completing structured inquiry, teachers can introduce one semi-structured inquiry activity that may last a couple of sessions. Here, the goal is to acquaint students with designing and conducting their own inquiry while having support from the instructors. Keep in mind that some inquiry activities require appropriate materials and supplies. Other semi-structured activities can be completed in the classroom to help students master scientific ways of thinking and doing. At least one open-ended inquiry project can be proposed to students as a culminating class project. The project can include one challenge, common to all students or at the individual level. A set of guidelines should be provided to students about the expectations for a successfully completed project. The guidelines should be written clearly including expected outcomes inclusive of science knowledge and appropriate of use of science and academic language. The use of English-Spanish cognates should be encouraged. All inquiry activities can be used as authentic assessments in the learners' composite final grades. With practice, practitioners will gain a better understanding of the activities that motivate their students and can then begin accumulating a repertoire of most effective teaching strategies and projects for science learners.

Implications for my future research: Inquiry activities. Science inquiry activities, specially semi-structured and open-ended, are often limited in bilingual and ELL classrooms. This is partly attributed to (1) limited resources, (2) teaching to standardized testing at the expense of inquiry, and (3) teacher's lack of expertise in these areas. Developing curricula that is motivating and conducive to hands-on, minds on inquiry activities for the bilingual secondary-level science is clearly warranted. It follows then that future studies in this effort would include the development of an inventory of available teaching resources that draws upon inquiry science activities for the Latino bilingual learner. Such an inventory can then be used as a resource bank for teachers in the classrooms. Follow up studies can identify effective inquiry activities for Latino bilinguals that make use of students' cultural capital. Another area of study I would like to address is the kinds of science knowledge that is interchanged with family members when science LBLs bring and work on their science projects at home. Studies that employ formal or informal interviews and PO could be most effective in this endeavor, since I share the Latino culture with LBLs and their families. This relationship may provide me with easier access to participants' home cultures.

Latino bilingual learners can identify and articulate strategies that facilitate their personal learning and understanding of science.

Social agents. This study was theorized using constructivist theories of learning, and as such, it is appropriate to address the role of social agents as co-constructors of knowledge. As the result of this study, I have gained specific insights about the multiple roles I, as well as other LASPS teachers, played as instructors and role models. As a researcher, I have gained a deeper understanding about how science knowledge is co-constructed in LBLs. Most importantly, this research opportunity has served as reflective tool for my own learning. Not only were LBLs identifying and articulating their personal learning and understanding of science, but their engagement with LASPS facilitated my own exploration for the triangulation of Spanish, English, and the language of science. That is, while the participants were learning from me I was also learning from them.

I began this research and teaching journey with the idea that my own Latina experiences both as a LBL and as a bilingual science teacher would help me apply effective teaching strategies that met participants' linguistic and cultural demands. As such, participants confirmed my expectations and shared positive comments, not only about my teaching approaches, but also about the effectiveness of the program in general. Most importantly, this study helped me gain more insight about my effectiveness, as well as other instructors such as student teacher Carlos, to help participants move across the learners' performance continuum (LPC). Scaffolding approaches aimed at constructing knowledge at participants' ZPD were effective for most participants, subjectively speaking, because I was able to access participants' prior knowledge due in part to our cultural similarities. This cultural reciprocity was advantageous both for me and for the participants. At the very least, participants experienced teaching targeting their ZPD. Additionally, knowledge was co-constructed and reconstructed among the participants. As the instructor, I moved across my own teaching performance continuum, revisiting fossilized knowledge about instruction and returning to my own ZPD for further clarifications. This is an important finding for me because as a teacher I rarely focused on my own metacognitive development regarding teaching. I saw myself as the co-constructor of knowledge for others and not for myself. This research experience has given one more insight about being a more reflective science teacher.

The learning challenges that LBLs face in schools resonate with me, as I myself faced similar struggles. As a student, I was also demanded to triangulate the Spanish, English and science languages. I now find myself successfully doing so with family members and in bilingual science classrooms. But it is these struggles with the triangulation of the languages and the Spanish, American and science ambassador roles that helped me gained more expertise. As such, these experiences may be revealed through language, expressions and behaviors that I share when teaching. Though these behaviors may not be as apparent to me, it is possible that learners in my classrooms can identify them as such. In that event, such identification may have a huge impact on learners' affective domains with the potential to positively change or further support learners' perspectives about science learning and bilingualism.

Research implications: Social agents. Multicultural education literature is replete with studies including suggestions and recommendations for more culturally congruent teaching in diverse classrooms (Banks, 1995; Atwater, 1996; Nieto, 2004). Numerous other studies report on teachers and the numerous challenges they face when teaching in culturally and linguistically diverse classrooms (Rodriguez, 1998). Fewer studies report on bilingual Spanish-English teachers, high school science teachers in particular, and their roles as social agents in the construction of scientific literacy among bilingual Latino students. Similarly, few studies report on the perspectives and learning experiences of secondary-level LBLs in science classrooms. Findings in this study support the work done by Phelan, Locke-Davidson and Thanh Cao (1991) who report on Latino bilingual students and their roles as mediators and integrators of meaning and experience. They provide a Multiple Worlds Model to explain the interrelationships between students' family, peer and school cultures. They describe the struggles and challenges bilingual students face, especially low SES Latinos as they try to navigate the different cultures. However, more studies are necessary to understand how bilingual teachers who share similar cultures with their students can help build cultural connections in regards to science. More specifically, what is the impact of shared ethnicity between HS teachers and students with respect to scientific literacy? Furthermore, future studies can focus on the effect of shared ethnicity between teachers and students with respect to effective teaching strategies for the co-construction of knowledge with students, including LBLs, and their respective ZPDs. Findings from such studies can help illuminate teaching and learning challenges specific to science learning and students' affective domains. In turn, science educators can be better informed about effective pedagogical and curricular approaches and help co-construct this knowledge with students.

