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Orchestrating Student Discourse Opportunities and Listening for Conceptual Understandings in High School Science Classrooms

Melissa Grass Kinard

ACCEPTANCE

This dissertation, ORCHESTRATING STUDENT DISCOURSE OPPORTUNITIES AND LISTENING FOR CONCEPTUAL UNDERSTANDINGS IN HIGH SCHOOL SCIENCE CLASSROOMS, by MELISSA GRASS KINARD, was prepared under the direction of the candidate's Dissertation Advisory Committee. It is accepted by the committee members in partial fulfillment of the requirements for the degree Doctor of Philosophy in the College of Education, Georgia State University.

The Dissertation Advisory Committee and the student's Department Chair, as representatives of the faculty, certify that this dissertation has met all standards of excellence and scholarship as determined by the faculty. The Dean of the College of Education concurs.

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ABSTRACT

ORCHESTRATING STUDENT DISCOURSE OPPORTUNITIES AND LISTENING FOR CONCEPTUAL UNDERSTANDINGS IN HIGH SCHOOL SCIENCE CLASSROOMS

Scientific communities have established social mechanisms for proposing explanations, questioning evidence, and validating claims. Opportunities like these are often not a given in science classrooms (Vellom, Anderson, & Palincsar, 1993) even though the National Science Education Standards (NSES, 1996) state that a scientifically literate person should be able to "engage intelligently in public discourse and debate about important issues in science and technology" (National Research Council [NRC], 1996). Research further documents that students' science conceptions undergo little modification with the traditional teaching experienced in many high school science classrooms (Duit, 2003, Dykstra, 2005). This case study is an examination of the discourse that occurred as four high school physics students collaborated on solutions to three physics lab problems during which the students made predictions and experimentally generated data to support their predictions. The discourse patterns were initially examined for instances of concept negotiations. Selected instances were further examined using Toulmin's (2003) pattern for characterizing argumentation in order to understand the students' scientific reasoning strategies and to document the role of collaboration in facilitating conceptual modifications and changes. Audio recordings of the students' conversations during the labs, written problems turned in to the teacher, interviews of the students, and observations and field notes taken during student collaboration were used to document and describe the students' challenges and successes

encountered during their collaborative work. The findings of the study indicate that collaboration engaged the students and generated two types of productive science discourse: concept negotiations and procedure negotiations. Further analysis of the conceptual and procedure negotiations revealed that the students viewed science as sensible and plausible but not as a tool they could employ to answer their questions. The students' conceptual growth was inhibited by their allegiance to the authority of the science laws as learned in their school classroom. Thus, collaboration did not insure conceptual change. Describing student discourse in situ contributes to science education research about teaching practices that facilitate conceptual understandings in the science classroom.

ORCHESTRATING STUDENT DISCOURSE OPPORTUNITIES AND LISTENING FOR CONCEPTUAL UNDERSTANDINGS IN HIGH SCHOOL SCIENCE CLASSROOMS

by

Melissa Grass Kinard

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ABBREVIATIONS

IRE	Interrogation-Response-Evaluation (see p. 64)
NRC	National Research Council
NSES	*National Science Education Standards*
ZPD	Zone of Proximal Development

CHAPTER 1

INTRODUCTION

The purpose of this research was to investigate the changes in science conceptual understanding that took place when students had the opportunity to collaborate on solutions to extended science problems assigned by the classroom teacher. The study focused on the students' discourse during collaboration because it is the way students make their conceptual understanding apparent, and it is the primary tool the students use to negotiate their conceptual understandings when faced with other students' potentially different understandings. This study analyzed the collaborative discourse in order to understand the group process and its effects on conceptual understanding.

When considering the construction of science knowledge it is important to consider the social context within which that knowledge is constructed and accepted (Kittleson & Southerland, 2004). Science involves construction of theories and explanations for observed events, and all proposed explanations are open to challenges. What comes to be acceptable science evolves only after conflict and challenges to design, methodologies, analyses, and conclusions occur.

Scientific communities have established social mechanisms for validating claims and providing opportunities for its members to question evidence and explanations; however, opportunities like these rarely occur in science classrooms (Vellom, et al, 1993). Providing explanations and facing the challenges that are made to the

explanations are skills that are in concert with the *National Science Education Standards*, NSES. These standards state that a scientifically literate person should be able to "engage intelligently in public discourse and debate about important issues in science and technology" (NRC, 1996, p.1). The following teaching standards and strategies in the *National Science Education Standards* (NRC, 1996) have been identified as necessary components for accomplishing this goal:

1. Standard B: Teachers of science guide and facilitate learning (NRC, 1996, p. 32).
    a. Strategy: In doing this, teachers *orchestrate discourse* among students about scientific ideas. They require students to record their work…and they promote many different forms of communication. Using a collaborative group structure, teachers encourage interdependency. Such group work leads students to recognize the expertise that different members of the group bring to each endeavor and the greater value of evidence and argument over personality and style (NRC, 1996, p. 45, excerpted and emphasis added).

2. Standard E: Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.
    a. Strategy: This requires teachers to nurture collaboration among students to foster the practice of many of the skills, attitudes, and values that characterize science. It also depends on communication amongst the community of learners. *The ability to engage in the presentation of evidence, reasoned argument, and explanation comes from practice*. Teachers encourage informal discussion and structure science activities so that students are required to explain and justify their understanding, argue from data and defend their conclusions, and critically assess and challenge the scientific explanations of one another (NRC, 1996, p. 50, emphasis added).

The goal of promoting scientific literacy, with its component standards and strategies designed to promote student communication, is not being met in most science classrooms today. Instead, communication in science classrooms is in the form of teacher-talk with reproductive understanding by the students (Driver, Newton, & Osborne, 2000). Essentially, teachers talk and students listen, and lengthy, on-subject

discourse in classrooms is a rare event (Driver et al., 2000; Dunlap, 1999; Kawanaka & Stigler, 1999).

An alternative strategy for teaching science is one that shifts the classroom communication pattern from predominantly teacher-centered to student-centered. Having students work together to solve a challenging problem can facilitate such a communication shift. Peer collaboration provides students with opportunities to practice their emerging science communication skills. This is a situation that is reflective of the scientific community, which requires its members to communicate their ideas in very defined ways. For example, scientists place a heavy emphasis on the importance of evidence in backing claims made by its members. So, too, a collaborative group in a science classroom negotiates its conceptual understandings and establishes its cultural norms—that is, what the group considers valid science knowledge (Kelly & Green, 1998).

Through their collaboration, students' individual concepts are pooled and the discourse that ensues may lead to a mutual understanding of the concepts involved. This represents an opportunity for conceptual development and/or change for group members. The conceptual understandings each member of the group takes away from the experience is potentially different from the understanding the member entered the experience with, and this change is at least partly due to the social interaction that occurs within the group.

Conceptual change theory describes learning as coming to comprehend and accept ideas because they are seen as intelligible and rational (Posner, Strike, Hewson, Gertzog, 1982). The change in conceptual change refers to the idea that students come to any new

learning experience with a host of prior experiences and beliefs for which they have constructed explanations that work for them, but may or may not be congruent with what the teacher intended and may not stand up to scientific analysis. The conceptual constructs students hold or develop in the classroom may be naïve, premature, or actually incorrect in relation to accepted science (Duit, 2003; Zirbel, in press). Thus, teaching for conceptual change would mean engaging students in developing new understandings of science phenomena (Dykstra, 2005). This would involve helping students correct their misunderstandings; facilitate the reorganization of their naïve concepts into useable, integrated understandings; and develop intellectual tools useful to them in a variety of contexts (Suping, 2003). Science education, as part of the cultural institution of school, is charged with transmission of the scientific knowledge created by scientists and deemed important by society and is therefore the agent for conceptual change (Kelly & Green, 1998).

Conceptual change can be thought of as a "journey toward literacy within a domain" (Alexander, 1998, p. 56) and a collaborative group is a potent source for generating this change. Posner et al (1982), contend that conceptual change will only occur if a learner encounters an event for which his or her existing understanding provides an unsatisfactory or incomplete explanation. As members of a collaborating group express their differing renditions of the problem they are confronting, discrepancies will inevitably result. This discrepancy may provide the kind of disequilibrating event that provokes the dissatisfaction described by Posner et al. What follows among the group members is a negotiation of these discrepancies.

In fact, Kittleson and Southerland (2004), in a study of mechanical engineering students involved in solving a design problem, noted that just such negotiations often followed disequilibrating events such as unexplained trends in data. These researchers categorize this interaction as concept negotiation, that is, an interaction that involves more than one participant contributing to the conceptual content of a conversation. If the concept negotiations generate plausible explanations for the observed events, then these conversations have the potential for generating conceptual change. This type of shared discourse, in the best of situations, leads to "a new understanding that everyone involved agrees is superior to their own previous understanding" (Bereiter, 1994, p. 6).

Science is characterized by a unique discourse that students must be taught and allowed to practice if they are to become scientifically literate citizens able to argue a position, value others' contributions, and recognize faulty logic. Lemke (1990) summarizes this mandate: "We have to learn to see science teaching as a social process and to bring students, at least partially, into this community of people who talk science" (p. X).

The bulk of classroom talk follows a triadic conversation pattern in which a teacher asks a close-ended question, a student responds, and the teacher evaluates the response (Lemke, 1990). This is a widespread and robust classroom communication pattern (Cazden & Beck, 2003). This three-part exchange allows the students some opportunities to articulate their thinking and understandings and provides the other members of the classroom with alternative explanations essential to conceptual understanding. However, this level of exchange does not adequately address and explore each individual's varying conceptions (Dawes, 2004) nor does it prompt high levels of

student engagement. Also, the students are left to "find" the science in the dialogue on their own and construct their own conceptual understanding (Lemke, 1990). Within the constraints of this triadic conversation pattern, only a very few students have the opportunity to verbalize their understandings or questions. The concepts that may be made apparent by these few students are evaluated by other students in the classroom (if they are paying attention), in private. Most of the students in the classroom do not have the opportunity to articulate their thinking such that a teacher is able to judge whether a concept is being constructed as intended. The teacher's *intended* conceptual understanding and the students' *constructed* conceptual understanding may be very different indeed (Schneps & Sadler, 1987).

