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How Inquiry Based, Social Constructivist Teaching Methodologies Can Improve the Access to and Quality of Physics Education

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Abstract

The following paper contains an examination of the current state of the United States public education system, specifically as it pertains to international achievement in science. In a local and personal effort to improve secondary science pedagogy, two high school science teachers and an undergraduate physics education major developed a curriculum unit on circuits utilizing Social Constructivist, Multicultural and Inquiry-based instructional approaches. We taught the unit to four classes and surveyed the students about their learning experience with the unit and their feelings about different instructional approaches. The students also took an exam on circuits, typical of the exams given after more conventional instruction.

Introduction

20th Century educational theorist Paulo Freire once wrote “Apart from inquiry, apart from the praxis, individuals cannot be truly human. Knowledge emerges only through invention and re-invention, through the restless, impatient, continuing, hopeful inquiry human beings pursue in the world, with the world, and with each other” (Freire, 1970). Our edification as a society is not only a crucial element to our success and ability to thrive, but an essential part of who we are and how we understand ourselves. The success of our nation is firmly grounded in high educational standards for our youngest generation. However, between the year 2000 and the year 2006 the number of countries scoring higher in science than the United States on the Program for International Student Assessment (P.I.S.A.) rose from 6 to 12 (National Science Foundation, 2010). Not only are we not keeping pace with the rest of the world in terms of science and mathematics education, but we are leaving behind entire demographics of our own country’s population in the process. According the National Center for Educational Statistics thirty-five percent of language minority students are enrolled in classes below grade level and are also more likely to drop out of school than native English speakers (Spurlin, 1995). We must begin to take a crucial look at the pedagogy behind these shortcomings in an attempt to protect the future of science and mathematics education. Although the causes of these problems are multifactorial, there is at least one immediate aspect of learning we can influence. This is the classroom.

As a Physics Education student, it is my job to pursue teaching methodologies that will both motivate and educate students. By observing high school and middle school classrooms and interviewing students I hoped to understand what they look for from an informative class and an encouraging teacher. Together, we try to find ways to integrate learning math and science into something accessible to a wider range of students with potentially no background in the fields. By creating more involved laboratory experiences and concept-based learning forums where students can formally explore everyday questions through the lens of science, it is possible to nurture their motivation to further these fields.

It is the hope of educators today that by understanding the way in which the mind learns and the proper channels for motivating students that we can turn around California schools and expose our children to the beauty of science and mathematics in a provocative, non-intimidating way.

Over the last century several paradigms of cognitive development have been developed and considered. This paper will also deal with different conceptions of learning and various psychological theories. Our oldest generation might remember a teaching style inspired by B.F. Skinner's Behaviorist approach to learning in which corporal punishment was frequently used to discourage failure. Under this regime, it is believed that students can be conditioned to perform well in school by punishing failure and rewarding success (Skinner, 1947). However, other views of cognitive development, such as that of Russian psychologist Lev Vygotsky, disagree and consider the student to be more than a subject purely responding to stimulus. This theory of learning is founded on student-centered teaching and the belief that social interaction plays a fundamental role in the process of cognitive development (Vygotsky, 1929).

Social constructivist theory considers the student as much more than a series of stimulus and response. Practitioners of this epistemological learning theory believe that all people form knowledge and create shared meaning through social construction. Without entering into a social dialogue in which the student can understand what is being discussed and relate it back to his or her prior knowledge and culture, no actual learning will take place. If this is how we conceive of the way knowledge is formed, then our instruction should create an environment that can aid students in collaboratively assigning their own meaning to learning. A critical focus of creating such an environment is allowing students to discuss science in their own vernacular so that they may effectively communicate. Without first creating a common or shared experience, academic language has no meaning for students. Additionally, under this regime students should be assessed not only by their performance on examinations but by their ability to work through more complex tasks as a group. By matching students with peers of overlapping but varied levels of understanding the students will be able to discuss concepts more clearly, using a vernacular and sensibility that is appropriate to their current level of understanding, making science something that is socially accessible to them. This form of analysis contrasts the situation presented by a classroom in which students are exposed to a more traditional lecture methodology.

In this paper I will explore the current educational research surrounding methodologies to improve the equity of and access to science education with a focus on Social Constructivism, Multiculturalism and Inquiry-based approaches to instruction. I will explore the model for how knowledge is formed under Social Constructivist views and how this should affect our teaching strategies and classroom environments. I will further explore this topic by describing my collaborative work with an Aptos High School physics teacher, Joseph Manildi, in which we developed a curriculum unit motivated by this learning theory. By helping to teach and develop this unit on circuitry and by collecting feedback from students, I hoped to gain first-hand insight into the efficacy of teaching styles motivated by these understandings of how knowledge is formed. Through classroom observations, student interviews, formative student self-assessments, and traditional test results, I assessed the efficacy of my performance in the classroom and the value of this pedagogy in relation to other more common teacher-oriented styles. I used this experimental teaching to explore the benefits that constructivist teaching methodologies have for increasing access to science proficiency of English language learners who represent fifteen percent of Aptos High School's student body. I utilized these experiences to inform my literature research surrounding the role that constructivist pedagogies play in increasing the equity of opportunity for all students, particularly those who are not English proficient.

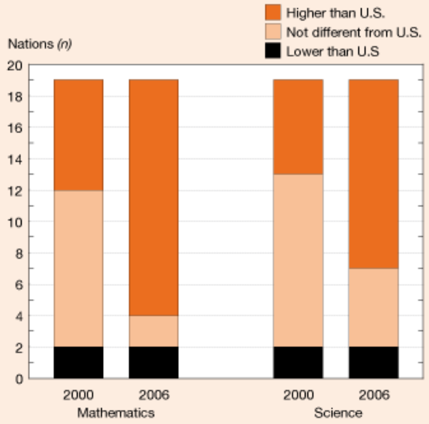
In chapter one I outline some of causes for our international decline in science literacy. I explore some of the challenges presented to teachers in the United States and outline a need for education reform in this country. In chapter two I explain how an understanding of Social Constructivism, multiculturalism and inquiry based strategies should inform pedagogies and determine the kind of learning environments that we create for our students. In chapter 3, I present how I implemented these strategies into a lesson plan designed with Mr. Manildi at Aptos High School with materials related to these lessons included in the Appendix. In the closing chapter, I reflect on my experiences designing and teaching the unit and the effect that this pedagogy had on improving understanding for all students, with special attention to the advantages that this style may have for English language learners.

Chapter 1: Science and math proficiency in the United States and how constructivist multicultural pedagogies can help.

What is at the root of our decline in international performance? What is it that is fundamentally different between us, and the countries advancing their international standing in science literacy? While an entire paper could be written on this question alone, one glaring difference is evident in comparing the educational systems of other leading countries such as Sweden, Japan and South Korea to the educational situation in the United States. I posit that this difference has strongly to do with the cultural demographics comprising students in these schools. In comparison with the countries mentioned above, the United States has a student body coming from extremely varied cultural, linguistic and socio-economic backgrounds. While diversity is certain to be found anywhere, the United States is in a uniquely challenging situation due to the magnitude of variance found in our students' backgrounds of all kinds. These cultural, social and economic differences directly impact the ways in which students understand the world, and unavoidably the ways in which teachers should alter instruction to meet students' so that pedagogy may be culturally relevant.

Between the year 2000 and 2006, the United States was surpassed by six more countries, dropping its international rank from sixth to twelfth in terms of an international assessment of student science achievement (NSF, 2010). Shown Below in figure 1a.

Figure 1-8
Changes in selected nations' performance on PISA assessments of 15-year-olds, relative to U.S. performance: 2000 and 2006



PISA = Program for International Student Assessment

NOTES: All comparisons refer to the number of selected nations scoring higher or lower than, or not statistically different from, the U.S. for the same test (among those participating in both years). The selected countries include Australia, Brazil, Canada, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Korea, Norway, Russian Federation, Spain, Sweden, Switzerland, and United Kingdom.

SOURCE: Baldi S, Jin Y, Skemer M, Green PJ, Herget D, Highlights From PISA 2006: Performance of U.S. 15-Year-Old Students in Science and Mathematics Literacy in an International Context, NCES 2008-016 (2007).

Science and Engineering Indicators 2010

Figure 1a, **National Science Foundation**

This fact should be alarming on a much more serious level than just a spirit of international competition. It not only marks a decline in the participation and importance of the United States in International cutting edge science in years to come but also makes a statement about the futures of students who are represented by this metric. The study of science and mathematics are not purely ends to themselves in the realm of education. Another study released by the National Science Foundation (Appendix 1b) reveals an extremely significant correlation between number of years spent in science and math classrooms at a high-school level and enrollment in a four-year college after graduation. According to this study, students who received credit for two or more years of advanced science showed a remarkable ninety-percent enrollment in four-year colleges, while students who took no advanced science courses at the high-school level showed only a twelve-percent enrollment in four year colleges (NSF, 2010).