Implications for practitioners: Social agents. Practitioners teaching LBLs can resort to the literature on culturally congruent teaching (Buxton, Lee, & Santu, 2008; Lee, & Fradd, 1998). Science teachers teaching LBLs can also help create a supportive learning environment for LBLs by acknowledging students' cultural perspectives, cultural and family demands, and integrating these understandings into the curriculum. Whenever possible, practitioners should interact with students' families in or out school. Such interactions have the potential to develop positive connections between home cultures and school cultures. In my experience, LBLs are very receptive to these interactions.

Implications for my future research: Social agents. This study has increased my awareness of the social interactions I share with LBLs in the science classroom. I am interested in helping and nurturing academic and cultural role models, including Latino students, Latino student teachers, science teachers and bilingual Latino science teachers in an effort to support positive and constructive learning experiences for the Latino community in and out of classrooms. To develop nurturing academic mentors specific to the HS LBL, studies on LBLs' mentorship perspectives are necessary. Moreover, studies that identify and report on Latinos who are successful at navigating the Spanish, English and science languages and cultures are necessary. Findings from these studies can also inform educators and advocates for additive bilingualism alike about effective ways to cultivate trilingual Spanish, English and science ambassadors. I have been inspired by the process and hope to continue my effort to cultivate more trilingual ambassadors.

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APPENDICES

APPENDIX A

FIRST FOCUS GROUP: VIGNETTE

Ms. Luisa is a young science teacher who only speaks English. She teaches physical science at a local high school. Her students cannot speak English very well. Ms. Luisa had to figure out how to best teach science to her students. She knew that her students had difficulty understanding the English language. Ms. Luisa thought she should try at least three teaching methods that may help her students learn science and English at the same time. For the first method, she thought it was really good for students to write in English about their science activities in a science journal. She thought that if the students practice English while writing about science, students will learn to write their ideas about science while at the same time learning how to write in English. However, she didn’t know, how often she should have the students write in their journal. Two things bothered Ms. Luisa about this teaching method. She didn’t know if the students liked writing in English or Spanish, and whether the writing exercises really helped the students learn English or science.

The second teaching method Ms. Luisa thought may help the students learn English and science was to have the students work in groups while they do science. She thought that the students can learn to speak English and learn science while working with a partner who knew as much English as the other. She decided that when students did science experiments in the class, she would allow the students to work together and help each other understand what was going on. She questioned this teaching technique and wondered whether the students would learn science better if they spoke in Spanish and sometimes English and if this activity helped the students speak English better. She also did not know if the students really understood the science they were supposed to learn.

The third teaching method Ms. Luisa thought was very helpful for students learning English and science was to have students present a science project to the class. She thought that the students can do a science project with a partner and present the results of the project to the class. Students then would be able to write and speak English and learn science at the same time while working with a partner. She wasn't sure whether the students felt comfortable with presenting to the class. She wondered whether students should present in small groups to one another, or whether they would prefer to present to the entire class.

In addition to these teaching methods, Ms. Luisa questioned other teaching strategies she was using to teach the class. For instance, one teaching strategy she thought might be useful to the students was to translate important words into Spanish and explain where each word come from. Another strategy Ms. Luisa thought might be helpful was to speak and explain ideas in English and Spanish. However, she wasn't sure whether the students preferred this method.

Ms. Luisa has suggested the following teaching methods for helping science students who are still learning English:

1. Writing science ideas in a journal
2. Working in groups
3. Presenting projects and assignments to the class
4. Translating words into Spanish
5. Telling the students where did each word come from
6. Speaking and explaining ideas in both English and Spanish

FIRST FOCUS GROUP INTERVIEW QUESTIONS

1. Explain which teaching method (s) would work best for science students who are still learning English.

2. Which of these teaching strategies have work best for you to learn science? Why?

3. Which of these teaching strategies have worked the least for you? Why?

4. Are there any other teaching strategies Ms. Luisa should use? Explain.

5. What recommendations would you make to Ms. Luisa so that she may help her students learn science better?

SECOND FOCUS GROUP INTERVIEW QUESTIONS

During the last focus interview, a couple of you gave your ideas about learning and teaching strategies that worked for you. Today, we will discuss those ideas a little bit further.

I) At least one of you mentioned that writing science ideas in journals is beneficial because it helps you review the material that was just taught.

1. Can you remember an experience where journal writing helped you learn the material better? Talk about that experience with us.

2. What do you think worked well for you? When did journal writing not work for you?

3. If a teacher were to use this learning strategy, suggest ways in which journal writing can be more effective for learning science concepts.

Here are some examples:
Have the students

a. write, draw, summarize key points or a combination of these
b. write about how you felt the lesson went, what worked for you and what did not.
c. Other suggestions????

4. In the event that a teacher decides to use writing journals in their class,

   a. How often should journal writing be included on a weekly basis?
   b. Should the journal entries be used as part of your grading? Why or why not?
   c. Should the teacher provide set questions or should it be free writing? Why?
   d. Should a student write in their native language if they so choose? Why?

II) Working in groups is the learning strategy most identified by all of you. Let's explore this strategy a bit more. We are going to discuss your group work experiences in your science classes.
1. Can you remember a group work experience that worked well for you? Tell us about this experience. Why do you think it worked well?

2. Can you remember a group experience that did not work for you or was not a good experience? Tell us more about that. What did not work for you?

3. Did group work experiences worked best for you when:

a. The teacher assigned your lab partners or when you chose whom to work with? Why?
b. The teacher assigned the roles for group work, or when the group members decided who was playing which role? Why?
   - For example, Reporter, observer, material collector, group leader

c. In your experience, what kinds of tasks do you find yourself doing most of the time?

- Reporter, observer, material collector, group leader

d. How do you feel about these roles?

e. When doing group work in science classes, which kinds of students do you like to work with the best? Why?
f. In as much detail as possible, describe your best science lab partner.
g. How should a teacher organize students when doing group work so it is more effective?
h. When doing science lab group work activities, which learning method do you prefer for doing and learning science? Why?

   - Structured inquiry – follow every step provided by the teacher (i.e., measuring how much power it took you to go up the stairs)

   - Guided inquiry- the teacher provides you with some basic questions and materials, but you experiment and draw conclusions (i.e., measuring acceleration activities)

   - Open inquiry- the teacher provides the materials only and you design, question, hypothesize, experiment and draw conclusions (i.e., The Rube Goldberg and the Derby car projects)

i. What do you suggest students do to make it easier for teachers to do these activities?