A valid question in this discussion of classroom discourse patterns is why aren't teachers providing opportunities for student discourse? As a part of their study into what types of activities go on in the classroom, Driver et al (2000), interviewed science teachers in order to determine why discussion in the classroom was not occurring more frequently. Their results showed that teachers agree that classroom discussions are an important part of science education. However, most of these same teachers expressed misgivings about their ability to manage classroom discussions effectively or help students find ways to solve the questions that may be generated by the discussions. In addition, there was a concern that a science classroom with students contributing heavily to the discourse would seem disorganized and be misinterpreted by the school administration as a classroom out of control. Finally, teachers feel the press of time and do not see discussions as an efficient use of the learning time allotted.

Statement of the Problem

The problem that formed the focus of this study centered on the lack of opportunity for students to enter into science discourse in the classroom. As documented in the literature, teacher talk dominates classroom communication patterns, thus only what the teacher knows and communicates is apparent (Driver et al, 2000; Dunlap, 1999; Kawanaka & Stigler, 1999; Lemke, 1990). Conversely, concepts the students hold are not often apparent. Further, it is recognized that participation in science discourse is essential in order for students' to reach a deep understanding of the subject (Graesser, Person, & Hu, 2002), and discourse may promote conceptual development and change (Bereiter, 1994; Dawes, 2004; Kelly & Green, 1998; Zirbel, in press). The NRC (1996) goal that encourages teachers to orchestrate discourse opportunities further supports this need for students to have the chance to talk out their understandings. These discourse opportunities allow students to articulate their conceptual understanding, recognize the value of others' contributions and engage in reasoned arguments that foster conceptual development.

The problem with the lack of student discourse in the science classroom can be broken into two parts:

1. Teacher talk dominates classroom discourse (Driver et al., 2000; Dunlap, 1999; Kawanaka & Stigler, 1999; Lemke, 1990). Teachers feel pressure to cover a required curriculum within a limited time so that their students will have the "right" knowledge. The "right" knowledge is determined by administrative mandates (standardized curricula) and/or knowledge that is required in order to prepare students to face high stakes tests (Chee, 1997;

Wallace & Kang, 2004). Because of these classroom pressures, students do not have the opportunity to engage in science discourse events that would be similar to those that scientists participate in such as framing arguments.

2. Because students do not have opportunities to enter into on-subject discourse, the science concepts the students hold or construct within the classroom remain largely private. What the students learn in the classroom may be fragmented bits of information, naïve understandings, or even wrong understandings with respect to accepted science (Duit, 2003; Zirbel, in press).

Teaching practices in most science classes follow a traditional pattern in which students hear a lecture or read from a text about a topic and are thus considered *informed* on that topic. The students then carry out lab activities to *verify* presented information and follow this up with problems or questions as *practice* in using the presented information (Dykstra, 2005). These teaching practices are supported by such constraints as the physical layout of most classrooms, the pressure of curricular demands on teachers to "cover" required material, and a positivist belief that there is a set body of knowledge to be passed on to students (Chee, 1997; Dykstra, 2005; and Wallace & Kang, 2004). These practices are not supported by results if the point of teaching science is to effect a change in conceptual understanding of science phenomena. That is "in all science instruction for more than a century, the result has been little or no change in student understanding of the phenomena studied" (Dykstra, 2005, p. 50). Many students come out of a science classroom pretty much unchanged by the experience.

To effect science conceptual change in students, Dykstra (2005) maintains that teachers need to provide students the opportunities to examine their existing understandings, compare these understandings to other possible explanations, and then resolve the differences that become evident. Time must be allocated in the curriculum to allow such summary and reflective activities. A balance between preparatory teaching and engaging in activities that foster conceptual development such as collaborative problem solving must be sought in order to support learning within the competing frameworks of the mandated curriculum and student-centered learning (Wallace & Kang, 2004).

Rationale and Significance of the Problem

Collaboration provides students with opportunities to reveal their conceptual understandings, confront others' understandings, and perhaps be called upon to reconcile differences that become apparent. Collaboration mimes the actions of the community of scientists and is a strategy suggested by the NSES for science teachers to provide students with practice enacting the role of scientist. Studying the discourse during a collaborative group's problem solving may reveal part of the path of conceptual understanding from the personally-held, privately-constructed individual understanding to the final understanding as developed by the group.

Language-in-action—discourse—is a building process (Gee, 2005) and the collaborative group uses its language to build its common conceptual understanding of the problems and solutions it undertakes. Thus, concepts constructed by the group are both a product of the group, and a new resource for each member of the group. Conceptual change within a collaborative group, then, is not an individual process and

whatever conceptual changes occur do so only in relationship to the group processes (Kelly & Green, 1998).

To address the NSES goal that encourages discourse skills, it is incumbent on educators to provide situations for students to work out precise understandings of scientific concepts and come to own scientific discourse. Only by actually doing scientific discourse can students acquire these skills. It is important for teachers to understand and develop strategies and methodologies that enable students to achieve these skills. In order to develop such strategies it is helpful to study how the collaborative science discourse develops within a group.

This study stemmed from observations I have made in my own Chemistry classroom. When students have learned a series of science concepts in a traditional inform-verify-practice sequence over the course of several units of work, what they have learned seems to be discrete bits of information. This information apparently holds no explanatory power for the students when they are confronted with a practical problem to solve involving the concepts from these units. That is, the students may be able to give back the information and concepts learned when given a typical test, but they have not "put it together" in such a way as to enable them to solve a comprehensive and complex problem (Mintzes, Wandersee, & Novak, 2000). In watching and listening to the students when confronted with this problem, I noted that their talk indicated that what I thought I had taught and what the students had successfully reproduced on their tests was, in fact, a confusing jumble for them.

I found that many of the students involved, through their collaborative discourse, did work through the problems they were presented with and were able to reasonably

present their solutions to the class. Students seemed to develop a deeper understanding of the appropriate chemical concepts, and their fragmented, naïve understandings became useful knowledge applicable to the solution of their problem (Duit, 2003). Further (and anecdotally), subsequent contacts with students highlighted that what the student remembered from this chemistry course were these collaborative problem-solving events, including the general concepts they were meant to cover. These observations are in alignment with studies that show collaborative groups are able to solve problems that individual members would not be able to reasonably solve on their own (Hogan, Nastasi, & Pressley, 1999) and that collaboration promotes engagement, a necessary component to conceptual development (Dawes, 2004).

What happens within the collaborative group that seems to move the students to a deeper level of understanding? I am interested in exploring the students' transition from confusion and frustration to the successful completion of problem solving events—especially the conversations that may support this change. Through the collaborative problem-solving activity, *concept negotiation* may provide the student with the opportunity and means to make the necessary connections between their existing fragmented, frail concepts and lead to conceptual change. In doing such studies, researchers can describe effective strategies that can be implemented in science education that foreground the activities of students. Descriptive studies of these "practical epistemologies" describe how "the encounters made by students in the classroom change their undertakings and what they learn" (Wickman, 2006, p.23).

Collaborative groups and the discourse they use during their activities have been studied. These studies have focused on the benefits and drawbacks of collaboration to

the individual's conceptual or cognitive development (Bearison, 1982; Dillenbourg, Baker, Blaye, & O'Malley, 1996; Kruger, 1993), and the influence of the group composition, membership, and participant disposition on the success of the group's collaboration (Azmitia & Montgomery, 1993; Ellis, 1992; Hogan, 1999). In addition, much of the research has been done under special circumstances such as camps, extracurricular science programs, or programs with planned interventions. What has not been extensively studied is such interaction within the situated learning context—with all of its institutional and societal expectations and values—of the science classroom (Duit, 2003; Wallace & Kang, 2004; Wells, 2000). "What works in special arrangements does not necessarily work in everyday practice" (Duit, 2003 p. 684).

The inherent social context of classroom learning means that the understandings that students develop are due to or heavily influenced by the social context within which they occur. In other words, studies of collaboration must deal with the collaborative processes themselves, not necessarily the effects of the processes (Tudge & Hogan, 1997). This would suggest a fruitful line of inquiry to be the group processes that lead to the group's perhaps peculiar determination of what counts as scientific knowledge and values. What types of knowledge can be accessed, built, or changed from the group discourse (Pontecorvo, 1993)?

Much remains to be understood about the nature of the interaction between members of a collaborative group (Kittleson & Southerland, 2004). Examining student discourse, in this study, aimed to uncover the goals, agendas, and premises that influenced what knowledge was shaped by the group and the way this knowledge was developed (Kittleson & Southerland, 2004). Examining the discourse that surrounds a

collaborative event may reveal the shifts in reasoning within the group as well as the strategies used and social procedures enacted while developing the group constructs. Examination of the discourse revealed the socially constructed nature of science knowledge—how members organized, retrieved, presented, and manipulated their conceptual understandings. The participant discourse was used to make sense of the interaction patterns within this group because it described the ways of thinking, acting, and interacting that were common to the group. It is these patterns that constrained and shaped the meaning that members constructed as a group (Gee, 2005).

A premise of this study was that engendering discourse among students in science is critical to their understanding of science (Graesser, Person, & Hu, 2002). In light of this, discourse is both an educational goal that helps students "talk themselves to understanding" (Sperling as quoted by Dunlap, 1999) and a source for researching and understanding the group processes that affect the outcome of collaborative efforts (Bearison, 1982). The discourse the students used highlighted patterns of participation and thinking. These patterns were used to answer relevant questions about those factors that supported or constrained group conceptual understanding and consequent knowledge construction. The insights that evolve from the analysis of these student discourse patterns along with similar studies can then be used to inform classroom practices that would generate the sorts of discourse events that promote conceptual change.

It is important that science educators not only understand that this sort of discourse should take place, but conduct research to try to understand how it occurs, why it works, and under what conditions it works. The research on collaborative groups, as cited previously, has focused on the dynamics that occur as a result of the social roles of

the members of the group and how these roles affect access to knowledge construction by group members (Hogan, 1999). In these studies, the individual's change, often determined by the use of individual pre-test/post-test measures (Dillenbourg et al, 1996), was the emphasis of the research, rather than the socially constructed nature of the learning that takes place during the collaborative process. Other studies have focused on the discourse between student pairs that generates cognitive growth. These studies have concluded that students working collaboratively generate more conflicts than students working alone and spend more time on the assigned task than students working alone (Bearison, 1982; Kruger, 1993). Apparently it is not just the conflicts that arise in the course of collaboration, but the extended discourse exploring the reasoning behind the various viewpoints that promotes cognitive development (Kruger, 1993).