Through this lens it can be seen that enrollment in these optional science and math courses is a gateway to financial and educational opportunities for many students. If we accept the correlation between math and science courses taken and college enrollment then we must recognize the importance of providing all students with the opportunity to take such classes, which for better or worse dictate large aspects of their academic, and ultimately financial, future.

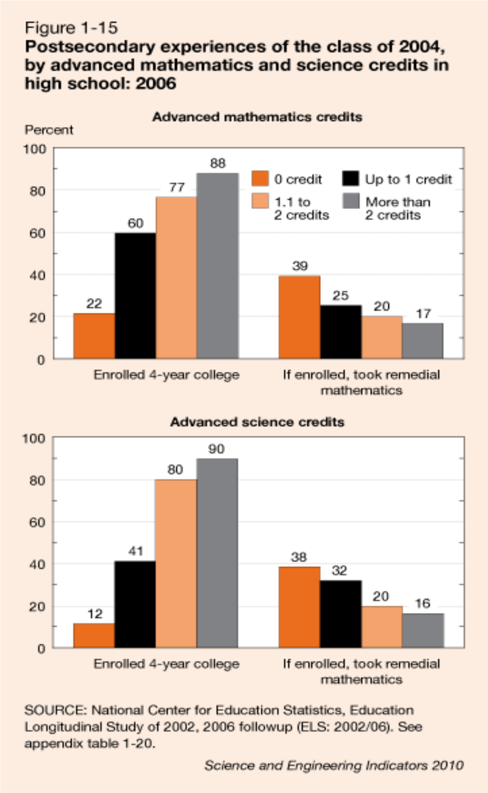


Figure 1-15
Postsecondary experiences of the class of 2004, by advanced mathematics and science credits in high school: 2006

Advanced mathematics credits

Advanced science credits

SOURCE: National Center for Education Statistics, Education Longitudinal Study of 2002, 2006 followup (ELS: 2002/06). See appendix table 1-20.

Science and Engineering Indicators 2010

Figure 2a, National Science Foundation

While this result is not new, it is commonly explained as a simple correlation, not as a causal relationship. The belief held by many policy makers today is that students who are already self-motivated and scholastically apt are the students who find themselves enrolled in these courses at the high school level. If this is true then it should be no surprise that these students are largely the same students who continue on to four-year colleges. However, an examination of the data shows that this is not the case. Jeannie Oakes and Rochelle Gutierrez have been researching the effects of tracking on primary and secondary school students. In Oakes' piece "The Distribution of Knowledge," a study involving twenty-five schools was performed analyzing what goes on in different track classrooms at the same grade level and specifically "what information students were being taught, how teachers carried out their instruction, what classroom relationships were like and how involved students seemed in the learning process" (Oakes, 1985). Across the board, students in lower-track classes are not exposed to the same rigorous content that students in higher-track classes come to expect. Virtually every study shows that poor, minority students are placed disproportionately into these low-track classes, it is always shown that poor, minority students are placed disproportionately into these classes. Why does this happen? There are many well accounted for causes, such as differences in student aptitude and familial involvement however these are primarily characteristics that the school has no real control over (Gutierrez, 2007). It seems obvious that there will always be some level of discrepancy between students' achievements. However, there are attributes of the learning process that the school does have control over, namely, what they expose their students to when they are at school (Oakes, 1985). I propose that minority students and students of lower socio-economic strata find themselves disproportionally represented in these lower tracks due to a lack of culturally-relevant pedagogy in the classroom, combined with a compounded lack of familial support stemming from previous generations' similar struggle in the educational system. Furthermore, students who are considered to be English Language Learners (ELL) are often automatically put into lower-track classes due to concern about their ability to comprehend higher-level content (Mosqueda, 2010).

According to Oakes, "Most of the curricular content of low-track classes was such that it would be likely to lock students into that track level (…) So, by omission of certain content from low-track classes, students in effect were denied the opportunity to learn material essential for mobility among track levels" (Oakes, 1985). As such, many current pedagogical styles are inadvertently sorting students for success based upon their cultural styles and once these students get placed into lower-track courses, there is effectively no way for them to overcome this disadvantage. If a student's likelihood of being enrolled into a four-year college is directly related to the amount of Math and Science education they received and that, in turn, is a direct function of the course track they are put on, then we are effectively condemning large cultural, and linguistic subsets of our population to failure through the public school system. This is a social justice issue that cannot be ignored.

In light of the profound effect that such early tracking can have on students in public education in the United States, we need to redesign our pedagogies so that instruction can be culturally relevant to and inclusive of all students. Furthermore, we must incorporate explicit language instruction into our mainstream teaching so that ELL students have an opportunity to gain access to these higher level courses during the time they are in public school.

In order to deal with this uniquely challenging situation we must utilize multicultural learning theories that are well informed by the latest psychological understandings of knowledge construction.

Chapter 2: Social Constructivism, multiculturalism and inquiry: How should they inform our pedagogies?

Today’s science classrooms provide a wide array of challenges for students. This chapter will focus on how Social Constructivism, Multiculturalism and Inquiry-based methodologies come together in a way that can be used to inform pedagogy and meet the needs of a wide variety of students. Not only must students grapple with challenging conceptual understandings, but they must also attempt to understand these concepts in a technical language that is essentially foreign to them. In this chapter, I will explore how the elucidation of language in science is crucial to scientific learning, and how the aforementioned conceptions of understanding can inform this endeavor. We will explore how careful attention to language also contributes to a student’s contextualization in the class room and learning environment and the effects this can have on student comprehension.

There has been much discussion surrounding the language challenges that mathematics and science classrooms face. A common term used by Social Constructivists is the “Zone of Proximal Development.” This zone is defined as the difference between what a student can achieve by his or her self, compared to what they can achieve with the help of a skilled peer or teacher. It is the belief of Social Constructivists that a large amount of growth and knowledge construction occurs as students explore this zone of potential ability. By designing lesson plans that focus on matching students of slightly varied, but overlapping, Zones of Proximal Development, an environment is created where students can grapple with challenging science concepts in a vernacular that is comfortable to them (Warren et al., 2001). Assuming we are not dealing with language minorities of one, this should allow students to discuss topics and wrestle with science at least in part without being constrained directly by the dominant language in the classroom. Not only do such lesson designs potentially create opportunities for ELL students, but also this format is a more realistic model of the post-academic scientific world in which collaboration and discussion are integral parts of science in business and industry. However simply encouraging group work is not a complete solution to this issue.

Although potentially more challenging to evaluate, assessing group activity or what a student can accomplish with help can lead to more meaningful “test” results than standardized written tests. Perhaps students’ ability to problem solve effectively in groups is a skill that would serve them more directly in the scientific world than the ability to pass standardized tests. What would a social constructivist group examination look like? Is this kind of testing implementable only in the classroom or as a form of state testing in the sciences as well?

It is crucial that we provide students with learning environments that promote equity. If we do not see to it that language minority students are able to succeed in science classrooms we are severely limiting the number and quality of careers available to these students (Spurlin, 1995). According to Spurlin, language-minority students experience very high levels of stress and anxiety in formal language-based science classrooms that can interfere with learning. However, “Environments in which the focus is on understanding of concepts and the meaning of communicative acts rather than on correct language use,” will allow students to learn more easily (Spurlin, 1995).

The process of learning science involves many components. Critical thinking, abstraction, mathematics and language all play crucial roles in making sense of the science that students are exposed to in classrooms. The need to address formal science language in the classroom is real, as this technical jargon is ultimately required for performing science at a collegiate level. However, a primary focus on formal science language can be extremely alienating for a large subset of students. Allowing students to discuss scientific topics in “everyday sense-making” terms can be extremely beneficial for students (Warren et al., 2001). We must rethink the way we analyze students’ own representations and constructions of science knowledge and realize that there are other equally valid ways to understand and discuss science topics in a meaningful way. According to Warren et al. (2001), students using non-English primary languages to discuss science can be viewed as not having a deep understanding of the material, just due to the lack of formality in their speech. We must begin to understand the importance of allowing students to use any form of “sense-making” that will allow them to learn, no matter how it is packaged.

While it is crucial for us to allow students to use their own languages of sense making, we must also create a space in the curriculum for direct vocabulary instruction. Academic language has no context without shared meaning or shared experience between communicators (Marzano, 2003). Thus, if we are to use vocabulary in our science teaching we must scaffold understanding of this science vocabulary in a variety of ways. Students must be exposed to any given vocabulary term more than once, and the first time students encounter a vocabulary word, the focus of learning should be to elucidate its meaning, not to promote understanding of another topic. According to Marzano (2003), students who received prior instruction on vocabulary words before encountering them in context, exhibited one-third more achievement in understanding than students who had not previously been exposed to the language. Providing students with a sheet of definitions and tying those definitions into other representations through imagery or analogy can greatly increase the effectiveness and comprehension of communication in the science classroom (Marzano, 2003).