III) Several of you mentioned that translating ideas, words and concepts into Spanish is a good teaching strategy because:

- it helps you understand ideas and concepts better
- you learn words in Spanish that you didn't know
- you value the Spanish language and you want to learn it more

1. In your experience, share with us some of the learning strategies that you use when you don't understand words, ideas and concepts in English?

2. If a teacher has difficulties translating words/ideas/concepts into the Spanish language, what do you suggest the teacher does to use this strategy effectively?

   Here are some examples
   The teacher could
   a. use textbooks written in both English and Spanish
   b. have students translate key terms and ideas before each lesson
   c. other suggestions?

3. What do you suggest a student do to learn science bilingually?

THIRD FOCUS GROUP INTERVIEW QUESTIONS

In this interview, we would like to hear your experiences with the LASPS program.

General impressions

1. In your experience, how has this after-school program worked for you?
    a. what really worked well for you?
    b. what do you suggest should be changed about this program?

2. Tell us about a science activity or experience that this program provided for you that helped you understand science better?

3. In terms of learning physical science, how has this program helped you?

    a. what really worked well for you?
    b. what do you suggest should be changed about the teaching of physical science in future after-school programs?

4. All the science concepts that were covered in this program you have previously seen or learned before. What really worked or did not work for you this second time around?

5. Compare to regularly scheduled classes, this after school program allowed you to speak Spanish to your teacher, and to all your classmates whenever you wanted. Tell us how this environment worked for you in learning science better.

Think about some of the activities that you did for this physical science program.

6. At the beginning of every class meeting, you worked on worksheets that asked you to do various activities such as read a graph, work our formulas and answer questions.
7. In your experience, did the worksheets help you understand the concept being taught that day? Why or why not?

Final comments

8. If this program was offered again, would you recommend it to your friends? Why or why not?

9. Are there any other experience or stories that you’d like to share about this after-school program?

APPENDIX B

Test administration: Four lab stations will be provided for students to answer test questions. Station 1 will consist of a water tank and a laser pen. Students will answer questions 1-4 regarding waves. Station 2 will consist of two circuit boards; one serial and one parallel. Students will answer questions 5-12 regarding electricity and energy. Station 3 will have two small cars and numerous weights. Cars will have the ability to carry different weights. Students at this station will answer questions 13-18 regarding velocity, acceleration and Newton's laws. Station 4 will have a variety of simple machines. Students will answer questions 21-24 regarding mechanical advantage and simple machines.

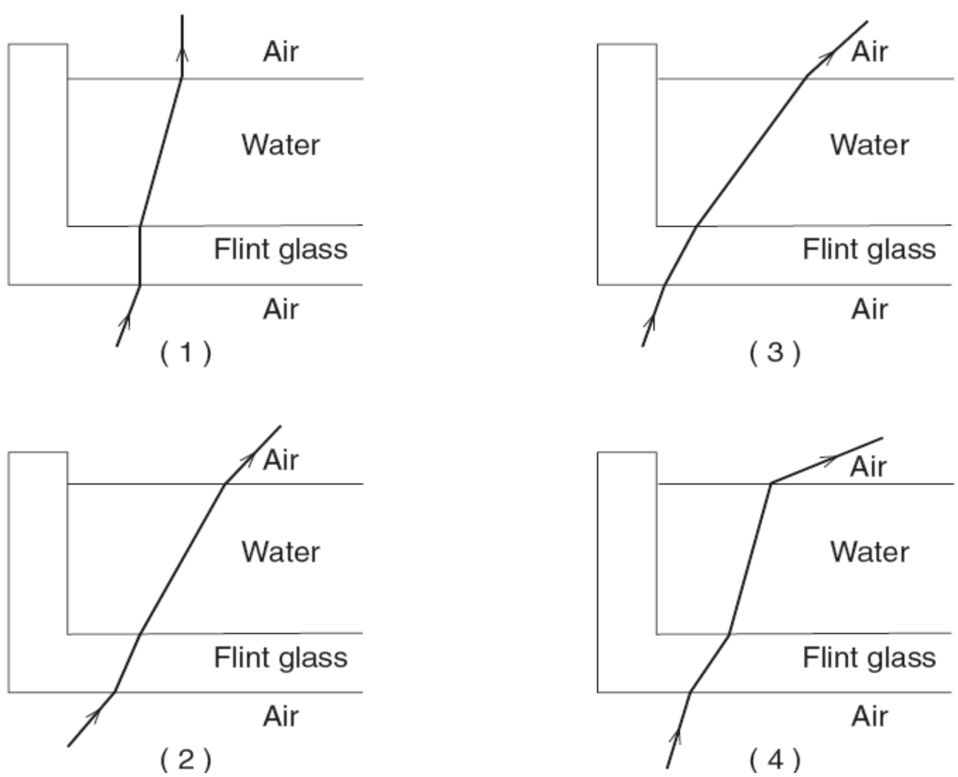
Name ________________________________ Date__________________________

Physical Science Examination

Waves

Directions: For each statement or question, circle the expression that, of those given, best completes the statement or answers the question.

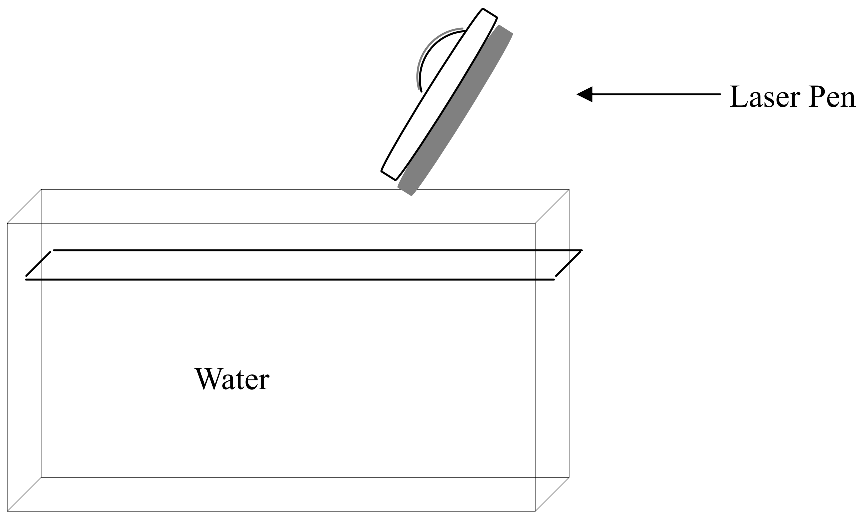
1. Which diagram best represents the path taken by a ray of monochromatic light as it passes from air through the materials shown?