Students learn from each other. Their interaction requires reflection, adaptation, reasoning, and decision-making—in other words, negotiation—to become established in relation to each other. These are all components of the particular Discourse of science. Gee (2005) defines a Discourse—capitol D intended—as the integration of language, actions, and interactions that enable an individual to enact a particular socially recognizable identity (p. 21). Lemke (1990) particularizes Gee's definition of a Discourse for science by describing components that mark the Discourse of science. Talking science includes observing, describing, comparing, classifying, analyzing, discussing, hypothesizing, theorizing, questioning, challenging, arguing, designing experiments, following procedures, judging, evaluating, deciding, concluding, generalizing, reporting, and writing (Lemke, 1990 p. ix). The student is a newcomer to

science and must be afforded the opportunity to learn its specific Discourse and put it into practice.

Students will appropriate the concepts presented in a science class but they may be appropriated as incomplete, naïve, or even wrong in relation to accepted science (Duit, 2003). Furthermore, with little opportunity for expressing themselves, students cannot always make their conceptual understandings open for review, reflection, and potential change if that is necessary for appropriate understanding of the intended concepts. The conceptual changes students may need to make could be radical changes that require them to completely restructure their existing understandings in order to accommodate new ideas (Posner et al, 1982), or they may be less dramatic changes (Dawes, 2004). For example, conceptual change may occur when students' premature concepts change as they undergo more critical analyses of these concepts (Zirbel, 2004) or when students are able to organize their naïve, fragmented understandings (Fisher, 2000). It could be argued that conceptual change is more "evolutionary than revolutionary" (Savinainen, Scott, & Viiri, 2005, p. 192).

Within the context of collaboration, students present their idiosyncratic and, perhaps, contradictory conceptual understandings. The alternative views presented by group members may act like discrepant events, prompting negotiation and argumentation that leads to a new conceptual understanding. Further, the interactive discourse will force the student to more critically examine his or her current understanding, and the constant reexamining of concepts can narrow the gap between elementary and advanced knowledge (Zirbel, in press).

By examining one aspect of science discourse identified as concept negotiation, a rich description of one way students may undergo conceptual change was generated. Concept negotiation occurs when there is a mutual exchange of ideas that contributes to the conceptual content of a group conversation. Two or more people must be exchanging ideas that revolve around conceptual understandings. The talk would not be of an explanatory nature with one person doing the talking and others listening. Some negotiation can occur during procedural talks as group members decide on the best procedures to follow and negotiate their reasoning for these procedures. In either case, negotiation ensues until mutual understanding occurs. The final science conceptual understanding is the result of the group's efforts and represents the common knowledge developed by and then accessible to the group's members (G. Kelly & Green, 1998).

Guiding Questions

Collaborative groups have been shown to facilitate individual cognitive development (Bearison, 1982; Kruger, 1993) and provide students with practice "talking science", thus deepening their conceptual understanding (Graesser et al 2002). However, the social nature of collaboration and its impact on what conceptual development is jointly constructed, as well as what processes students go through during joint conceptual development, is less well documented (Kittleson & Southerland, 2004). In addition, most studies undertaken on collaboration have not taken place within the constraints of the science classroom.

In light of these considerations, three guiding questions focused the research on collaborative conceptual development in science.

1. How do the participating students engage in concept negotiation during their collaborative work in the science classroom?
2. How does participating in a collaborative group activity in science facilitate conceptual development in students?
3. How do concept negotiations undertaken during collaborative work in the science classroom contribute to a conceptual understanding that is common to the group?

How do the participating students engage in concept negotiation during their collaborative work in the science classroom?

The intent of this study was to determine if and how a group negotiates science conceptual understanding when it is confronted with a problem that requires the group's collaborative efforts. Does personality and style or reasoned negotiations of science understandings have more of an influence on the group product? If the group does negotiate conceptual understanding, does this contribute to the formation of more "connections" between the concepts, i.e., conceptual change in light of moving students toward competence within a domain? This focus question centers on how concept negotiation events occur and was an attempt to get at the relationship between how and what students learn because of their collaboration (Wickman, 2006).

How does participating in a collaborative group activity in science facilitate conceptual development in students?

This question assumed that collaboration facilitates conceptual development and change. This assumption is based on the notion that scientists, as a cultural community, self-determine what counts as science through a collaborative process using established cultural practices such as presentation of data and negotiation of proposed explanations for observed phenomena. However, the concepts developed collaboratively by scientists are open to revision or change as evidence, further explanations, or culture warrants (Kelly & Green, 1998). Analogous to this is a group of students collaborating on the solution to a science problem. The group of students in this study was followed as they negotiated their conceptual understanding of a problem and its solution. The decisions they reach as a group are a product of the group and a resource for each member to take away with them and apply to future problems they encounter. Examining how the students interacted, what they said, how they said it, and whether the nature of the exchanges changed as they negotiated their solutions to the problems revealed what conceptual development and changes occurred within the group. What counts as conceptual change by an individual has been reported in the literature, but this study was based on the premise that what counts as individual understanding cannot be considered without understanding the group processes that contribute to its genesis.

How do concept negotiations undertaken during collaborative work in the science classroom contribute to a conceptual understanding that is common to the group?

This question tied together the actions of the collaborating group with the concept negotiations they undertook to determine what happened to the group's conceptual

understandings. If the understanding each member takes from an activity is influenced by participation in the group it is possible that a common conceptual understanding is produced through their discourse. The students' discourse within the group contributes to a negotiated understanding of appropriate science concepts and may be reflected in a change in the way the students talk about science.

Theoretical Framework

Collaborative groups provide a social context for learning and students enter the collaboration with their privately held conceptual understandings. The conceptual understandings that are subsequently constructed during the course of their collaborative work are representative of and, perhaps, unique to the group. The emergent conceptual understandings may well differ from each student's original science conceptual understanding due to the discourse undertaken during the collaboration. Therefore, the support for this study is grounded in a social constructivist theoretical framework.

Based on work by Russian psychologist Lev Vygotsky, a social constructivist view of learning recognizes that meaning and understanding emerge out of social encounters. Children learn by appropriating the tools and signs of their culture through interaction with more competent members of the culture (Tudge & Hogan, 1997). Vygotsky's central tenets—learning is mediated from person to person, all participants in the learning experience are cognitively changed by the interaction, and the learning tools, mainly language, have been socially and historically constructed—challenges the view that learning can be fully accounted for in terms of the individual independent of a social/cultural context (Resnick, Salmon, Zeitz, Wathen, & Holowchak, 1993).

A social constructivist theory of learning emphasizes the need for interaction. A group of students working together is a collaborative community with participants providing mutual support and assistance. This is consonant with one of Vygotsky's most important theoretical proposals: In *The Problem of Age* (Rieber, 1998) Vygotsky maintains that problems solved independently by a child measure how development had occurred in the past. "A genuine diagnosis of development must be able to catch those processes that are in the period of maturation."(p. 200). To determine a child's actual level of development—what he or she is really capable of—is better determined by what a child can do cooperatively. Individuals learn by interacting with more competent members of the culture (Wells, 2000). That is, learners are able to accomplish more and solve more difficult problems when helped by others. Vygotsky described the difference between what a learner could accomplish alone and what that same learner could accomplish if mentored by a more competent person as the *Zone of Proximal Development* (ZPD). However, studies of collaborative groups demonstrate that members of a group improve their problem solving ability regardless of whether the members differ in initial ability (Bearison, 1982; Kruger, 1993). This would suggest that a collaborative group consisting of peers, like scientists, could act as a collective ZPD (Dunlap, 1999) with each member contributing to, taking from, and being changed by the group's interaction (Kelly & Green, 1998). This is in concert with the NSES strategy that suggests, "…group work leads students to recognize the expertise that different members of the group bring to each endeavor…" (NRC, 1996, p. 45).

Learning as a socially constructed activity assumes a starting point for each learner. That is, each individual comes to the learning experience with some pre-

established understanding (Zirbel, in press). In the classroom, this understanding will be acted upon through the social mediation of classroom activities and perhaps transformed into another understanding. An important goal of science education is to bring each learner's preconceived ideas about science into line with the current understanding of science such that their conceptual understanding can withstand rigorous scientific analysis.

Conceptual change theory looks at learning from the standpoint of what each student brings to the table. The notion of teaching for conceptual change was introduced into education by Posner, Strike, Hewson, and Gertzog (1982) during investigations into the misconceptions students often have that interfere with their ability to learn more acceptable scientific concepts. Initially, the use of the term conceptual change was reserved for the kind of change that required students to radically restructure their existing understanding in order to accommodate new understandings. Subsequent researchers have used alternative terms to describe conceptual change because conceptual change can happen at a number of levels (Duit, 2003). For example, conceptual change can include consolidation and organization of naïve understandings, such as moving students from a novice conceptual understanding to competence within a domain (Alexander, 1998).

Common to any view of conceptual change is that learners will undergo conceptual change only if they encounter an event that is not explained by their existing conceptual framework. Such an encounter is more likely if students are engaged in discourse with others. Students *see* observations and attend to various aspects of teaching differently from one another. That is, they focus on different features of the same

classroom event(s), possibly resulting in different mental models of scientific concepts presented. When working together as a group, the potential clash between the mental models each student articulates may provoke conceptual change.

Conceptual understanding occurs when an individual or group has an integrated picture of whole structures, processes, or events rather than a disconnected collection of fragmented ideas (Fisher, 2000). For example, one concept might be mass; another, different concept might be volume. A resulting proposition could be density, if the relationship between mass and volume is understood (Zirbel, in press). Although much research in conceptual change theory has revolved around the area of misconceptions and how to change them, conceptual change can be thought of more broadly. Conceptual change can be thought to include modifications or transformations in one's knowledge base. Conceptual change can be, simply, everyday growth within a domain (Alexander, 1998).

If conceptual understanding is to be co-constructed during the actions of a collaborative group, it will happen through the discourse that takes place among its members. A core concept of Vygotsky's theories of learning is the centrality of language as the most important cultural tool for learning (Tudge & Hogan, 1997). In contributing to problem-solving conversations, a student simultaneously adds to the structure of the joint conceptual understanding as well as his or her own understanding (Wells, 2000).