What is the role of Social Constructivism, group work, and the Zone of Proximal Development, in both increasing literacy in science classrooms and providing ways for students to discuss science in their own terms? In addition to the outlined suggestions, there are many other holistic views we can take and strategies we can employ in the classroom (Marzano, 2003; Warren, 2001). Atwater (1996) outlines the importance for students to work in groups where student to student interaction can generate meaningful conversation. Constructivism itself is considered to be an epistemology, or exploration on the nature of knowledge. The origin of the term constructivist comes from the belief that the function of knowledge is to "organize the experiential world". Under this viewpoint, the teaching and understanding of science "has to do with the students and the teacher seeing and coming to see in certain ways" (Atwater, 1996). The understanding of the social constructivist is that these ways in which students and teachers "come to see" as Atwater puts it, are heavily influenced by social interactions that ultimately define "the construction of self" (Atwater, 1996). Social constructivists believe that the process of assigning meaning to language is a completely socially interdependent process in which members of a social group rely on each other to hold a shared meaning. This notion strongly challenges a traditional conception of science as many scientists themselves see it today, showing it not as "objective and revealed" but rather as something malleable and socially constructed (Millar and Driver, 1987).

It should be no surprise, based on this Social Constructivist conception of the very nature of knowledge, that group work should play an integral role in the classroom. If students negotiate meaning and construct knowledge through a social process, then we must create an environment that allows for that social process to take place. A traditional teacher-centered, lecture-based pedagogy does not provide an adequate environment for knowledge to be constructed for students from a variety of cultural backgrounds. According to Yackel et al. (1990), mathematical knowledge cannot simply be given to students. Rather, he proposes that students, "develop mathematical concepts as they engage in mathematical activity, including trying to make sense of methods and explanations they see or hear from others" (Yackel et al., 1990). Constructivists view the learning of math and science as a creative problem solving activity. By pairing students up with other students of overlapping Zones of Proximal Development, we encourage the social process of knowledge construction to occur. Under this consideration of knowledge, through creating opportunities for small group work, we are not only training students in good science knowledge, but also training them in how to be effective scientific investigators.

When learners participate in group work and take place in genuine communicative interactions such as hypothesizing, explaining or justifying, purposeful language is promoted (Stoddart et al., 2010). Research into effective pedagogy for English language learners has demonstrated that group work increases content understanding and language development. Stoddart claims that the relationship between learning language and learning science is "reciprocal and synergistic." More importantly, working in groups provides ELL students with an authentic chance to use their own language in a social context (Stoddart et al., 2010). As students work together with the supervision and facilitation of the instructor, all students are able to participate "at a level appropriate to their language development" (Stoddart et al., 2010). However, simply arranging students into groups will not immediately solve challenges presented to English language learners. Teachers must offer resources and strategies for ELL students and ensure that English-proficient students are also informed on how to be productive and helpful for students with a primary language different from English. When the right conditions are in place, it is possible for science learning to be the collaborative and engaging process that it should be (Stoddart et al., 2010).

The goal of epistemology, or the study of the nature of knowledge, is to better understand how we, as humans, know. We can then use this information to inform our pedagogies and classroom environments in order to produce real learning and knowledge construction. We have discussed the need for a delicate consideration of the roles of both formal and informal science language in the classroom and the challenges that these issues present to all students, especially English language learners (Marzano, 2003; Spurlin 1995; Warren et al 2001).

Through our understanding of the Social Constructivist viewpoint, we know that meaning is constructed collaboratively through a shared social structure and that these meanings can only be formed and negotiated through means of effective communication, further highlighting the crucial role of language in science education (Atwater, 1996; Millar and Driver, 1987). I have explored how group work can become a critical component in ensuring both the efficacy and equity of science classrooms by allowing students to communicate effectively and engage in the social discourse of knowledge construction. By building on prior knowledge and utilizing the linguistic resource of other students in the class, teachers can begin to scaffold some portion of the vocabulary challenges presented in science. Through matching students with peers of overlapping Zones of Proximal Development in both science and language we can begin to take steps to ensure that students are equipped with the linguistic and scientific knowledge needed, not only to pass a science class, but ultimately to succeed in pursuing a scientific career should they so choose (Yackel et al., 1990; Stoddart et al., 2010; Spurlin, 1995).

Several pedagogical styles are being developed and tested in this context. The first style I would like to explore is Inquiry-based teaching. Although this pedagogy can find its roots in the work of thinkers such as Piaget, Vygotsky, and Freire, educational theorists such as John Dewey and Martin Wagenschein are credited with its formalization and implementation. While it is a broad field, all Inquiry-based science teaching relies on the innate curiosity of students and is a process by which students engage in genuine explorations of unscripted experiments. This contrasts with more conventional classroom experimental dynamics in which students often know the expected outcome of a lab and are merely confirming its truth. While there are many variations and gradations of Inquiry-based teaching, it is common for the student to have a large amount of autonomy in deciding exactly what is to be studied. While teachers engaging in this pedagogy do have clear learning goals for their students, the idea is to simply facilitate the student's own, first hand discovery of what is to be learned (Dewey, 1938). As such, under this pedagogy, the role of the teacher is no longer to be the transmitter of knowledge but instead the facilitator of knowledge generation for his students. As we give students the autonomy to design experiments relevant to their own curiosity and understanding we are creating a classroom environment where students have the space to engage in a culturally relevant exploration. Additionally, this process of open learning empowers students to realize that they are capable of engaging in genuine scientific thought and exploration, not just the pre-canned recitations of laboratory experiments with well-established outcomes.

The second, more specific strategy I would like to explore is the ESTELL pedagogy, currently in development at UCSC with funding from the National Science Foundation by researchers Trish Stoddart and Eduardo Mosqueda. ESTELL stands for Effective Science Teaching for English Language Learners and is designed to meet the needs of ELL students through simultaneous instruction of content and language. In many ways this pedagogy is the culmination and product of years of research into meeting the needs of ELL students. These standards for teaching ELL students center around six key instructional practices that are beneficial to all students. These practices are collaborative inquiry, science talk, language and literacy in science, scaffolding English language development, contextualizing science activity, and developing scientific understanding (Stoddart, 2011). In many ways this pedagogy is a collection and condensation of all of the research that has been discussed here and it was extremely useful as I endeavored to design my own unit.

Learning science can and should be a wonderful and explorative process that taps into our curiosity, one of the most truly human conditions. Modern American pedagogies do not consider the social and cultural background of many students, which ultimately leads to an environment in which students either do not feel safe or are not equipped with the necessary tools to explore their scientific curiosity. Through encouraging group work and student-driven curricula, as opposed to teacher-based lecture methodologies, we can make our classrooms pleasant, effective and pillars for social justice.

Chapter 3: My experiences developing and teaching a lesson plan implementing these viewpoints.

I designed a curriculum unit on circuits in collaboration with two teachers at Aptos High School, Joseph Manildi, a Physics and AP Physics teacher, and Douglas DeMouth, an Integrated Science and Earth and Space Sciences teacher. Our goal in the design of this curriculum unit was not merely to develop a set of lessons that would be effective for teaching students, but also to develop a unit capable of testing claims made by modern Social Constructivists and other educational theorists. The goal of this collaboration was to create a lesson that adhered directly to the model for inquiry-based teaching set forth in current and relevant research literature. Additionally, we designed our lessons with a psychological conception of the student that is consistent with modern Sociocultural Learning theory.

The unit was taught in Mr. Manildi’s Aptos High School physics classroom. Aptos High School is a part of the Pajaro Valley Unified School District and has thirty-five percent ELL students. The specific subset of the Aptos High School Population we were interacting with was Mr. Manildi’s 3rd, 4th, 5th, and 6th period Regular Physics classes. However, only fifteen percent of Mr. Manildi’s predominately college bound, tenth and eleventh grade, students are considered to be some gradation of ELL.

Before explaining the specific content and implementation of the lessons, I will give a brief overview of the ideas we used for our units’ design. Everything in this unit is supposed to be motivated by the student and their own natural curiosity, or as the ESTELL pedagogy puts it, “collaborative inquiry.” Our idea was to create a space in which students could genuinely explore circuits without being constrained by immediate expectations, or the need to comprehend the subject in a formal language before exploration could begin. Once this space was created, we used questions generated by students as the springboard for instruction going forward. Instead of taking a teacher-centered approach to instruction and designing labs for students, we turned the questions they generated during exploration back, asking students to design and perform a lab suitable to answering the question that they were interested in exploring. Finally, students' diverse lab experiences were shared back with the class as student groups took turns assuming the role of the teacher and sharing the knowledge they generated. This design hopes that as students generate their own knowledge through unique explorations, instead of in lecture format from the instructor, they will assume a sense of ownership of what they learned. Furthermore students will not only be learning the physics of circuits but will also be actively engaged in a process of experimental design and scientific discovery that is crucial to success in real world science. Finally we hope students will find this experience empowering as they discover that they possess the tools needed to answer their own scientific questions.