Direction: Record your answers in the spaces provided on this sheet.

Base your answers to questions 2, 3 and 4 on the information and the diagram below.

The following diagram represents a tank filled with water. A laser pen has been placed on top of the water tank.



2. Use the diagram to draw the path of a laser beam as it reflects in the water tank. Label the reflecting beam.

3. Use the diagram to draw the path of a laser beam as it refracts in the water tank. Label the refracting beam.

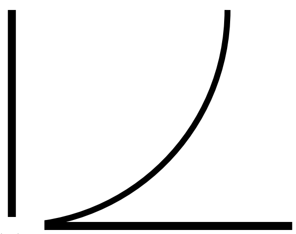
4. Using your own words, explain why light refracts as it changes medium.

Electricity

Directions: For each statement or question, circle the expression that, of those given, best completes the statement or answers the question.

5. Which graph best represents the relationship between the strength of an electric field and distance from a point charge?

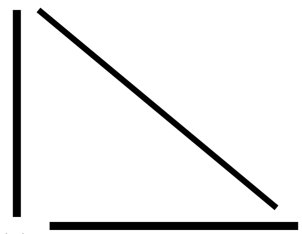
Electric Field
Strength



Distance

(1)

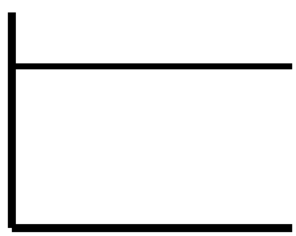
Electric Field
Strength



Distance

(3)

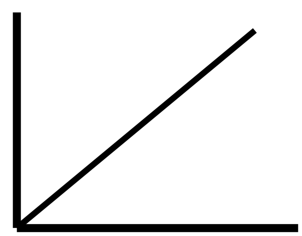
Electric Field
Strength



Distance

(2)

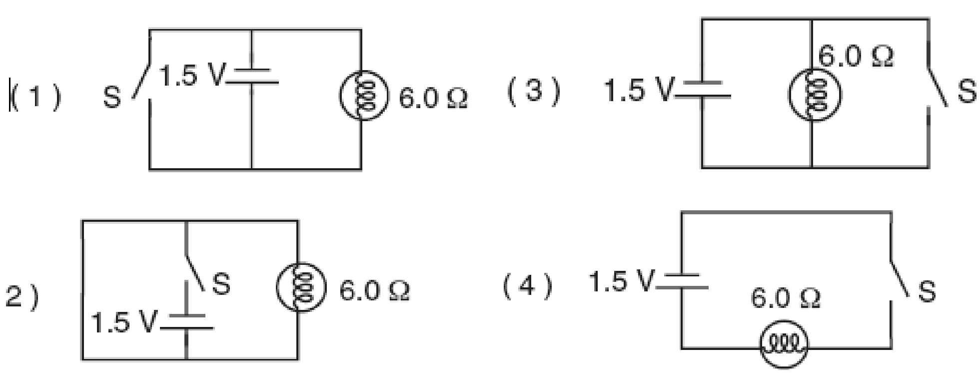
Electric Field
Strength



Distance

(4)

6. A 6.0-ohm lamp requires 0.25 ampere of current to operate. In which circuit(s) below would the lamp operate when switch S is closed?



Direction: Record your answers in the spaces provided on this sheet.
Base your answers to questions 7, 8, 9, 10 and 11 on the information and the diagram below.

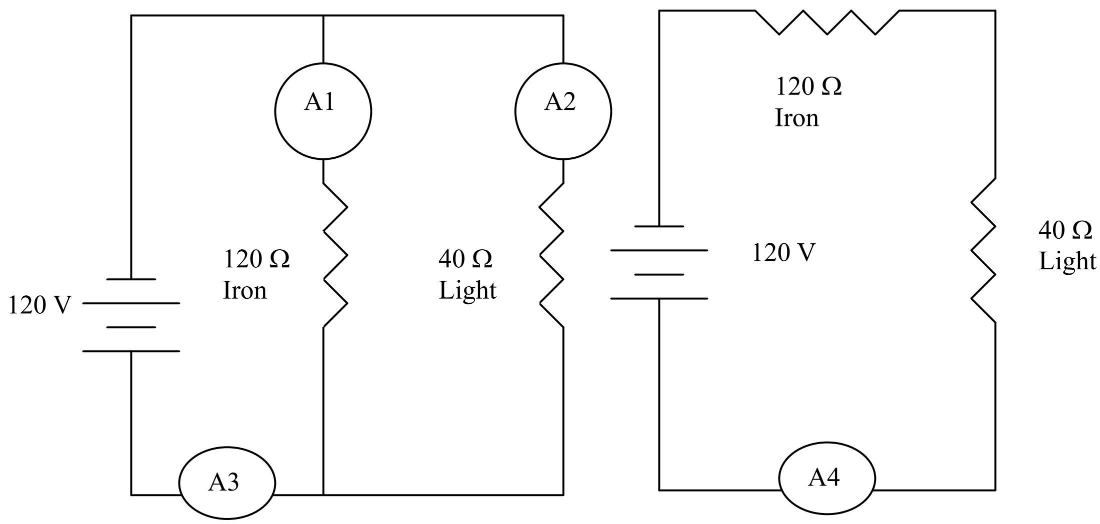


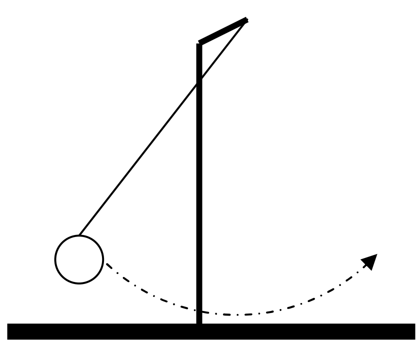
Diagram A

Diagram B

7. Which circuit would you suggest an electrician use to wire a room your house?
8. Which circuit has more overall resistance? Why?
9. Calculate the resistance from the circuit you selected in Question 8.
10. Which circuit has more current flowing through the battery?
11. Prove your answer by calculating the current for each circuit.