Discourse is the oral communication of thoughts, the purposeful use of language (Wells, 2000). Examining discourse, then, provides a means of studying how language is used in situ to enact specific activities and identities (Gee, 2005). As opposed to discourse, which is a general term applied to language in use, Gee (2005) defines the

integration of language, actions, values, and interactions that give an individual a recognizable identity as a Discourse. This would mean that scientists have an identifiable Discourse characterized by particular language, actions, and interactions. In this study, examining student discourse had two functions.

First, discourse is an educational goal that provides students with the cultural tools and conventions of the science community (Beeth & Hewson, 1999). Thus, students must be given the opportunity to learn and practice scientific Discourse. Success in science will mean learning to present one's ideals and understandings in a manner recognized as science (Lemke, 1990). Collaborative groups provide this opportunity, which is generally lacking in most science classrooms.

Because discourse opportunities are rarely afforded students in science classrooms, much of the relationships the students form about the presented science concepts remain a mystery. Traditional assessments in science reward rote learning that requires a student to recall insignificant bits of information (Mintzes et al, 2000) and, so, may not provide a picture of the understandings students may have (or not have) about science concepts. Providing opportunities for students to enter into a science Discourse makes their understandings explicit to their teacher who is mediating their learning (Bearison, 1982).

The second function that student discourse served in this study was as a source of data that revealed students' emergent science conceptual understanding. The discourse the students used represents the resources and strategies characteristic of their community and was used as a tool for understanding one way that groups co-construct conceptual understandings. Understanding the processes may suggest one way that science

education can be improved (Erduran, 2004). Ultimately, if the discourse processes of a collaborative group can be understood, a model for how engaging in collaborative discourse may support students' science conceptual understanding can be built (Dillenbourg et al, 1996). This may lead to workable solutions for teachers to provide discourse opportunities that work well within the constraints of the classroom. However, key to understanding these discourse processes is a detailed description of them as they are enacted among students.

The activities of the academic field of science mirror social constructivism. Scientists work together to accept or reject claims and/or theories based on their negotiation of evidence (Newton, Driver, & Osborne, 1999). Thus, science knowledge is the

> product of the actions of members of a group who, in the face of a problem situation, draw on their intellectual history of ideas as well as the social and physical features of the problem situation to construct understandings…new phenomena can be viewed as being talked and acted into being through members of a scientific community (Kelly & Green, 1998 p. 149).

So, too, students' conceptual development and possible change can take shape within the social context of a collaborative group. The discourse enacted during this encounter was analyzed to provide insight into the processes that influence how and what science was learned by the group.

Methodology

This study employed a qualitative research methodology because it was concerned with understanding behavior from the participants' frame of reference and involves data that richly describes the people, places, and conversations that form the

basis of this study (Bogdan & Biklen, 2003). Qualitative research is useful for describing and answering questions about participants in a particular setting.

This research was guided by a preliminary case study conducted by Kittleson and Southerland (2004) that looked at the role of discourse in the group knowledge construction by mechanical engineering students completing a senior capstone design project. Kittleson and Southerland (2004) developed the notion of concept negotiation as the hallmark of knowledge construction within the group in order to differentiate instances of knowledge construction from other forms of conversations. Within the collaborative group the mutual exchange of ideas and the ensuing negotiation surrounding these ideas enabled members to reach a mutual understanding and come to consensual knowledge. Based on this, Kittleson and Southerland (2004) describe concept negotiation as discourse that involves more than one participant contributing to the conceptual content of a group conversation.

The research proposed used a qualitative case study methodology (Bogdan & Biklen, 2003) to focus on student co-construction of scientific conceptual understanding during collaborative problem-solving activities. Case studies focus on understanding a single entity or phenomenon and allow for generation of an in-depth picture of the selected cases. In this study one group of four students enrolled in a high school Physics class was observed over the course of three problem-solving lab activities assigned by their classroom teacher. The group was examined in situ in order to better understand the relationship between group discourse and science conceptual change. The choice of the particular group to study was based on the practical need for permission to study them and ready access to their problem-solving interaction.

Qualitative research is descriptive and holistic (Fraenkel & Wallen, 2003). As such, the main data taken was observations of the collaborative group made by myself as. Observations and field notes situated the students' activities within the context of the classroom and included as much notation of gestures, actions, interactions, symbols, tools, technologies, attitudes, beliefs, and emotions as possible in order to "get at" what specific activities the students were trying to enact. The most important data for this study was the reconstruction of the participants' collaborative discourse and its context. I audiotaped the case group to supplement field notes and improve the accuracy of the observations being made. It is important in a case study to "make the subjects' words bountiful" and the audiotapes insured that the participants' words were both bountiful and accurate (Bogdan & Biklen, 2003, p. 113). The participants also generated individual and group solutions to problems selected by their teacher as representative of the concepts the students were studying in each lab activity. This piece of data can be a useful way of finding out what students know about a topic as well as how they apply that knowledge (Mintzes et al, 2000). These paper and pencil solutions as well as recordings of the students working through these solutions contributed to the database.

A follow up interview of each member of the case group was conducted. The follow-up interview consisted of questions that solicited the students' perspectives on the relationship of collaboration to learning. Some of the interview questions clarified classroom procedures with regard to collaboration and some of the interview questions were ad hoc and based on events that occurred during the study itself.

As stated above, this study is centered on qualitative research, which is descriptive. Therefore, the main data was the observations of the student groups as they

collaboratively constructed their conceptual understanding of, and solution to, authentic physics problems assigned by their classroom teacher. The observations were direct observations made by me and supported by audio-recordings. These recordings were transcribed and coded. The transcriptions were initially coded with an a priori coding scheme meant to identify instances of concept negotiation that occurred during the observation period. Some of the transcripts coded as instances of concept negotiation were further analyzed for elements of argumentation and epistemic actions demonstrated by the participants.

This methodology inherently depended upon the human evaluator, in this case myself, acting as a non-participant observer. I approached this research with the bias that collaborative group learning promotes science conceptual understanding. In order to avoid allowing my bias to drive a slanted analysis, I gathered a variety of data including audiotapings; persistent, ongoing observations with field notes; and artifacts the group produced. Data collected from several sources protects against bias because it is not likely that the multiple data sources will be biased in the same way (Gay & Airasian, 2003). If recollections of the case group members support the same conclusions as observations and related documents do the conclusions drawn have a better chance of being credible.

Summary

The nature of science is such that the natural world is understandable and science attempts to explain the natural world. However, what is generated as scientific knowledge is a result of the negotiation that occurs among scientists and this, in turn, is affected by personal, societal, and cultural beliefs (Abd-El-Khalick & Lederman, 2000).

In fact, the *National Science Education Standards* call for an emphasis on argument and explanation in teaching science (NRC, 1996).

Because of curricular and administrative demands as well as discomfort with student-centered learning, teachers do most of the communicating within classrooms (Driver et al., 2000; Dunlap, 1999; Kawanaka & Stigler, 1999; Lemke, 1990). The opportunities for students to practice the social endeavors that mark science are not often afforded students in schools and so their development as "communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning" (NRC, 1996, p. 50) is often limited. Further, without much "voice" in the classroom, the relationship between how and what science concepts students learn and take with them from the classroom remains a mystery.

A collaborative group provides a vehicle for students to enter into a community of science learners and "try on" the identity of a scientist, and to achieve a better understanding of science concepts. Just as scientists collectively negotiate their understanding of a problem, a collaborative student group confronted with a challenging problem negotiates their understanding. And, this has the potential to foster conceptual development and change. The direction of student learning will be influenced by their encounters within the classroom, thus the conceptual understandings developed within the group will influence what the students ultimately take away as science (Wickman, 2006).

Concept negotiation, as one aspect of science discourse, may reveal this potential conceptual development as it occurs. In an ideal collaboration, members share their personal conceptual understandings and question each other's understandings until they

establish a new understanding that they see as better than what each began with (Wells, 2000). As such, research such as this describes how this process occurs and what positively supports the process.

The focus of this study was the collaborative interaction in a high school Physics class to describe how students engage in conceptual development and what factors are relevant during this process. Studying how students negotiate and co-construct their science understanding in social settings, such as collaborative problem-solving events, provided insight into students' conceptual understanding. Analyzing the discourse processes that occurred within a collaborative group contributed to building a model for how engaging in collaborative discourse can promote the conceptual change desired in science education. This model may ultimately provide insight into how to structure classroom practices to foster conceptual change.

CHAPTER 2

THEORETICAL FRAMEWORK AND LITERATURE REVIEW

Introduction

The purpose of this study was to investigate the ways students co-construct science conceptual understanding while collaborating on solutions to science problems. This study focused on the processes students used, particularly the discourse the students employed, to shape science knowledge within a particular group. Student discourse was examined because it is the main resource the students use to deploy their personal concepts for negotiation and change or for development of a common science understanding among members of the group. This chapter will review literature that describes the theoretical support for this study and some of the research within each area that supports and informs this study.

Social Constructivism

Constructivism is an epistemology that views learning as a constructive process in which each individual builds his/her own knowledge by applying logic to lived experiences (Atherton, 2003). Evidence for learning as a personal constructive activity can be seen in the many misconceptions that people form (Cobb, 1994). For example, many students think that heavier objects fall faster than lighter objects, revealing an incomplete understanding of the physics concept of acceleration due to gravity (Hynd, 1998).

Although not a recent idea, constructivism came to be associated with education when work being done by the psychologist/epistemologist Piaget on how children learn,

was cited by United States' psychologist Jerome Bruner in the context of science education. Piaget claimed that children construct their own personal knowledge as they interact with their environment and assimilate the new encounters into their existing mental structures. These mental structures are then altered to accommodate the new knowledge (DeBoer, 1991). Constructivism, in its most radical form, results in knowledge that will be relativistic and idiosyncratic—that is, each person will construct a unique knowledge base and it may or may not be right in comparison to accepted science understanding. In a statement that reflects the basic premise of constructivism, Schrödinger said, "…every man's world picture is and always remains a construct of his mind and cannot be proved to have any other existence…" (Schrödinger, 1958, p. 44).

The homogeneity of cultural knowledge, however, suggests that knowledge is more than just individually constructed. This kind of evidence forms the basis for a modification of constructivism. This modified constructivism—social constructivism–is the belief that meaning and understandings grow out of social encounters and therefore knowledge construction is socially mediated (Cobb, 1994).