While Mr. Manilidi, Mr. DeMouth and I spent a significant amount of time in the classroom, the majority of the lessons were led by Mr. Manildi, the experienced physics instructor. Mr. DeMouth was only able to be present and assisting in the classroom during prep time and during the 6th period course, as that was the only period where he did not have a class of his own to teach. I was present in the classroom for a majority of the lessons, although I was not able to be present for two days during the two weeks that this unit was taught due to scheduling problems. Additionally, Mr. Manildi's 4th period class was taught by his student teacher, Mr. Moos, who was a student in UCSC's Masters in Education program at the time. Despite these lessons being taught by a variety of instructors period to period, there were almost always at least two educators present in the classroom at any given time and a constant dialogue of collaboration between the instructors throughout the unit.

At the end of the unit all students took an online survey, which asked them to reflect upon their motivations and experiences with different teaching strategies throughout the course of this unit.

Lesson One:

Drawing from the literature research, and the arguments made by Stoddart and Spurlin, our first lesson was designed to set the stage for an entirely inquiry-based curriculum unit (Stoddart, 2010; Spurlin, 1995). Inquiry-based teaching as defined before is instruction where students' own questioning lays the framework for what is to be learned and how. This process is very directly related to Atwater's model of knowledge construction found in the Social Constructivist mindset and described in chapter two. A complete list of materials needed for the execution of lessons one and two can be found in the appendix item 3b.

As students came into the classroom on the first day of the unit we asked them to get into their preformed lab groups and rotate through a variety of lab stations around the classroom containing various circuit configurations. Students were asked to read preliminary sections of the class textbook for homework the previous night and had just completed an entire unit on static electricity. So while they should have had some formal knowledge related to the lab stations, in reality this was a first exposure to circuits inside the classroom, and for many a completely fresh exposure to circuits all together.

The ultimate goal of the first day was for students to freely explore these lab stations, culminating in a compilation of questions that was generated by each group by the end of the period. Each lab station had a guideline sheet of “Things to try” and “Things to notice”. Beyond a note to pay attention to these sheets, students had no explicit instruction other than to explore these stations and write down questions that arose for them during this exploration. All of the lab stations’ circuits included light bulbs, which served as an intuitive indicator to students that something in the circuit is changing as the brightness of the bulbs changed.

For this lesson four different lab stations were generated in duplicate for a total of eight lab set ups. The lab stations are described below.

1) Was a simple series circuit in which students were asked to add and remove light bulbs. While one cannot ensure exactly what a student will take away from such an exploration, each type of lab set up was aimed at evoking some basic principle crucial to elementary circuits and Ohm’s Law. We hoped students would notice that the number of bulbs in the circuit directly affects the average brightness, and that with the removal of a light bulb in the series, the circuit will not light at all. Supplies: Board-mounted series circuit using any appropriately resistive wire connecting three small light bulb sockets. Appropriate voltage source, usually a 9-volt battery and at least three light bulbs.

2) Also a series circuit including one light bulb. At this station students were able to manipulate an alligator clip that was connected to a very long thin resistive wire. This station was aimed at provoking questions related to resistivity of the wire. The students’ main tool for observing this phenomenon was simply the brightness of the bulb. While this is the latent concept that we expect students to become curious about, it is important to note that such terms as resistivity and current are most likely not yet in the vocabulary of students. Each station was designed in a way that allows students to superficially explore these circuit properties in a way

that would raise questions for them, and spark their interest which ultimately will be drawn on in later lessons in the unit. Supplies: Board-mounted series circuit including low resistance wiring and one small light bulb socket. A long, thin resistive wire connected to the rest of the circuit by alligator clip which students can easily manipulate, altering the length of wire included in the circuit. Appropriate voltage source, usually a 9-volt battery and at least one light bulb.

3) Students interact with a battery, light bulb, and single wire. The goal of this "challenge" was for students to light up the bulb using only these materials. The aim of this lab was to get students to begin to explore the nature of positive and negative terminals. No board-mounting is required for this lab. Supplies: Simply provide one C battery, one light bulb, and one appropriately long length of wire, perhaps 1 ft. in length for each station.

4) Was a simple parallel circuit equipped with light bulbs structurally similar to its series counterpart mentioned as the first lab station. "Things to try" for this station were similar to the basic series circuit, however, we hoped students would notice that the light bulbs respond differently to the removal of a bulb than in the series set up. In this setup students were intended to notice that the circuit would still run if one bulb was removed, even without rewiring, and that the change in brightness of the bulbs functions in a different way than in the series circuit. Supplies: Board-mounted parallel circuit using any appropriately resistive wire connecting three small light bulb sockets in parallel, one socket in each parallel branch. Appropriate voltage source, usually a 9-volt battery and at least three light bulbs.

Our most basic expectation for all experiments was the generation of questions. These questions were then submitted as a group to the teacher before leaving class and will serve going forward as the motivation for the rest of the unit. Whatever questions students generate, the hope is that these questions will serve as an honest and culturally relevant investigation for them going forward. A list of the student questions can be found in the Appendix item 3a.

Lesson Two:

When students returned to class the next day, they were given a compilation of all questions generated by their class during the previous days' inquiry and were asked to select three questions from the class list that they would be interested in exploring. These students' choices were eventually used to sort students into well-balanced groups based upon their interests. The goal of this lesson was to begin to formalize some of the vocabulary and diagramming in the field by building on students' prior knowledge and explorations performed on the previous day. This scaffolding was crucial to the students' ability to design and perform their own experiments in a sophisticated way.

At this point I facilitated students' group work at the stations. Each lab station contained one circuit, parallel or series, as well as a whiteboard and marker. We began by asking students in the group to draw a simple sketch in their lab books of their circuit as they see it. After they had outlined their drawing, we passed out a sheet (Appendix item 3b) that introduced three basic vocabulary terms, *resistance, current* and *voltage*. The handout explained the role of these items in the circuit and which elements of the circuit represented the items on the list. Additionally, the vocabulary terms *resistor* and *voltage source* were paired with the symbol that represents them in formal circuit diagrams.

After students had some time to look over and discuss these two new terms, we asked them to re-sketch the circuit in their notebook, now replacing the light bulbs in their sketch with the symbol for a resistor and the batteries with the symbol for a voltage source, using only plain lines to represent the connective wires. In this way students could readily make the jump from intuitive sketching to formal circuit diagramming.

As students worked together to reconfigure their circuit diagrams, we asked them to come to a consensus within their group members about an appropriate way to diagram their circuit. Once a consensus had been reached we asked each group to do a formal sketch of their circuit on the white board. We then had students compare and contrast their circuit diagram with another group sharing their same circuit configuration (either series or parallel). Once students had time to debate and discuss the differences in their diagrams with a similar group we asked them to pair with another classroom group who was at a station with a different type of circuit. Here students were asked to take turns instructing the other group on the way they diagrammed their circuit using the illustrations they had made on their whiteboards. We asked students to pay special attention to the use of vocabulary and an elucidation of the differences between the two types of circuit configurations. By allowing students to discuss these vocabulary terms in a group after they have been contextualized through exploration, we hoped to bridge the gap between their everyday understanding and formal understanding of the concepts of resistors and voltage sources. In any remaining time we began to introduce the use of voltmeters and ammeters to prepare students for their experiments.

This lesson was heavily based upon ESTELL framework practices such as “science talk” or engaging students in sustained discussion of science topics and explanations of scientific reasoning and argumentation. This lesson also promotes language and literacy in science as well as the scaffolding of English language development (ESTELL, 2011).

Lesson Three:

Class began by assigning students into groups, selected by the teacher, based upon the questions that students chose to investigate from the class list. While this was not initially part of the plan, a review of the questions generated by students called for a short discussion of what constitutes a “testable” question. Even when a question was not “testable” in the scientific sense, students were still allowed to be grouped under such a question. They were asked to rework their questions into something that could be tested directly, which while confusing for many at first, ultimately resulted in a very relevant dialogue. After students had pinned down their question of interest, the rest of the period was dedicated to experimental design, group collaboration and planning. At this point the classroom took on a much more intimate small group feel. With the benefit of having three educators in the classroom and only seven to eight lab groups, most groups were able to receive facilitation or guidance from an instructor as needed.

At this high school level, the planning of the experiment is in some sense more important at a high school level than its execution. This focus on developing scientific understanding, is not only an important tool for students to be able to manipulate later in life, but is also the component of learning in science that has the most potential to inspire and motivate students. Although challenging and relatively open ended compared to most high school science activities, this is a crucial element of the unit, as it simultaneously allows students to explore an object of their interest and have a serious engagement with the scientific process and how to be good scientists. While the role of the facilitators is very important in this situation, and would potentially be challenging with only one teacher present, it is critical that the students ultimately come up with the basic idea for their experiment on their own. To assist students directly with this task is to rob them of the essence of inquiry and ownership that is necessary for the success of the lesson.