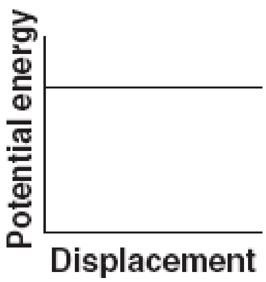
Energy

Directions: For each statement or question, circle the expression that, of those given, best completes the statement or answers the question.



Pendulum

12. A pendulum is pulled to the side and released from rest. Which graph best represents the relationship between the gravitational potential energy of the pendulum and its displacement from its point release?



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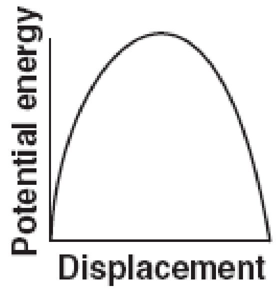

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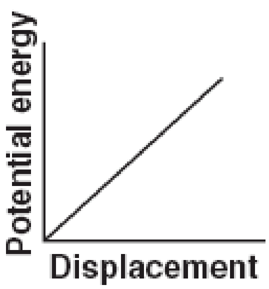

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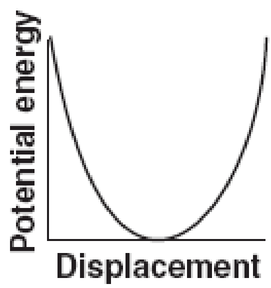


(4)

Acceleration

Directions: For each statement or question, circle the expression that, of those given, best completes the statement or answers the question.

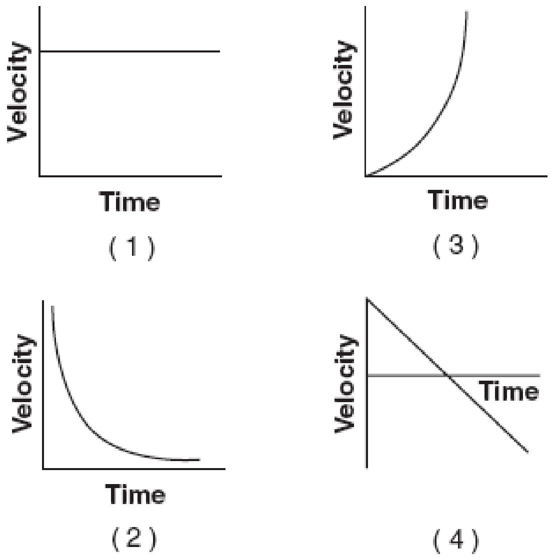
An observer recorded the following data for the motion of a car undergoing constant acceleration.

Time (s)	Speed (m/s)
3.0	4.0
5.0	7.0
6.0	8.5

13. What was the magnitude of the acceleration of the car?

(1) 1.3 m/s^2 (3) 1.5 m/s^2
(2) 2.0 m/s^2 (4) 4.5 m/s^2

14. Which graph best represents the relationship between the velocity of an object thrown straight upward from Earth's surface and the time that elapses while it is in the air? [Neglect friction.]



Newton's Laws

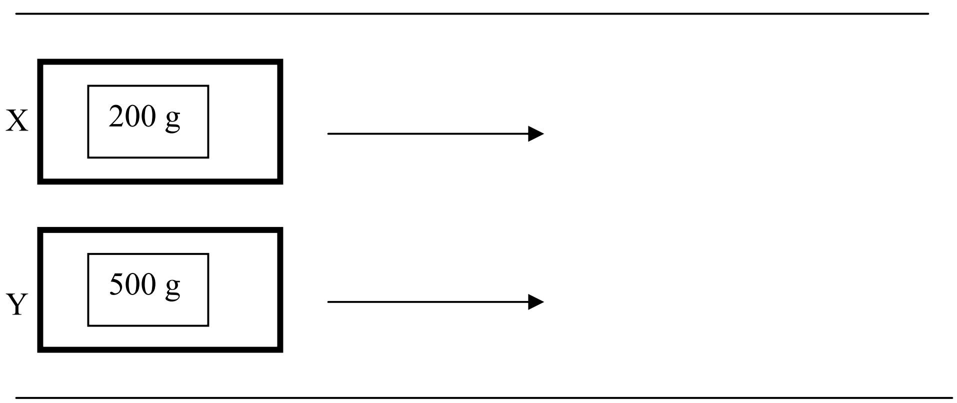
Direction: Record your answers in the spaces provided on this sheet.

Base your answers to questions 15, 16 and 17 on the diagram and information described below.

One car is moving straight ahead to the right on a flat surface.

15. Identify all the forces acting on the moving car.
16. If the car is accelerating, are all the forces acting in equilibrium? Why or why not?
17. Identify the action and reaction forces acting on the tires.

Base your answer to question 18 on the statement and diagram below.



A 200 gram mass is placed on top of a wooden car (X) and a 500 gram mass is placed on top of another wooden car (Y). Both cars are moving in a straight line.

18.Which car will have a faster acceleration if both cars are pushed with the same force? Explain your answer.

Mechanical advantage

Directions: For each statement or question, circle the expression that, of those given, best completes the statement or answers the question.