Social constructivism does not represent the first time the importance of social interaction to cognitive development was recognized. Social constructivism in education reflects ideas that were central to a socio-cultural theory of learning that developed from the work of a Russian psychologist, Lev Vygotsky. With the translation of *Thought and Language* in 1962, Vygotsky's insights and studies into human behavior and their consequences to such cultural activities as education became more available to a broad spectrum of researchers, thus opening up new ways of looking at development and learning (Wells, 2000).

Lev Vygotsky maintained that culture was critical to human development and that it is culture that signifies the separation of humans from other animals. Culture is more than just making and using tools, something done by other animals besides humans. Culture is the interaction between humans and their environment using these tools. For example, humans use tools to establish a farm, which subsequently frees them from the nomadic existence of hunting and the erratic availability of food. However, cultural tools may be more than just objects that perform a function. They may also take symbolic forms such as using lucky charms; or they may be concepts and mental techniques as well. Such tools are the mediating devices of culture. Particularly, Vygotsky's work made explicit the centrality of language as the primary tool through which members of a culture make sense of phenomena and solve the problems with which they are confronted (Lee & Smagorinsky, 2000). "…We must not forget for a moment that both knowing nature and knowing personality is done with the help of understanding other people, understanding those around us, understanding social experience."(Rieber, 1998, p. 50).

In the late 1970s, David Bearison (1982) conducted a study to investigate the role of social interaction on the cognitive development of children. His work was based on prior work conducted by W. Doise and his colleagues in Geneva who had determined that children working in pairs to solve cognitive problems did so at a more advanced level than children working on the same problem alone. Bearison's study, while differing some in methodology and results, largely corroborated Doise's findings. Studies such as these marked a departure from the existent research paradigm that focused on the *intra*individual coordination of knowledge—a Piagetian constructivist stance—to the *inter*individual coordination of knowledge within the context of social interaction—a

more social constructivist stance. Among the important findings from these early studies was that through the interaction the less advanced partner's cognitive development increased. Perhaps surprisingly, it was also found that the more advanced partner showed improved cognitive abilities as well. Further, the pairs spent more time working on the solutions to the problems than did children working alone (Bearison, 1982).

Two important ideas central to Vygotsky's theories on the social origins of learning are the *Zone of Proximal Development* (ZPD) and *inner speech*. The ZPD concept states that outside social forces are as important in psychological development as are the individual's inner resources. In *The Problem of Age* Vygotsky notes that true development cannot be based solely on what the child can do alone. This basis marks only what the child has already accomplished, not what his or her potential is (Rieber, 1998). Children copy actions and solve problems that are beyond what they can accomplish alone when aided or scaffolded by an adult or more competent peer (Dunlap, 1999). This notion is in contrast to Piaget's ideas that state that what a child can accomplish has limits based on his/her developmental level. The ZPD, then, is the distance between a child's actual developmental level as determined by independent problem solving and his potential developmental level as determined by problem solving accomplished with scaffolding (Ardichvili, 2003). As Vygotsky (as cited in Wink & Putney, 2002) said, "What the child can do in cooperation today he can do alone tomorrow. Therefore the only good kind of instruction is that which marches ahead of development and leads it" (p. 85).

Vygotsky states that learning is mediated primarily on an interpsychological plane, i.e., from person to person, and appropriated by the learner. The teacher or mentor

scaffolds the child's learning, but both the mentor and the learner co-construct the knowledge contextually and both are changed by the experience. For example, mothers given the task of teaching counting to their children do so knowing the cultural importance of this concept for their child's future. As the mothers approach the task with their children, they adjust their teaching to the child's responses during the learning sequence (Glassman, 2001). Both the mother and the child are active participants in the learning. The mediational tools used in this collaborative learning, mainly language, have been socially and historically constructed and passed on. Thus, this knowledge is distributed knowledge, a resource that is owned by all the cultural members (Lee & Smagorinsky, 2000).

Vygotsky's second concept, *inner speech,* is his attempt to find the relationship between thought and language. Behavioral psychologists contemporary to Vygotsky maintained that thought was simply soundless speech that had progressed from audible speech to whispering to, finally, a soundless form. Vygotsky, in contrast to this commonly-held belief, maintained that inner speech—thought—evolved as children incorporated words and their meanings, which they glean through their communication attempts with others, into a socially coherent—and personal—reality. This inner speech was different in structure to external speech. For example, inner speech is much more abbreviated than external speech. An important assertion Vygotsky makes is that the development of inner speech depends on outside factors and is a direct function of socialized speech. A child's intellectual ability is dependent on mastering the social means of thought which is language (Vygotsky, 1934). This socio-cultural incorporation of language, in turn, is used by the individual to regulate his behavior in socially

acceptable ways. Language by itself creates a context both for activity and for reflective thinking about that activity (Glassman, 2001). For Vygotsky, speech and understanding are inseparable and represent the means for communication and thinking (Vygotsky, 1934).

Vygotsky researched the development and structure of human consciousness, especially how children internalize language in the course of their development. Understanding the development of individuals requires looking at them as products of the institutions (school and family for example) in which they find themselves and the culture in which these institutions are embedded. This cultural milieu must be considered in addition to the biological potential of the individual. Ultimately, an individual's identity, values, and skills occur through their participation and membership in this larger social context (Wells, 2000). Specifically, learning does not take place in a vacuum but within a social, cultural, and political context (Wink & Putney, 2002). A child must master the habits and forms of cultural behavior in order to participate meaningfully within the culture (Tudge & Hogan, 1997).

An experiment conducted by Luria and Yudovich in 1935-36 and published in 1956 illustrates the role of participation in speech processes to the development of higher psychological functions in a child. This study looked at a pair of identical twins with delayed speech due to genetic factors. Their condition was aggravated by the fact that the twins lived, played, and communicated largely with each other, such that they had developed a communication that did not require fully developed speech. At five years of age, these bright twins' speech was not comprehensible to outsiders and their behavior was extremely primitive. For example, the twins made meaningless drawings. The

experiment separated the twins into two different nursery schools with one of the twins receiving additional speech training. After three months, both twins had developed relatively normal speech. Even more remarkable, both twins' activities were completely reorganized, their play appeared normal, and their drawings were meaningful. Both twins experienced the surge in development—even the child who was not given the additional speech training. Three months maturation alone could not account for the dramatic changes observed. The accelerated development in the structure of the twins behavior, according to Luria and Yudovich, was attributable to the development of speech in the context of a social setting (study cited by Lloyd & Fernyhough, 1999).

A consequence of culture is that it creates special forms of behavior and these, in turn, have profound effects on the ways in which children's development proceeds (Tudge & Hogan, 1997). In order to be successful within a culture, children's development must include mastering the appropriate cultural knowledge and behaviors. Because of this, understanding the development of an individual is accomplished by looking at the individual's history and socio-cultural milieu. What formative events has the child encountered? What is the impact of the family, school, and other institutions the child may be a part of? How are these situated within the context of the larger culture (Wells, 2000)?

Cultural tools enable construction of meaning, but the interaction that occurs in learning is more than simply passing on appropriate knowledge as a packet in a static manner. As the course of history shows, existing cultures have evolved and are very different from each other and from the cultures from which they were derived. Apparently, the cultural tools, as well as the ways in which they are internalized by its

members, provide the potential for cultural change and advancement as novel knowledge and ideas are constantly being constructed using these cultural tools.

Vygotsky's central tenets—learning is mediated from person to person; all participants are cognitively changed by the interaction; and the mediational tools for learning, mainly language, have been socially and historically constructed—challenges the view that learning can be fully accounted for in terms of the individual independent of his social and cultural context (Resnick, 1993). This realization of the importance of social context to learning has led to a shift away from the study of the individual to the study of the social group in order to begin to understand how knowledge is constructed (Lee & Smagorinsky, 2000). Human beings' learning is not simply limited by their genetic inheritance, because they are born into an environment shaped by the artifacts and practices of humankind (Wells, 2000). Current reform movements in education recognize the "…mutually constitutive relationship between individuals and the society of which they are members" (Wells, p. 54). This recognition has renewed interest in educational practices that promote the social constructive nature of learning and the importance of tasks carried out in small groups (Wells, 2000). These educational practices rely heavily on language as the medium for making meaning.

A science education program designed around the theory of social constructivism would address issues of meaningful learning and socio-cultural perspectives. The benefits to the classroom would include:

1. Movement from a fact-driven curriculum toward a curriculum based on big ideas.
2. Encouraging students to become autonomous learners able to follow their own interests and to formulate ideas (or reformulate the ones they held

that were incorrect).

3. Providing students with the cognitive tools to critically assess the world around them and articulate what they know, do not know, and/or what they question (Chee, 1997).

The shift in focus would be from covering content to achieving understanding, from memorizing facts to exploring meaningful questions (Collins, 1997). One indicator of progress toward improved science education would be science classrooms in which students are actively engaged in "doing" and "speaking" science.

The theory of social constructivism is mirrored by the activities of the academic field of science. Scientists work together to accept or reject claims and/or theories based on their negotiation of evidence and arguments (Newton et al.,1999). Thus, science knowledge results from communities of people working together and, so, is representative of social constructivism. Having students learn together socially provides them opportunities similar to those of the science community. Like the science community, the students can negotiate both concepts and appropriate experimental procedures, and the meanings of their collective efforts and observations. Allowing students opportunities to act as scientists may lead to a better understanding of the nature of science and the scientific community. In turn, having some understanding of how the scientific community constructs what becomes acceptable knowledge strengthens students' own ability to critically assess the implications of scientific knowledge in their own lives.

Collaboration

From a Vygotskian social-constructivism perspective, a major role of schooling is to create social contexts for learning such that individuals master the use of cultural tools (Smagorinsky & O'Donnell-Allen, 2000). Collaboration can be described as interactions in which participants mutually discover solutions and create knowledge together (Kittleson & Southerland, 2004). Collaborative learning experiences, then, provide a social context within which students can jointly build understanding.

When collaborating, students work together to solve a problem. There is no pre-set division of labor; instead the participants distribute and coordinate the tasks and develop a shared view of the nature and extent of the problem they have to tackle (Dillenbourg et al., 1996). In a school context, collaboration casts the students into the role of actively engaged learner within the social context of other actively engaged learners. This leads to an exchange of ideas—or discourse—among members of the group. Nystrand and Gamoran as cited by Dunlap (1999) point out that high quality discourse occurs when the talk takes on the aspect of normal conversation with speakers negotiating the content and engaging in turn-taking. This natural conversational discourse is difficult to achieve in adult-student collaboration such as teacher-directed discourse, but is more likely to occur in peer collaborative groups thus supporting joint knowledge construction (Hogan et al., 1999).