The students were asked to submit a general experimental plan and a data table suitable for the exploration of their question to be approved by the teacher. We asked that students make measurements of at least two physical properties of the circuit, current, resistance and voltage along with any other relevant measurements such as the thickness of the wire they used or the temperature of their circuit. The primary role of the facilitators in this lesson is to aid in the construction of these more formal aspects of experimental design and to ensure that groups' questions are, indeed, testable.

Lesson Four and beyond:

The next lesson began with a brief introduction to Ohm's law. While in many cases, the end result of the experiments is the students' discovery of Ohm's law for themselves, it was important to cursorily introduce the topic to students, so they would have a way to measure resistivity given voltage and current. After this brief introduction, students began to perform their experiments over a period of two to three days. The facilitators engaged students in "Science Talk" as groups discussed their scientific reasoning and the logic behind their experimental design and methodology. This time frame served primarily as "group independent study" as each group in a period was likely to have a very different experiment from other students, at least on the surface. While there was almost no formal instruction during this time period, the facilitators were involved in aiding the groups with the use of Ammeters and Voltmeters, as well as aspects of some of the experiments that were not necessarily safe for students to perform on their own. An example of this situation is measuring the temperature dependence of resistivity for a hollow copper tube. Wide variations in temperature were achieved by running ice water and boiling water through the tubes before performing measurements.

Ultimately, as students completed their experiments, they also began to prepare to present their findings to the class in a poster presentation. The posters had to include circuit diagrams, data tables, graphical analysis and an answer to their proposed question, or at least an explanation of why their experiment was not able to answer the question and how they would redesign the experiment in the future. In this way students were generating their own knowledge and were in the role of intellectual authority. During the presentations we promoted active questioning of the conclusions drawn by students. In cases where an experiment was inconclusive, we will simply asked students to reflect on how the experiment could be made more effective next time. It was not important that a student's experiment was a success, but that the students could reflect realistically upon how and why the experiment did or did not work.

At this time in the unit, students were given a survey and formative self-assessment sheet. The student's own reflection on what grade they felt they deserved influenced the grade they received for participation in the experimental design and execution phase of the unit. Additionally we asked students to outline what they felt they did and did not learn during their own process of exploration and peer instruction post facto. This information was particularly important in designing the last few days of instruction before the exam, as we learned what students still needed more direct formal instruction on.

My experiences designing and implementing these lessons were very powerful. I was able to watch as students who had remained largely disinterested throughout the earlier portions of the course slowly became engaged. Even students who were not enthusiastic during the process of developing and performing the experiments seemed unable to avoid gaining understanding and even enjoyment out of the process as we facilitated the experiments. While I knew that such a lesson had the power to motivate and inspire a large number of students, I was not as sure that students would all gain the same kind of knowledge in a sense that would prepare them for the examination. However, the beauty of having an inquiry-based assignment is that no matter what experiments students came up with, they all ultimately came to the same conclusions about the relationships between current, voltage and resistance. They arrived at this knowledge through the vehicle of their own innate curiosity. They not only answered their own question, but more importantly, they were empowered with the knowledge that they are capable of being scientists and actively pursuing any sort of further knowledge they want to attain. Although trusting students to perform the complex tasks asked of them in this unit without traditional teacher-centered methodologies was at first troubling, providing them with this trust and space was an entirely necessary step toward experiencing engagement and ownership in their learning.

Chapter 4: Reflection and Results

The design and implementation of this lesson has been very rewarding in my preparation to become a teacher. However, with my academic background in physical sciences, I found such an open-ended experiment as this case study to be problematic from the start in terms of gleaning conclusive results about my theories. Most research studies in the field involve a much wider range of classrooms and schools over a period of many years. However, given the data at my disposal and my intimate involvement with the lesson, and student groups as we progressed, I feel as if it is still appropriate to make some inferences from this experience.

In the time I spent teaching and observing these lessons it was obvious to me that there is a vast amount of curiosity in even the most seemingly disinterested students that can be evoked through careful lesson design and classroom structure. I had the privilege of observing students who in the past have seemed disinterested suddenly assume a different classroom attitude as the traditional role of the teacher and intellectual authority gradually shifted away from the instructors. As students began to come up with the questions they wanted to research I was pleasantly surprised. Even before students were given the formal language tools necessary to describe all aspects of circuitry thoroughly they were able to propose excellent questions such as "Does the thickness of the wire affect the brightness of the bulb?," "Why is the brightness in the bulb lost as we move the alligator clip farther down the wire?" and even some questions as remarkable as "What is the temperature dependence of the resistivity of the wires?". While these questions may seem relatively mundane and the sorts of questions an instructor himself might choose as he designed an experiment for his class, I believe that as students themselves are placed, to some extent, in control of their education and are given an active role in terms of what is to be learned and how, long-reaching impacts on their confidence and mental presence at school are achieved. Being able to change a student's attitude towards learning is perhaps the best gift an educator can impart to his students as this will serve them for the rest of their life.

Regrettably, this shift in attitudes is not something that can be observed based upon the results of one physics test. I believe that the potential of this pedagogy lies in redefining student attitudes towards school, learning and self-confidence. As students feel more empowered and in control of their learning experience, they become less focused on the grade and more on learning.

Furthermore, introducing this style of inquiry to students is something best done over a long period of time. Many students are so conditioned by the "drill and kill" mentality that can be found in most traditional classrooms, that they are uneasy with the shift in intellectual authority that occurs during inquiry-based learning. While I believe the lesson was ultimately well received by a vast majority of students, those students who had become adept and accustomed to cut and dry assignments with distinct right answers commented on the "confusing" nature of this assignment. Those students who had mastered success under this other regime and had learned to guarantee themselves good grades through this methodology seemed at first, uneasy with this shift in the way the classroom worked. Ironically, it was the "best" students as the grades would suggest that seemed to have the most issues with the way this unit was being introduced, while many students that struggled in a more traditional setting seemed to thrive. I do not think this suggests that this learning style is not suitable to educate these more traditionally successful students, merely that the way we condition our students to work and think have long reaching impacts on how they behave in academic settings going forward. In other words inquiry is not something that can occur once, during one unit, in one class. As such, I think the merits of inquiry based teaching are not something ultimately observable in the short term by way of one set of quantitative test results.

The average of the examination across the four periods of regular physics was 72%. These scores are slightly below the average test scores that Mr. Manildi sees in his classes, however, not remarkably different. Unfortunately, there is no benchmark for comparison, as all of the classes were exposed to the inquiry instruction on the basis of fairness. While I attempted to compare these scores to last year's examination on the same topic, this information was not attainable, and again, would not have even been a direct or necessarily meaningful comparison. Despite this set back, we did attain some useful quantitative from the survey submitted to all students who took part in the lesson. Displayed in appendix 4a and 4b are graphical representations of responses to the survey administered after the unit. These graphs in particular display which components of teaching students felt they learned best from. For the purpose of this investigation, the chart shown in figure 4a represents the responses of those students who did not have English as their primary language, while figure 4b includes the responses of the class as a whole. 65% percent of students with a primary language other than English reported that they learn "very well" or "best" from activities that involve choice while 57.5% of students with English as their first language report the same. An analysis of the survey suggests that many students, both ELL students and English as a primary language students alike, feel comfortable with more formal styles of instruction such as powerpoints, lectures, and worksheets. I would suggest that this level of familiarity and comfort is more indicative of the types of learning that students have been exposed to in the past than what students are potentially able to learn through inquiry approaches.

Also included in the survey results section at the end of the chapter is information about student motivation during the lesson, at school in general, and towards education in the future. When relevant, this data is presented both in its entirety and juxtaposed with the responses from students who are not native English speakers or where English is not the primary language spoken at home. While interesting, I feel many of the questions asked were not pointed enough to ascertain how well students learned during inquiry.

I performed brief interviews with five randomly selected students out of the pool of ELL students, and three selected randomly out of the pool of students who spoke English as their first language. I asked them to reflect on their attitudes towards and experiences with the lesson. The ELL students, Student 1 and Student 2, both Juniors, reported that they felt Physics as a subject was “pretty cool,” while being a lot of work.

When I asked them to reflect on the differences between the unit on circuits and other units that had been taught in Mr. Manildi’s class, I received different responses. Student 1 stated that he noticed big differences “in the way information was given”, and the kind of environment in the classroom. For example, how he received “help from other students” and that he was able to address “questions that came up” very readily in this setting. He liked exploring his curiosity and learning what other students knew. For Student 2, on the other hand, the unit seemed like a regular lesson, and he felt that learning vocabulary in this setting was still a huge challenge for him and that he still needed to ask Mr. Manildi for additional help, often seeming to contrast the experience of Student 1.

In interviewing Student 3, a Junior with English as her first language I began to see a theme that I did not expect prior to the lesson design. She reflected that while the lessons seemed similar to others in the class, she noticed a few important differences. Her and her classmates often “just search for answers to complete the assignment as quickly as possible” and that this unit was “harder than normal”, because she actually had to spend time carefully considering what she was studying. Despite her familiarity with more traditional lecture and worksheet based teaching, when asked what blend of traditional and inquiry strategies she would like to see in the future she reported that “Half and half” would probably be good, but she felt she needed more time working on the mathematics of the equations than the comprehension of the subject.