19. A simple machine with a mechanical advantage greater than 1 will:

1. decrease the amount of work you do

2. increase the effort you use and decrease the distance you move

3. decrease the effort you use and distance you move

4. decrease the effort you use and increase the distance you move

20. Draw a diagram of a simple machine that will reduce the amount of force you would use to move a 25 Kg box.

21. Explain how your simple machine works.

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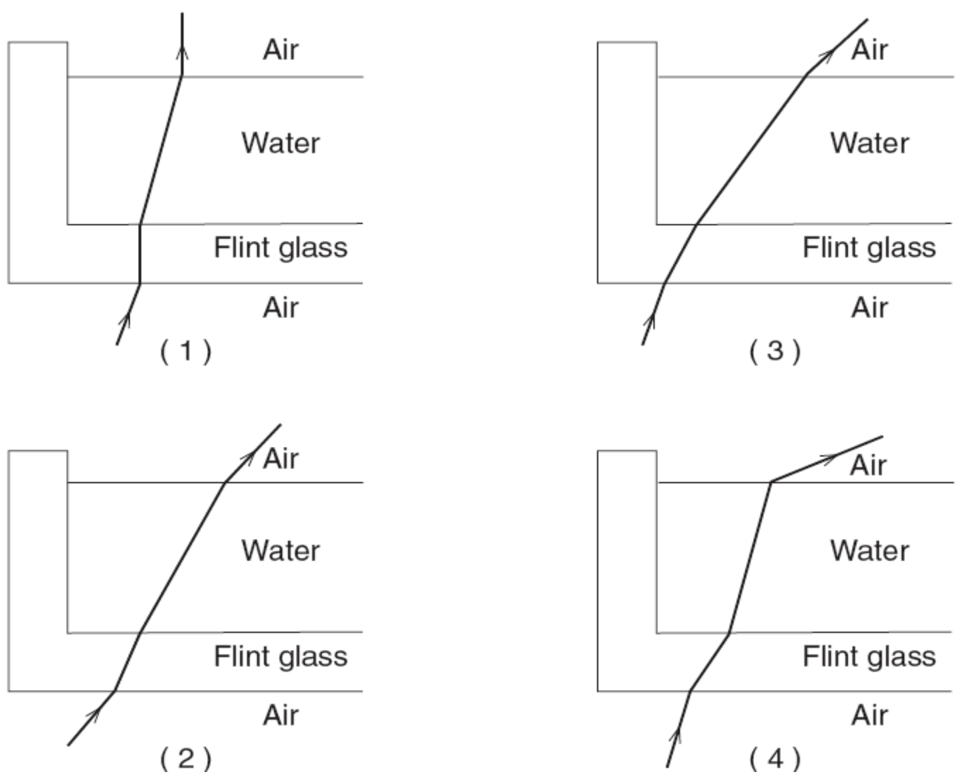
Nombre ________________________________Fecha__________________________

Examén de Cíencias Físicas

Ondas

Instrucciones: Por cada pregunta o declaración, circula la expresión que mejor completa la declaración o contesta la pregunta.

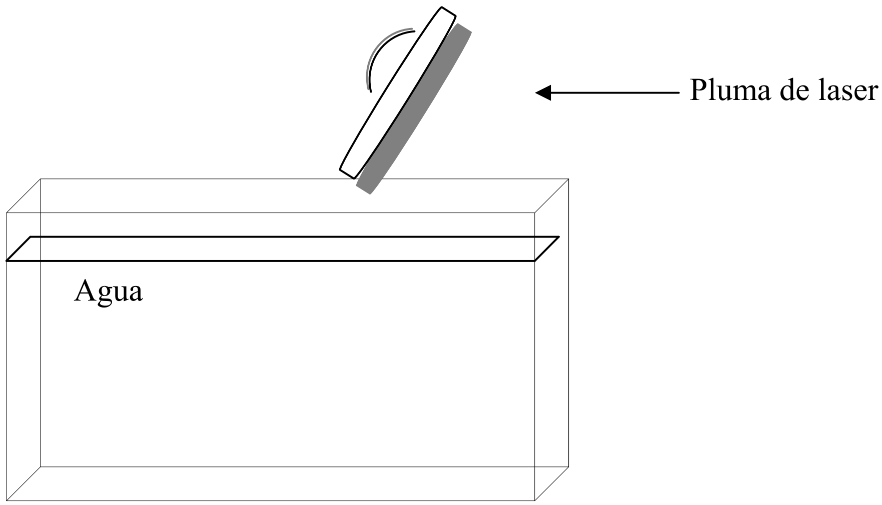
1. ¿Cúal diagrama mejor representa el camino que toma un rayo de luz monocromatico cuando pasa desde el aire y atravez de los materiales ilustrados?
Air (Aire), Water (Agua), Flint glass (vidrio).



Instrucciones: Escribe tus respuetas en el espacio dado.

Basa tus respuestas a las preguntas 2, 3 y 4 en el diagrama debajo.

El siguiente diagrama representa un tanque lleno de agua. Una pluma laser esta localizada enzima del tanque.



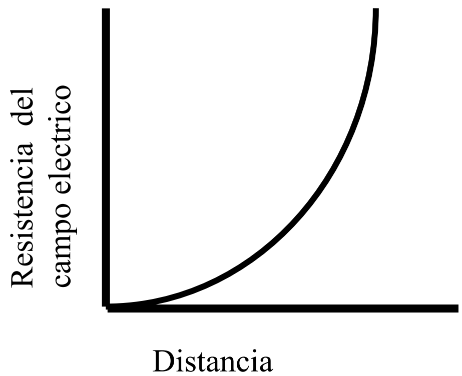
2. Usa el diagrama y dibuja el camino de un rayo laser cuando se reflecta en el tanque de agua. Nombra el rayo reflectante.

3. Usa el diagrama y dibuja el camino de un rayo laser cuando se refracta en el tanque de agua. Nombra el rayo refractante.

4. Usando tus propias palabras, explica como la luz se refracta cuando cambia medios.
Instrucciones: Por cada pregunta o declaración, circula la expresión que mejor completa la declaración o contesta la pregunta.

Electricidad

5. ¿Cúal gráfica mejor representa la relación entre la resistencia de un campo eléctrico (Electric field strength) y la distancia del punto de carga?