In joint activities, partners contribute to the solution of emergent problems according to their ability. The collective ZPD (Dunlap, 1999) naturally formed by the group when collaboration occurs provides mutual support and assistance to achieve a shared goal. Language provides the means for the coordination and interpretation of the

activities and is the process by which the collaborative experience becomes knowledge (Wells, 2000).

The collaborative process is apparently transformative. But what are the processes that lead to this transformation? If collaboration is defined as group members actively working together to solve problems, what promotes member engagement? What kinds of interaction, within a given context, do groups working together, and demonstrating a significant positive change, engage in that is not present in groups that do not show this same positive change (Bearison, 1982)? In other words, not all collaborative groups will be equally successful (Azmitia & Montgomery, 1993; Bearison, 1982; Hogan, 1999; Kruger, 1992; Tudge & Hogan, 1997) and not all collaborations will be positive (Dillenbourg et al., 1996). Both group membership and context have a bearing on the possibility of successful collaboration.

Group heterogeneity, size, member ability, and student self-perception of success all affect the collaborative group. The general rule of thumb is to group heterogeneously on the basis of ability, social, and demographic characteristics. In theory, this benefits lower-achieving students by giving them access to the intellectual resources of higher achievers and provides all group members with a variety of life experiences accompanied by prior knowledge from different perspectives (Webb, Baxter, & Thompson, 1997). Some studies refute this grouping technique as disadvantageous to certain members of the group. For example, Bearison (1982) found that the collaborative groups that showed the greatest improvement in performance on a spatial relationship task were pairs who both had pretest scores of zero. Individuals working alone who had a pretest score of zero or higher did not improve as much as these student pairs, nor did pairs that were

heterogeneous with regard to initial test score. This study would seem to indicate that homogeneity was an advantage over either individuals or pairs that were not matched with regard to initial ability. This seems to indicate that improvement is not simply dependent on the presence of higher and lower abilities. Simply working with an equal partner was sufficient to promote improvement on the task.

The size of the collaborative group makes a difference to its success. Unlike results from studies of collaborative pairs, Webb et al, (1997) found that heterogeneous ability groups of three or more seemed to be disadvantageous to the student of medium ability. Apparently the helping relationship that develops between the high and low achievers bypasses the medium ability student. Groups of three also seemed especially vulnerable to competition (Dillenbourg et al., 1996), which can bring out negative social behaviors that shut down collaboration (Hogan et al., 1999).

The effectiveness of pairs in advancing cognitive development is even more pronounced if the pairs are peers rather than adult-child pairs. Hogan et al (1999) found that when teachers entered into the collaborative group the tone of the student response patterns became more tense. This is probably because students felt pressure to display their knowledge in the presence of an authority figure.

A similar pattern of adult-child inhibition was demonstrated by Kruger (1992) in a study of collaborative moral reasoning. In this study collaborative pairs were established that were either adult-child pairs or child-child pairs. Each participant was given a pretest; then each pair was presented with a moral reasoning problem to solve. The discussions each pair undertook were recorded and analyzed and then a posttest was administered to each participant. It was found that greater cognitive gains in moral

reasoning were made by participants in the peer groups than those in the adult-child pairs. Analysis of the conversations within the groups revealed that both types of pairs generated conversations that involved criticisms, explanations, justification, and elaborations. However, these sorts of conversations occurred with more frequency within the peer groups than in the adult-child pairs. In addition, peers generated more spontaneous, other-oriented conversational elements while adult-child pairs generated more passive and self-oriented conversational elements by the child-member. These more other-oriented conversational elements were predictive of more sophisticated reasoning on post-test dilemmas. It seems the asymmetry in the adult-child pair inhibited the child's active conversation contributions and subsequent reasoning development. This inhibition was mitigated if the adult involved the child in the decision-making process (Dillenbourg et al., 1996) or if the child entered into egalitarian-type exchanges with the adult (Kruger, 1992).

There are some who argue that the type of task dictates whether an adult-child collaboration or a peer collaboration is more effective (Dillenbourg et al., 1996). While resolution of socio-moral dilemmas are enhanced by peer interaction and depressed by adult-child interaction (Kruger, 1992), Dillenbourg et al (1996) argues that cognitive problems may be better resolved with adult-child interaction, presumably because of the higher level of competence an adult would bring to the collaboration. However, if other-oriented transacts, more frequent in peer collaboration, are indicative of greater cognitive maturity, this same type of collaboration should translate into improved reasoning in other domains such as science.

To examine this idea, Azmitia and Montgomery (1993) looked at whether collaborations between friends improved scientific reasoning and what interactions were likely to promote higher-level reasoning. Their hypothesis was that friends would use higher-level reasoning and this would translate to increased cognitive development over the collaborations that occurred between acquaintances. They found that friends engaged in more conflict dialogue reflecting each other's ideas than acquaintances did and that this type of conversation correlated to better problem solving abilities. Perhaps friends create a psychological context that feels safe and facilitates conflict resolution.

Webb et al. (1997), cited studies that showed same-gender groups worked more effectively together, but ethnicity and cultural differences of members in larger groups (four or more) often highlighted social status differences that resulted in unequal sharing of group resources and ineffective or absent collaborative efforts.

Strough, Swenson, & Cheng, (2001), demonstrated that positive expectations of group membership—for example anticipation of being assigned to a group with a friend—affected the expectations a student held for satisfaction with the group. This study supported the idea that friendship makes a difference in the psychological context of collaboration.

One important consideration in collaboration is what the individual student brings to the group. Individuals experience learning contexts differently and they may also differ in their views on learning as well as on their level of motivation to learn. These differences do not disappear when participating in collaborative work (Hogan, 1999). Thus, students approach tasks with different learning strategies, abilities, and motivation. All of these contribute to the potential success of a group.

In a study that related students' personal frameworks for science learning to their activities in collaborative groups, Hogan (1999) found that students with a meaningful learning orientation showed behaviors associated with engagement, curiosity, and tenacity; related new knowledge to existing frameworks; and viewed learning as fulfilling. Students who believed that group work was valuable as a way to get to the correct answer with less personal effort engaged in discourse that showed low collaborative engagement and in behaviors associated with efforts to hurry their group along with the task. Learners who emphasized learning as recreating a reality (positivists) also showed decreased engagement in collaborative work. Students with a mindset that viewed science as hard or not interesting showed sporadic efforts and were either passive in the context of the collaborative group or were disruptive to the group processes.

These socio-cognitive behaviors were patterns that were observed while students engaged in collaborative knowledge building and generally related to each student's beliefs about learning, especially learning in science. These behavior patterns altered the effectiveness of collaborative efforts.

Studies such as these indicate that while collaborative groups have the potential for solving problems too daunting for a single person, at least some of the group members have to have confidence, tenacity, ideas, and strategies for attacking the problem. This would imply that consideration of intellectual dispositions as well as well as prior knowledge and cognitive skills are all contributors to a collaborating group's success or effectiveness (Hogan et al., 1999).

In a meta-analysis conducted by Lou et al (2001) of studies done on the effects of social context versus individual learning, analysis indicated that, on average, small group learning had significantly more positive effects than individual learning on individual student achievement. These authors found that a group's superior performance was more pronounced when the tasks were difficult, when the groups consisted of three to five members, or when minimal feedback was available to the group. The largest positive effect of social context was exhibited by groups that met all of these conditions.

Cognitive development cannot be explained solely in terms of students' solitary reflections. Knowledge is constructed within a social context in which it is shared and confirmed. The knowledge constructed by the collaborative group represents a resource for each member of the group to utilize even within other collaborative groups in differing contexts (Kelly & Green, 1998). Since the collaborative process is transformative, then it should be studied, not just to determine the change in the ability to solve problems, but to determine the processes that lead to the solutions generated by the group.

Studying the discourse within the group, particularly the discourse centered around negotiation and argumentation, holds the key to understanding collaboration (Dillenbourg et al, 1996). Negotiation refers to members reaching a mutual understanding. Argumentation refers to resolution of conflicts using mutually and contextually agreed upon claims and backing to settle the conflict (Warren & Rosebery, 1995). And each collaborative group gets to negotiate their own meanings and what constitutes acceptable claims and backing. Within a collaborative context, the necessity

to enter into discourse activities requires members to confront others' differing perspectives and allows for mutual conceptual change.

The discourse that group members must participate in has the added advantage of making student thinking processes more available for study (Bearison, 1982). A promising possibility for studying collaborative groups, then, is to examine the discourse surrounding the negotiations and arguments that occur among the collaborating group as an indicator of joint involvement. Conversation turns that exhibit negotiation can be seen as either an effort to reach agreement or as an effort to negotiate a common meaning. Meaning is not something that is fixed but something that will be jointly constructed throughout the discourse event and will be the product of the group (Kelly & Green, 1998).

Most studies done on collaborative groups have focused on the change that occurs to the individuals within the collaborative group. It is probably not appropriate to consider the changes within the individual as separate from the group because what is constructed and internalized by the participants is part and parcel of the interaction within the group. What the group negotiates as valid knowledge, in the absence of outside forces such as teacher intervention, becomes the accepted science for the members of this group.

Conceptual Change

This study will be interpreted in terms of conceptual change theory with the conceptual change being what actual knowledge the group collectively produces and agrees upon. A group, acting in concert, develops its own norms, thus it creates its own frames of reference and situated, distributed knowledge (Kelly & Green, 1998). This is

accomplished through the discourse that goes on in the group as members interact, and is likely to reflect the individual members' understandings. However, it will also be more than just the sum of the individuals' understandings. Much like the "whole is greater than the sum of its parts," what the group produces uses each individual's resources to synthesize a collective understanding. The resultant group understanding affects the understanding of each member possibly altering his or her conceptions. The "…group contributes to the creation of the individual, just as the individual contributes to the creation of the group" (Kelly & Green, 1998, p. 154).

Conceptual understanding occurs when an individual or group has an integrated picture of whole structures, processes, or events versus a disconnected collection of fragmented ideas (Fisher, 2000). Although much research in conceptual change theory has revolved around the area of misconceptions and how to change them, conceptual change can be thought of more broadly to include modifications or transformations in one's knowledge base. Conceptual change can be simply everyday growth within a particular domain, not just the big "Aha" moments. Conceptual change can be thought of as a "journey toward literacy within a domain" (Alexander, 1998, p. 56).