Student 4, a sophomore with English as his first language, also reported that he noticed the lesson was “a little different” in that he “took more questions” and that this strategy “got the groups more involved”. He found this teaching strategy to be “Cool, but kind of challenging” and when asked if he would like to see this strategy more often in his classes he reported that he would only like to see it “every now and then.” When asked how this unit prepared him for the exam, he said he thought “it did ok” but that the test was also more challenging than most he is exposed to in Mr. Manildi’s class.

Student 5, a Sophomore with English as her first language, noted that this unit was “a little different” in that the class “spent more time on everything”. When asked if this lesson prepared her well for the exam, she said “It did, but it didn’t” she then elaborated to say that she understood the content on a deeper level, but felt that this came at the expense of spending less time on equations and practicing the mathematics which ultimately made the exam more difficult.

In conclusion, there are no definitive results for this study. If I were to perform it again, it would be important to include a far wider variety of students. Additionally, I would revise the survey questions so that they would be more pointed towards gathering relevant information. Although, students answered a wide array of questions about their motivation during different parts of the lesson and what they felt they learned best from, the phrasing of these questions and the survey answers available to them were perhaps not adequate to assess the outcome of the lesson. While students had a variety of reactions to this lesson, nearly all students reported increased engagement in a deep conceptual understanding of the content, however often at the expense of comfort with the mathematics and equations used in the topic. Students who seem disinterested or unsuccessful in more traditional classroom settings seemed to blossom in this learning environment. A classroom focused on equity of opportunity should include a variety of teaching styles to accommodate all students.

While this lesson was created with equity for all students in mind, I feel it is important to note that to some extent, it is too late by the time students are juniors in High School. Indeed, it is important that we make our advanced science and mathematics classrooms cater to the cultural and linguistic needs of all students, but this kind of consideration is one that must be made at even earlier levels of public education. Due to the long reaching impact of tracking for ELL students, many were never truly given an opportunity to even be exposed to Mr. Manildi’s Physics class.

For those students who were able to be exposed to Mr. Manildi’s class, the test results were not particularly encouraging in this instance. However, in reflection with Mr. Manildi and Mr. DeMouth, one obvious advantage that this teaching style has over more traditional teacher centered methodologies is its ability to allow students to practice real scientific experimentation and design from start to finish. This ability, while one of the most important things to take away from a secondary science education, is not something that is tested for specifically on any content-oriented examination. While in my own educational experiences, this kind of assessment was reserved for upper division college level physics labs, I believe this skill is one of the most generalizable aspects of science that is exceedingly useful, even for those students who do not wish to pursue science or mathematics in the future. By taking science knowledge as something that is seemingly arcane, and transmitted as true from teacher to student and transforming it into something that is open to debate, constructed through logical discourse and readily accessible to all students in terms of their own experiences with the world, we empower students to carry this sort of methodology into other aspects of their lives. Finally, I hope that regardless of the ultimate acceptance or rejection of these current theories pertaining to strategies of equity of opportunity in education, that these fields of research remain funded and active until we see a day in which all students can be exposed to the same, content-rich, culturally-relevant pedagogy.