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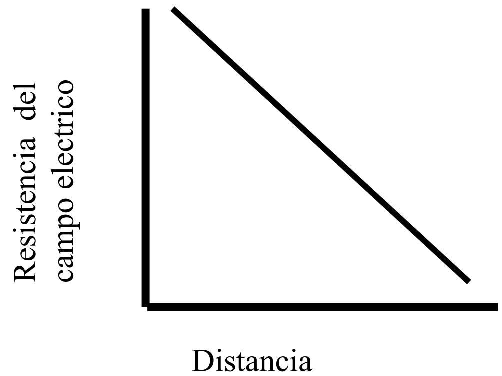

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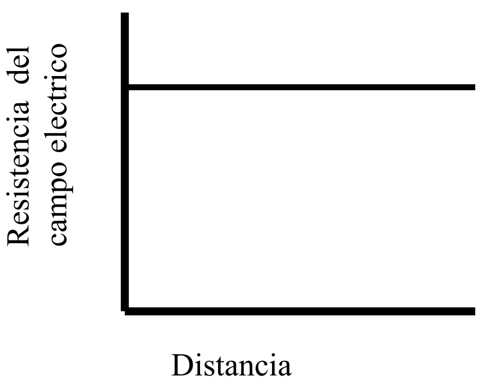

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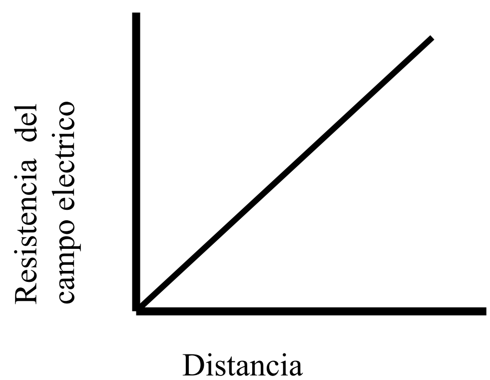
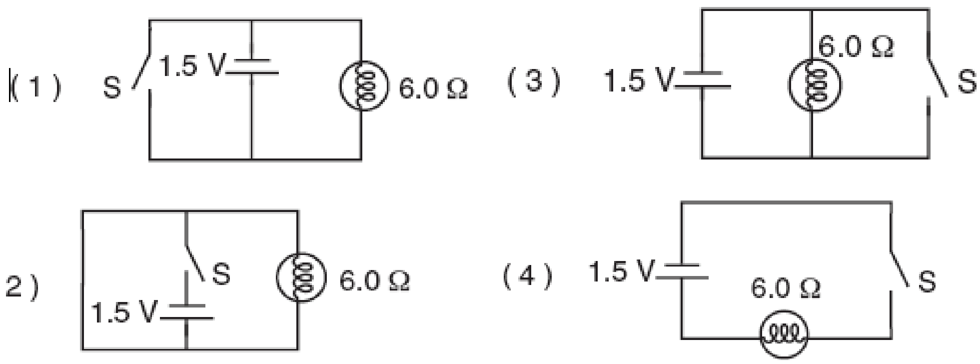


(4)

6. Una lámpara con 6.0-ohm requiere 0.25 amperio de corriente para operar. ¿En cúal circuito debajo operara la lámpara correctamente cuando el interrruptor esta cerrado?



Instrucciones: Escribe tus respuetas en el espacio dado.
Basa tus respuestas a las preguntas 7, 8, 9, 10 y 11 en los diagramas debajo.

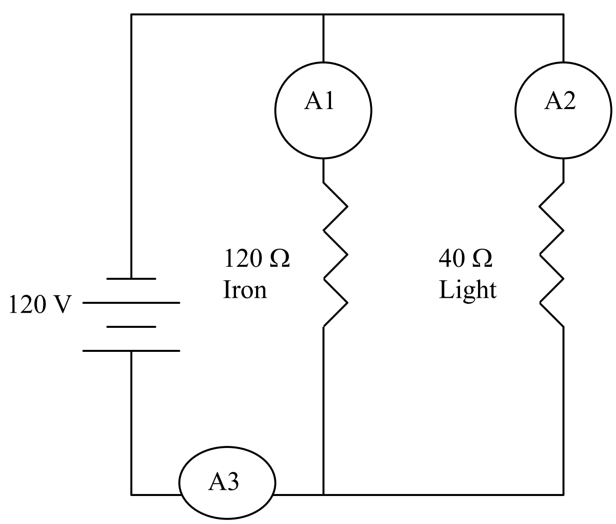


Diagrama A

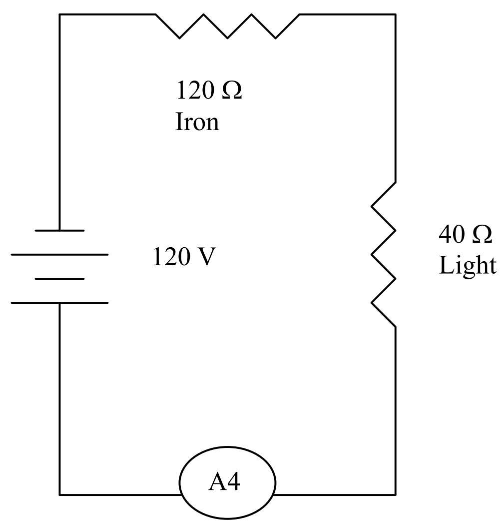
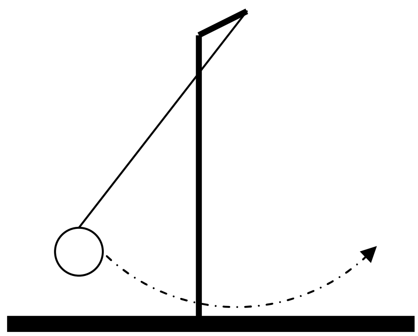


Diagrama B

7. ¿Cúal circuito sugieres que un eletricista instale en tu casa?
8. ¿Cúal circuito tiene la mejor resistencia? ¿Porqué?
9. Calcula la resistencia de el circuito que elegiste en la pregunta 8.
10. ¿Cúal circuito tiene más corriente circulando en la bateria?
11. Calcula la corriente de cada circuito.