Concepts are perceived regularities in events, objects, or records of events or objects, which humans recognize and label. The concepts that result from these human observations are not stored by a person as individual bits of information but developed into propositions—statements about how some aspect of the universe is perceived or functions. Propositions can be described as units of meaning (Mintzes et al., 2000). Concepts are often identified by a single word, and the propositions built from relating like concepts can be described by a few words. For example, one concept could be mass,

another concept volume, and a resulting proposition could be density—the relationship that exists between mass and volume (Zirbel, in press). The correctly formed proposition about density results from understanding the relationship between the different concepts, mass and volume. Knowledge, then, results from the organization of concepts into propositions that are able to be applied to problem-solving. Otherwise, it is not knowledge, just information (Mintzes et al., 2000). If conceptual understanding is not useful in problem-solving it is not knowledge, it is just information.

The bridge between concepts, their propositions, and knowledge is language. Language is the medium, or tool, used to build the propositions from the related concepts and used to apply the knowledge to problems encountered. The language used is based on the social milieu in which the individual is participating (Mintzes et al., 2000). Individuals and the groups with which they interact through language, then, create knowledge from and through the interaction of each member's concepts and propositions.

In a study done by Garfinkel, Lynch, and Livingston cited by Kelly and Green (1998), a group of astronomers were observed as they moved through several data runs taken in one evening of observations. The negotiations that occurred among the astronomers based on the phenomenon they were seeing in their data, moved the object from being an unidentified vague "it" to being labeled a Galilean [*sic*] pulsar. The object's ultimate identification and name resulted from the scientists' discourse as they confronted a particular problem. Each scientist applied his own repertoire of concepts and propositions until all of the participants came to a mutual understanding of the phenomena they had observed. The scientists went on to publish their observations, the consensus conclusions they drew from those observations, and the evidence used to

support these conclusions. Thus, their knowledge, created in situ by the group participants, became available for others to consider, question, and accept or reject.

Like the scientists with their personal concepts and propositions, students do not come into the classroom as blank slates. They, like the astronomers, have their own repertoire of concepts and propositions developed through their interactions in other cultures besides the classroom to apply to the problems they encounter. The students have been constructing knowledge throughout their childhood either by forming concepts themselves in their every day life or by accepting concepts others in their social milieu have presented or modeled. They will continue to apply their personal conceptual understandings to new science issues. The science knowledge the student subsequently constructs then may be correct or incorrect with respect to the current understanding of science knowledge.

Sometimes the concepts students have developed are sensible, that is, they have worked for the student, but they are incorrect in comparison to conventionally accepted science. For example, students frequently believe that acceleration of an object in free fall is mass dependent: The larger the mass of the object, the faster it will fall to the ground if dropped from the same height (Hynd, 1998a). This incorrect concept—variously known as a misconception or alternative framework—is understandable given what the student has probably experienced in his or her life. It is difficult for the ordinary student to find, observe, and make sense of an instance that would demonstrate the correct scientific notion that acceleration of a falling object is not affected by its mass. This example shows the student's private version of a particular concept is naïve and would not stand up to scientific analysis. The formation of incorrect conceptions and

therefore the knowledge constructed from them—the student in Hynd's study wanting to build a heavier object so it would fall faster—is not exclusive to students. Many reputable scientists' ideas have been accepted as correct science knowledge, only to end up being found incorrect when new data were taken and/or new observations were made. In fact, our current understanding of a heliocentric universe came only after 1000 years of science accepting a geocentric universe (Stern, 2004).

Development of science knowledge is negatively affected by two phenomena: inert knowledge and misconceptions (Vosniadou, 1996). Inert knowledge consists of bits of information that students encounter and store but are accessible only in very limited situations. For example, when a student learns an algebraic algorithm for solving for an unknown in math class but does not see its applicability to solving a chemistry density problem given the appropriate pieces of data, this student's algorithm is inert knowledge. This inability to transfer knowledge from one context to another shows a naïve, fragmented understanding of the concepts involved. This makes the algorithm an information bit not true knowledge, as it does not impart the ability to solve problems.

The second negative phenomenon is that of misconceptions. Misconceptions are incorrect concepts that have been developed by students as workable solutions to their daily encounters. The pre-instructional concepts students hold are often deeply rooted and difficult to abandon or modify to align with acceptable science (Duit, 2003).

Misconceptions, then, are caused by a negative transfer of a concept (Vosniadou, 1996). They are misconceptions because they are not in agreement with our current science understanding (Zirbel, in press) and they are negative because they actively

prevent the student from apprehending the correct conception and thus moving toward greater literacy within the domain of science.

The Private Universe Project of Harvard University created a powerful video that has been widely used by educators (Schneps & Sadler, 1987). This video shows successful Harvard graduates unable to explain why the earth has seasons. In the same video series, students with identified science misconceptions are given explicit, appropriate instruction, yet are shown to retain their original misconception. In the classroom, students attend to what "fits" with their personal conceptual framework and not to what does not fit, and they can and do construe and incorporate the knowledge presented differently than was intended by the teacher (Schneps & Sadler, 1987). Apparently, a misconception does not change just because teachers tell the student the right stuff. Students will need convincing if they are to replace or alter their preconceived notions.

The resistance to learning that results from students' pre-instructional concepts has resulted in increased research by science educators teaching for conceptual change. Thomas Kuhn, a twentieth century science historian, studied and wrote about the scientific revolution (Brush, 2000). Kuhn did not see science as the accretion of knowledge leading linearly to more advanced stages of understanding. Rather, he saw science as remaining static until some event(s) or data upset the status quo. An event/data, an anomaly, forced the scientists involved to rethink their understanding—their central commitments. In other words, individual scientific discoveries and insights coupled with historical crises give birth to new understandings and, ultimately, to a new scientific worldview. One of Kuhn's examples is the revolution from Ptolemaic

astronomy to Copernican: In the face of discrepancies found between observations and Ptolemaic theory, scientists simply made adjustments to Ptolemy's theory to accommodate emergent discrepancies. However, the complexity of the constantly readjusted theory was increasing faster than its accuracy could be re-established with the adjustments. This process opened the door for Copernicus' ideas about astronomy, initially rejected by scientists, to be considered as possible (Brush, 2000). The scientists underwent conceptual change only when their existing understanding no longer worked to solve the problems they encountered.

The process of science conceptual change that Brush (2000) ascribes to Kuhn, resembles the picture Jean Piaget paints about how children construct knowledge. Piaget, a genetic epistemologist concerned with how children learn, identified four cognitive concepts that applied to individual knowledge construction (Wadsworth, 1996). As a child encounters phenomena he or she organizes these encounters into categories or schemata. As the child continues interacting with his or her surroundings and encounters novel events there is an attempt by the child to place the novel event into existing schemata in a process Piaget called assimilation. Sometimes the new phenomenon does not fit any existing category and the child is left with the choice of modifying an existing category or creating a new one. Piaget describes this process as accommodation and maintained that learning involved both assimilation and accommodation. What prompts a child (or any learner) to undergo assimilation or accommodation is the need for equilibration. The learner must be able to incorporate an experience into some internal schemata for equilibration to occur. In the learner's process of assimilation, disequilibrium, and/or accommodation, a learner constructs his or her conceptual

understanding (Wadsworth, 1996). Equilibration, alternatively described as transformative, complex learning, is a constructive process that enables a learner to develop coherent abilities useable in any number of contexts (DeBoer, 1991).

Initial work in articulating an educational theory of conceptual change was accomplished by Posner, Strike, Hewson, and Gertzog in the early nineteen-eighties (1982). Building on Piaget's constructivist views of learning, Posner et al, maintained that an individual student must go through much the same process as the scientific revolution did. That is, the student must encounter an event that is not explained by his or her existing conceptual framework, and there must be discoveries or insights available to the student that do explain the anomaly. Posner et al's, view of conceptual change consists of two phases: assimilation and accommodation. If a student uses existing concepts to deal with new learning, the new phenomenon will be *assimilated*, essentially taken in without much change to existing personal schema. However, if the new phenomenon cannot be understood using the student's current conceptions, the student, if he or she chooses to work through the process, will have to completely reorganize his or her personal conceptions. Posner et al, call this *accommodation* and generally reserve the name *conceptual change* for this radical restructuring of a learner's current concepts (Posner et al., 1982).

These researchers go on to describe the four conditions that must exist in order for a learner to undergo accommodation or conceptual change. First, the student must be dissatisfied with his or her existing concept. The existing concept, when applied to the new phenomenon, leaves "holes" or unexplained areas. Second, the new concept must be intelligible. This means, ideally, the student should see the logic of the argument in favor

of the new concept (Zirbel, in press). Third, the new alternate concept must be plausible. To be plausible, the alternate concept should make more sense than the prior conception and should have the capacity to solve problems. Finally, the new concept should be fruitful with the potential to extend the new concept to other areas (Posner et al., 1982).

Since Posner et al's, initial work, other researchers investigating conceptual change learning have refined or modified Posner et al's, original ideas. Vosniadou (1996), for example, holds that conceptual change is a process that enables students to synthesize models in their minds from the starting point of their existing frameworks. Vosniadou further contends that conceptual change is a *gradual refinement of the individual's mental models*. Therefore, prior knowledge is the critical starting point for learning.

Suping (2003) describes other researchers' views of conceptual change: For example, Chi and Roscoe maintain that conceptual change is learning by repairing misconceptions. DiSessa sees conceptual change as the reorganization of diverse kinds of knowledge into complex systems. That is, students must cognitively organize fragmented naïve knowledge. Ivarsson, Schoultz, and Saljo hold that conceptual change is the appropriation of intellectual tools and the use of these tools in various contexts.

The various contexts that the students must grapple with occur at the societal level, when they are confronted with concepts that are alternative to theirs and they must apply the use of their intellectual tools to this dissonance (Suping, 2003). The multiplicity of views on conceptual change is due in part to research advances that have produced more insights and knowledge and in part to the very complex matter of how people learn (Tyson, Venville, Harrison, & Treagust, 1997).