Survey Results

Figure 4a. Student Responses for non-native English speakers–Survey Results

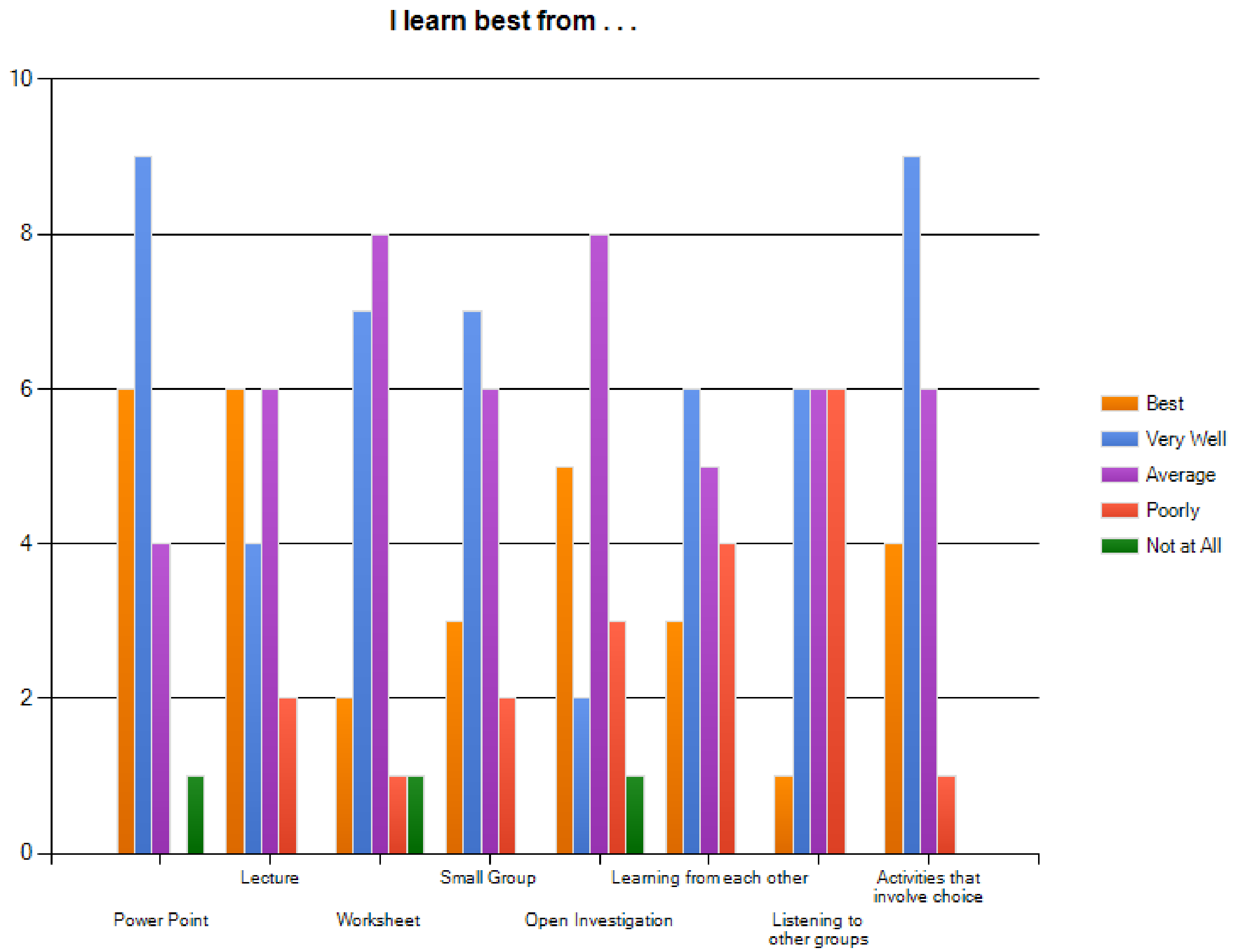


Figure 4b. All Students – Survey results

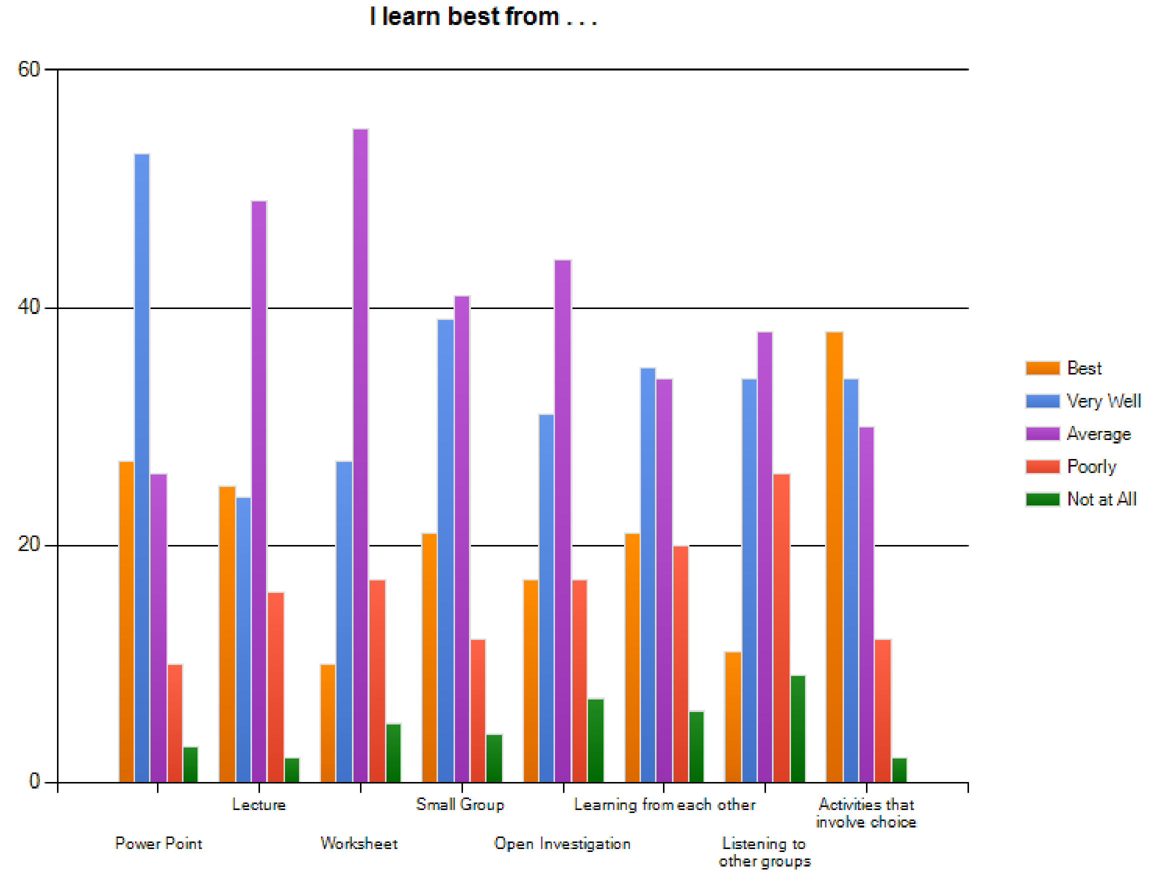


Figure 4c.

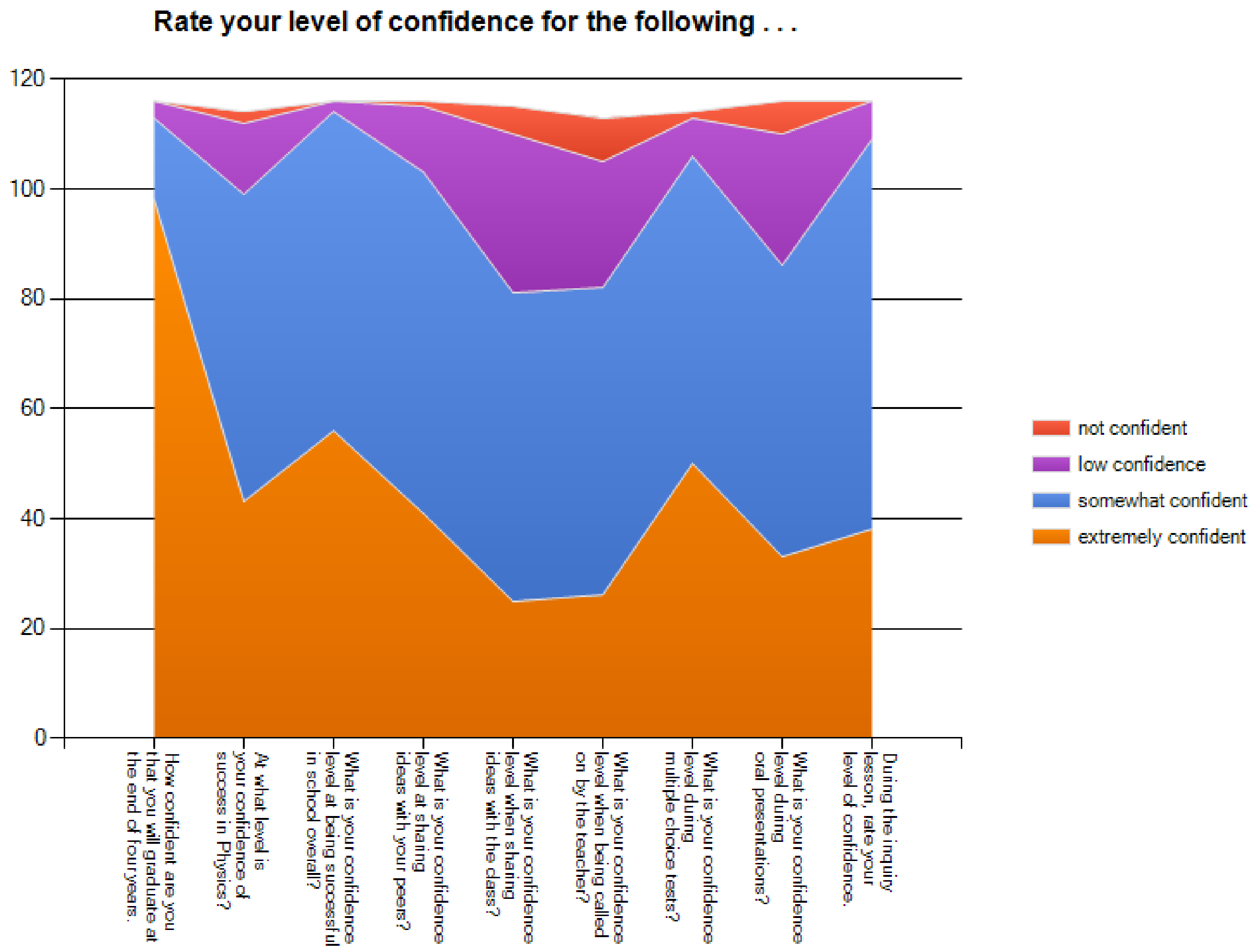

Rate your level of confidence for the following . . .
120
100
80
60
40
20
0
not confident
low confidence
somewhat confident
extremely confident
How confident are you that you will graduate at the end of four years.
At what level is your confidence of success in Physics?
What is your confidence level at being successful in school overall?
What is your confidence level at sharing ideas with your peers?
What is your confidence level when sharing ideas with the class?
What is your confidence level when being called on by the teacher?
What is your confidence level during multiple choice tests?
What is your confidence level during oral presentations?
During the inquiry lesson, rate your level of confidence.

Figure 4d.

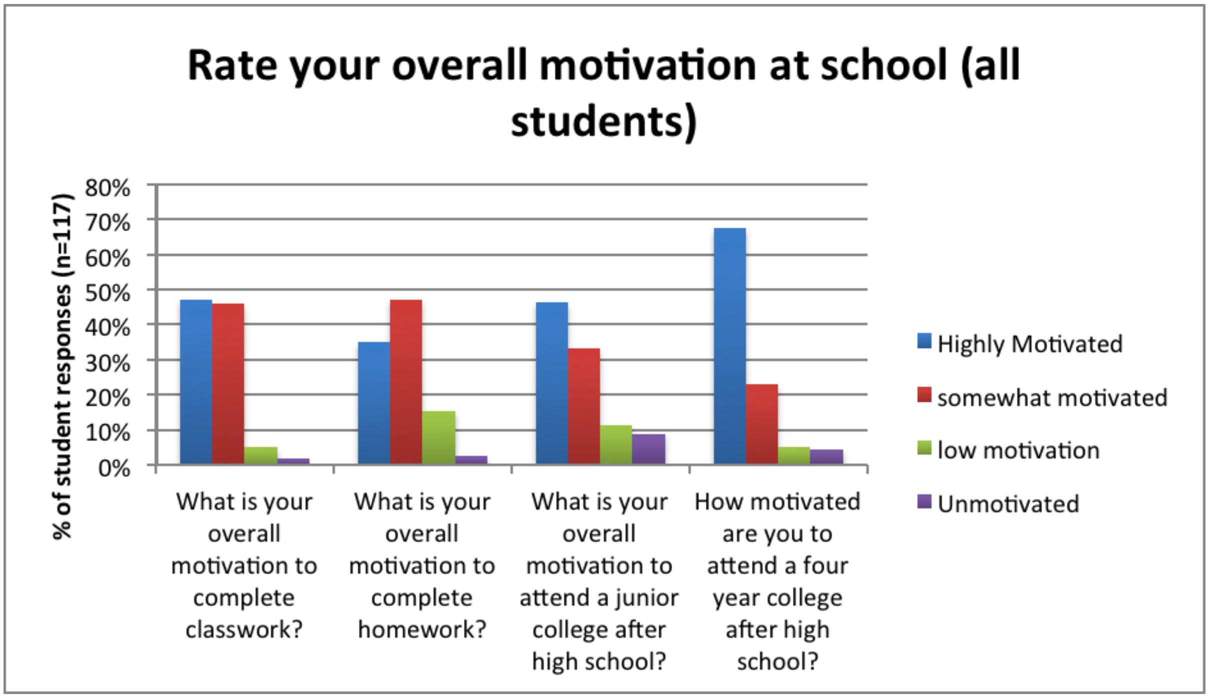
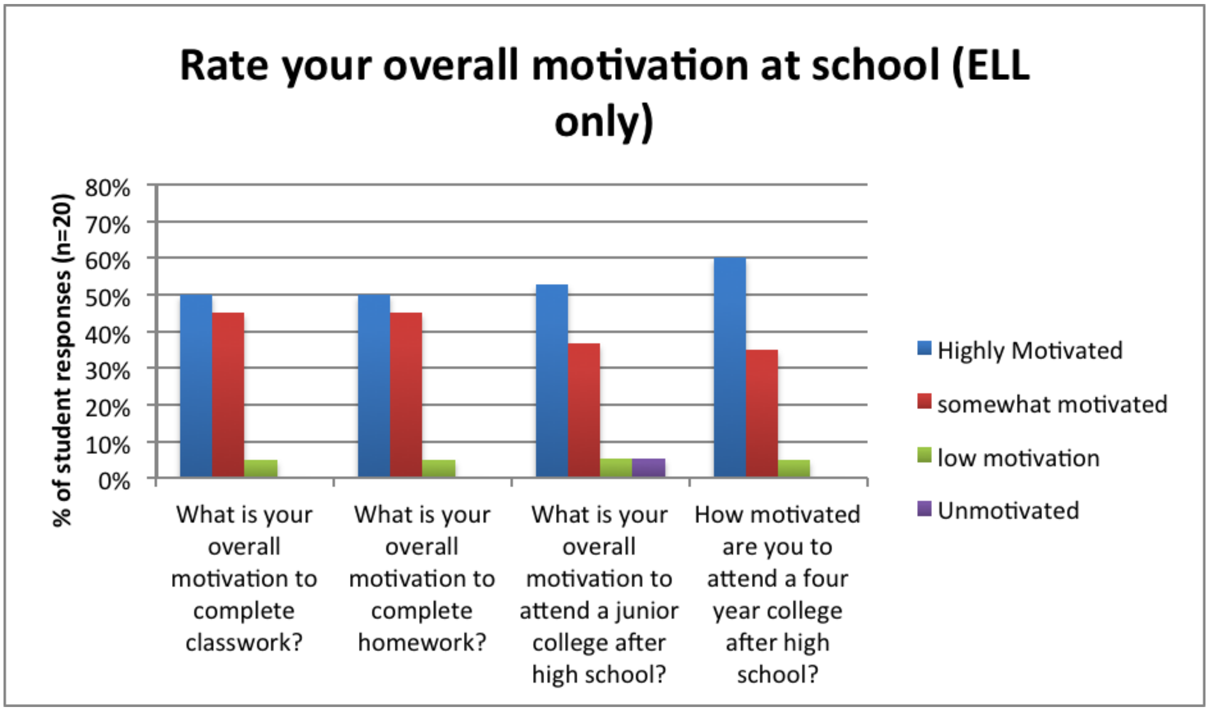