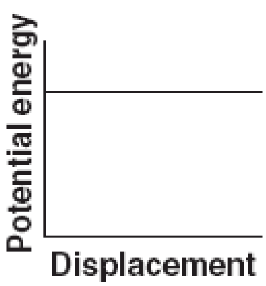
Energia

Instrucciones: Por cada pregunta o declaración, circula la expresión que mejor completa la declaración o contesta la pregunta.



Pendulum

12. Un péndulo es jalado por un lado y despues es suelto. ¿Cúal gráfica mejor representa la relación entre la energía potencial gravitacional del péndulo y su dislocación (Displacement) del punto cuando se suelta?



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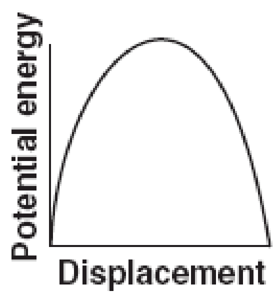

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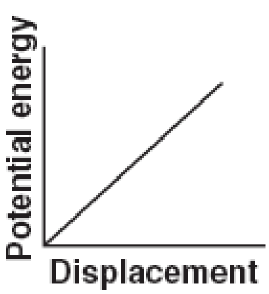

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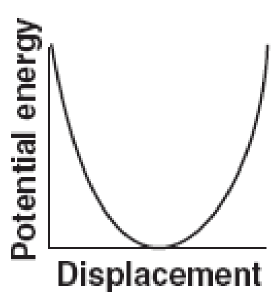


(4)

Aceleración

Instrucciones: Por cada pregunta o declaración, circula la expresión que mejor completa la declaración o contesta la pregunta.

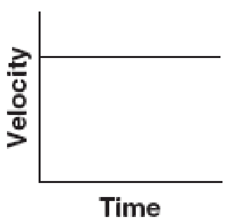
Un observador anoto la siguiente información acerca del movimiento de un carro viajando con una aceleración constante.

Tiempo (s)	Velocidad (m/s)
3.0	4.0
5.0	7.0
6.0	8.5

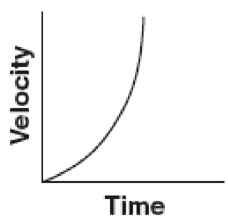
13. ¿Cúal es la magnitud de la aceleración del carro?

(1) 1.3 m/s^2 (3) 1.5 m/s^2
(2) 2.0 m/s^2 (4) 4.5 m/s^2

14. ¿Cúal gráfica mejor representa la relación entre la velocidad (velocity) de un objecto que se tira directamente hacia arriba lejos de la superficie de la tierra y el tiempo (time) que pasa cuando esta en el aire? [No cuente la fricción]



(1)



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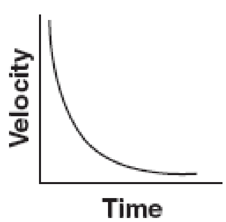
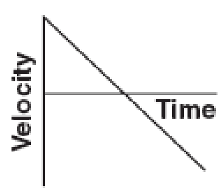


(2)



(4)

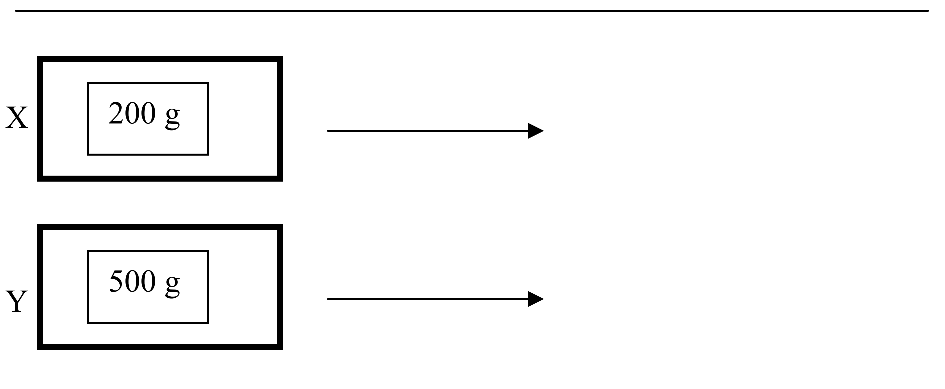
Las Leyes de Newton

Instrucciones: Escribe tus respuetas en el espacio dado.
Basa tus respuestas a las preguntas 15, 16 y 17 en la información descrita debajo.

Un carro se mueve hacía delante en un superficie llana.

15. Identífica todas las fuerzas que actuan en el carro.
16. Sí el carro acelera, ¿están todas las fuerzas en equilibrio? Explica tu respuesta.
17. ¿Cuáles son las fuerzas de acción y reacción que actuan en las ruedas?

Basa tu respuesta a la pregunta 18 en el diagrama y la información descrita debajo.



Una masa de 200 gramos es puesta encima del carro X y otra masa de 500 gramos es puesta en el otro carro Y. Ambos carros se estan moviendo hacia delante.

18. ¿Cuál carro tendra la mayor aceleración sí ambos carros son empujados con la misma fuerza? Explica tu respuesta.

Ventaja Mecánica

Instrucciones: Por cada pregunta o declaración, circula la expresión que mejor completa la declaración o contesta la pregunta.
19. Una máquina simple con una ventaja mecánica más de 1:
1. disminuira la cantidad de trabajo que hagas
2. aumentara el esfuerzo que usaras y disminuira la distancia que te muevas
3. disminuira el esfuerzo que uses y la distancia que te muevas
4.disminuira el esfuerzo que uses y aumentara la distancia que te muevas

20. Dibuja un diagrama de una máquina simple que reducira la cantidad de fuerza que usarias para mover una caja que pesa 25 Kg.
21. Explica como funciona tu máquina simple.

APPENDIX C

Marketing Department
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August 6, 2009 **Update: Reference #: 08060901**

Regina Suriel
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212 Aderhold Hall
Athens, GA 30602

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