Figure 4e.



Appendix

Item 3a – Student submitted questions, completely unedited

5th period Student Questions

1. Does the type of wire effect the energy transfer?
2. How far can energy be transferred?
3. Does the thinness of the metal effect the conductivity?
4. How many volts are needed (minimum) to light a light bulb?
5. Why is a copper wire connecting the light bulbs?
6. Why do all the copper wires need to be connected?
7. Why are there two pencils?
8. Why do both the wires need to be connected to the battery for the light bulb to light up?
9. Where does the voltage go?
10. Will the light bulbs get brighter if you add more batteries?
11. Does the color coded wires stand for a certain voltage or charge?
12. How and why does the voltage get reduced as it travels through more light bulbs and wires?
13. Why does the light dim when you slide one of the wires down the metal string?
14. Will the light be brighter with more batteries?
15. Why do only certain light bulbs light up?
16. Are all the wires necessary for the first lab station?
17. What are the pencils for?
18. What are the four ways to light up the light bulb?
19. Why does the switch turn off the light bulbs?
20. Why does the little wire make it brighter?
21. What does the leaver do?
22. Why does there need to be wood under each one?
23. Why does the ladder shape make everything work?
24. Does the wire need to touch both ends of the battery?
25. Why does the bulb that the wire was attached to not light up but the others did?
26. Do circuits work in a circular design?
27. How does the energy flow through the copper?
28. How do light bulbs work?
29. Who invented light and why?

3rd Period Student Questions

1. Are they grounded to the wood?
2. What was the balloon for?
3. How much volts do the batteries produce?
4. Why is the power not as strong?

5. Why a copper wire?
6. Why the switch?
7. Why the direct approach?
8. Why so little materials used?
9. Will the light bulb work if connected directly to the battery between two wires?
10. Are there other things to power other than bulbs?
11. Do more batteries provide more power?
12. Does the hanger wire give less or more power?
13. Why do we need a copper wire?
14. What would happen if you used smaller batteries?
15. Can we power anything else?
16. Can you get a shock from touching one of the wires?
17. Does it loose charge if there are more wires?
18. Is it possible to light all 4 in a series circuit?
19. What is the switch on the electrical resistance?
20. Is there more than one way to light up the light bulb?
21. Why do the middle two light up?
22. What does the wood board do to the affect of the light bulb?
23. Why do all the wires need the tubing insulation?
24. When you clump the clips on the same wire why doesn't it light up and bulbs?
25. Why won't it turn on when only touching one side of the battery?
26. Why didn't one battery work?
27. Will different batteries work better? (brand)

6th period Student Questions

1. Do the number of wires effect the rate at which electricity is tranferred?
2. Does the thickness of the wire affect the rate at which electricity is transferred?
3. Why does the battery make the lights go out? Is the energy stuck somewhere?
4. Why does the electricity not pass through all the bulbs when you touch one copper with the bulbs? Does something prevent it?
5. What is the fourth way to turn on the light bulb?
6. Why do the light bulbs dim as you touch the different ends of the batteries?
7. Why did the wires need to be on the opposite sides to work?
8. Why does the light dim as you distance the cables from each other on the wire?
9. Why is the power lost when the cable is moved farther away from the light?
10. In electrical resistance, what does the sting work as?
11. Why does it only conduct of copper?
12. Why does it work if the wires are touching the same end?
13. Why does it only conduct on the copper?
14. Why do the lights in between the two wires light up, but the outside lights don't?
15. Do the different color wires mean something different from each other?
16. How does the wood work as a conductor?

17. How does unscrewing one light bulb not effect the other light bulbs?
18. How come it works when you switch the batteries around?
19. What do the pencils do in parallel circuits?
20. Why can't the light bulb touch the battery in order for the bulb to light up?
21. Why don't all the lights light up when connected in different ways to the circuits?
22. How is there power in the battery?
23. How does electricity make light?
24. How is the power distributed to the bulb?

Required materials for lessons 1 and 2

Lesson One Materials:

Station 1, Series Resistance: Board-mounted series circuit using any appropriately resistive wire connecting three small light bulb sockets. Appropriate voltage source, usually a 9-volt battery and at least three light bulbs.

Station 2, Resistivity from Wiring: Board-mounted series circuit including low resistance wiring and one small light bulb socket. A long, thin resistive wire connected to the rest of the circuit by alligator clip which students can easily manipulate, altering the length of wire included in the circuit. Appropriate voltage source, usually a 9-volt battery and at least one light bulb.

Station 3, Light the Bulb Challenge: No board-mounting is required for this lab. Simply provide one C battery, one light bulb, and one appropriately long length of wire, perhaps 1 ft. in length for each station.

Station 4, Parallel Resistance: Board-mounted parallel circuit using any appropriately resistive wire connecting three small light bulb sockets in parallel, one socket in each parallel branch. Appropriate voltage source, usually a 9-volt battery and at least three light bulbs.

Lesson Two Materials:

Make four copies of stations one and four as shown above. One half should resemble Station 1 and one half should resemble Station 2. Each station needs a small white-board and at least two white-board markers.

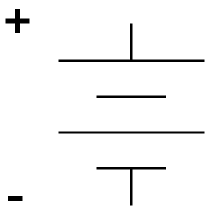
Figure 3b. Handout from lesson 2.

Circuit Diagrams

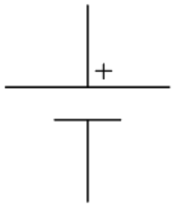
Listed below are graphical ways of representing circuit components:

Resistor: Resistor's slow down the speed of electron flow or current through a circuit. Many things add resistance to circuits such as light bulbs and even the wire used by the circuit.

Power Source/Voltage Source: The power source is what drives the circuit and provides the voltage. Batteries commonly provide voltage or the "electrical pressure" across a circuit. Current always flows from positive to negative or from + → -.

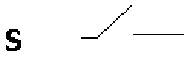


Battery Symbol

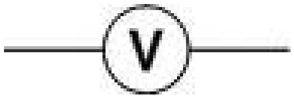
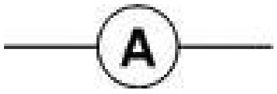


Generic Voltage Source

Switch: Used to start or stop the flow of current. All circuit components must be connected by a wire in order for current to flow. Switches change this quickly.



Or

Voltmeter or Ametter: Tools used to measure voltage across or current flowing through part of the circuit.  or 

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