In a research of the literature published during the 1980s and 1990s on conceptual change, Tyson et al., (1997) found that there were varying names assigned to conceptual change—for example, weak and strong restructuring, conceptual exchange, conceptual capture and enrichment, and revision—to name a few. These names and their descriptors were developed by researchers to try to describe varying degrees of conceptual change and are based on each researcher's background commitments and theory of conceptual structures (Tyson et al.).

A common theme in conceptual change literature, however, is that there are big conceptual changes and there are small conceptual changes. Figure 1 illustrates that some conceptual changes do not require complete restructuring. Rather, conceptual changes can occur as concepts are accumulated and coordinated. Over time, the interrelated and coordinated concepts may result in a change in conceptual understanding; however, there is no one "Aha" moment of change. If some change must be made to the existing conceptual structures, this is referred to as revision and may require minimal changes, as in a weak revision, or a major restructuring or strong revision.

Teaching for conceptual change involves moving students through a particular domain, in this case science, from a novice position to, ideally, a proficient position. A novice learner comes to the table with preconceived, fragmented, and/or incoherent concepts. The novice does not know enough to be able to distinguish between important or unimportant information or evaluate the relevance of information. A competent learner uses prior knowledge as a springboard and some domain-specific processes are routinized enough to free up learning time. At the same time, a competent learner may

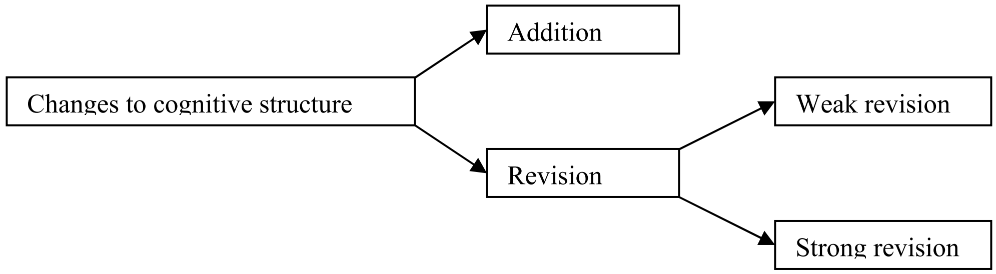


Figure 1: A model of the dichotomy of levels of conceptual change.
From "A multidimensional framework for interpreting conceptual change events in the classroom" by L.M. Tyson, G.J. Venville, A.G. Harrison, & D.F. Treagust, 1997, *Science Education*, p. 389.

concepts he/she has formed. The proficient learner is the expert—probably the ones creating domain-specific knowledge. These would be the scientists, for example, and it is unlikely that any student in school, with the exception of graduate school, would achieve this level of domain-specific conceptual understanding (Chinn, 1998).

Research has looked extensively at the pre-instruction conceptions held by students as well as changes in the conceptions held by individuals due to instruction. Hence, we know that students come with robust alternative conceptions that are hard to alter (Posner et al., 1982). Current research is investigating the conceptual changes necessary to facilitate learning (Tyson et al., 1997). The important considerations for this study are that conceptual revision or change has been examined at the individual student level versus at the level of the collaborative group. Research into science content embedded in collaborative learning environments that support conceptual development, revision, and/or change is a neglected area of research (Duit, 2003).

As cited earlier, the astronomers working together on the phenomenon presented by the data negotiated essentially new science knowledge. This group of scientists faced a problem, drew on their intellectual histories, and constructed an understanding of the problem (Kelly & Green, 1998). Posner et al (1982), posit that individuals come with personally developed concepts—their conceptual ecologies—and that these conceptual ecologies have developed through interactions with others. However, any revisions or accommodations—any conceptual change—are considered from the individual's viewpoint. This is in contrast to ideas that a collaborating group such as scientists working together or students working together determines the conceptual understandings for the group. The group, through the social interactions of its individual members, situationally construct science knowledge (Kelly & Green, 1998).

Kelly and Green (1998) contend that as the members of a group interact, individuals within the group shape and are shaped by the discourses that they use to establish themselves within the group. The knowledge constructed by the group through their discourse becomes the common knowledge of the group and a potential resource for each member. There is, then, a relationship between the privately held concepts of any given member and the common knowledge developed and agreed upon by the group. The sociocultural perspective these authors bring to bear on their studies draws on four premises: First, groups use discourse to define the norms, rights, obligations, and constructed meanings they will share. Second, the co-constructed nature of these processes make the knowledge that is co-constructed the group's product even if the individual takes this up as his or her own. Third, participants within the group interpret the group's actions and interactions in order to participate in a socially appropriate way.

And, fourth, each member comes to the group from other groups with different constructions and this means each member brings his/her own frame of reference to bear in the interaction within the group (Kelly & Green, 1998).

It can be argued that conceptual changes, big or small, are “evolutionary versus revolutionary” (Savinainen et al., 2005, p. 192). Explaining, arguing, providing evidence, and negotiating are all elements of collaboration that lead to concept development and change. These discourse activities are necessarily a group effort, and the resulting product, agreed-upon science knowledge, is the group’s product—not the individual’s—whatever the individual does with the knowledge privately, notwithstanding (Kelly & Green, 1998).

Tied closely to the ability or disposition to form a conceptual understanding or make a change in one’s existing understanding in science, is a student’s personal epistemology of science. Epistemology is the branch of philosophy that is concerned with the study of knowledge and how one comes to know something. That is, what counts as knowledge (Noddings, 1998). A personal epistemology is what beliefs an individual holds about the nature of knowledge, how he or she comes to knowing something.

An epistemology of science looks at what counts as knowledge from a scientific standpoint. A scientific epistemology encompasses the grounds upon which scientific claims are advanced and justified. Scientific epistemology is a description of the nature of scientific knowledge, the source of this knowledge, its validity, and what counts as scientifically appropriate warrants (Sandoval, 2005).

One's view of knowledge, his/her personal epistemology, certainly influences how one approaches learning any subject including science. One issue to consider in trying to teach for conceptual change, then, is: How does a student's practical epistemology—what he/she carries into the classroom—affect a student's ability or inclination toward conceptual change. Students' epistemologies may differ from scientists' epistemologies and when they do, the student acts upon the knowledge event with his/her own epistemology not necessarily a scientific one (Leach & Millar, 2006).

Studies have shown that students do not appreciate the reliance on data in scientific arguments (Rosebery et al, 1992) and they show deficiencies in designing experiments and drawing conclusions. Carey and Smith (1993) argue that while students' may actually lack knowledge of hypothesis testing—which partially explains these deficiencies—the deficiencies may also be a result of a commitment to a naïve epistemology. That is, with no clear understanding of the differences between theory, hypothesis, and evidence, students expect a direct relation between hypothesis and experiment and they tend to reach more certain conclusions from their data than their data warrants.

Getting students to ask themselves how they know what they know and why do they believe it from a scientific viewpoint would go a long way toward moving students from a naïve epistemology to a more sophisticated one. This would mean an evolution in their science conceptual understanding, a form of conceptual change (Savinainen, Scott, & Viiri, 2005). Not only is this movement necessary in order for students to do better at science in school, it is necessary in order for the students to apply it in the analysis of policy decisions that arise from any scientific enterprise (Sandoval, 2005). Finally, if

students' personal epistemology is not sufficiently sophisticated, it can pose a stumbling block for conceptual change.

Role of Discourse

A common thread running through social constructivism, collaboration, and conceptual change—the theoretical underpinnings for this study—is the importance of language as the medium, or tool, for making meaning. Discourse is the situated, purposeful use of language (Wells, 2000). Discourse enacts social identities and supports social activities, and is the cultural tool members of a group use to establish the roles, relationships, and obligations that define membership within any cultural group (Gee, 2005).

This study focused on describing and examining the discourse that occurred among members of a collaborative group as they work to solve various science problems posed by their teacher. The discourse required by the participants made explicit the ways students were thinking, what existing understandings they worked from, and the final knowledge-product(s) they developed as a group. That is, the participants' discourse reflected their shared scientific reasoning. Little is known about the extent to which students take up the scientific views presented by teachers and how, or even if, these views alter their conceptual understanding of science. To examine students' views, research must consider the range of discourse practices shaping science in school. Describing and examining discourse—especially as students engage in science activities—can provide a means of getting into the minds of the students to help make sense of the patterns of interaction and how these patterns may shape their science learning (Kelly & Chen, 1999).

In addition to its function as a tool, discourse is itself an instructional goal. The ability to communicate and the ability to work in groups are two skills increasingly cited as basic skills required for jobs. What counts as knowledge, then, is no longer just the information passively received by students from books and lectures but what is collaboratively constructed through discussion (Cazden & Beck, 2003).

Science teaching that meets the expectations of science education recommendations needs to provide students with the cultural tools and conventions of the science community (Beeth & Hewson, 1999). In fact, the relationship between science and science education is that the scientific community generates new knowledge about the physical and natural world, and science education is charged with bringing students together with that scientific knowledge and its practices; that is, enculturating the student into scientific practices (Kelly & Green, 1998). This connection is illustrated by the following stated goal in the *National Science Education Standards:* Science education should prepare students to be able to "…engage intelligently in public discourse and debate about important issues that involve science and technology" (NRC,1996, p. 1). Thus, science education should orchestrate discourse opportunities such as collaboration in order to foster the skills, attitudes, and values that characterize science (NRC, 1996).

This goal, with its suggested strategies, is not being achieved in most science classrooms today. Instead, communication in science classrooms is in the form of teacher-talk with reproductive understanding by the students (Driver, Newton, & Osborne, 2000). Essentially, teachers talk and students listen. Lengthy, on-subject discourse in classrooms is a rare event (Driver et al., 2000; Dunlap, 1999; Kawanaka & Stigler, 1999; Lemke, 1990; Rosebery et al., 1992). For example, Table 1 shows several

possible patterns of discourse in a science classroom.. Most of what goes on in classrooms is teacher-centered discourse and is featured on the left-hand side of Table 1. Progressing from left to right in Table 1 shows patterns of increasing student-centered discourse. Research shows very little of the right-hand features showing up in classes.

Table 1

Patterns of Classroom Discourse

	Lecture	Recitation	Guided Discussion	Student-Generated Inquiry discussion	Peer Collaboration
Mode of Teaching and Learning:	Teacher transmits knowledge to students by telling	Teacher assesses knowledge by asking	Teacher constructs knowledge with students by asking	Students construct knowledge with one another by asking and explaining	Students construct knowledge with one another by asking and explaining and doing
Conception of Nature of Knowledge:	Retention of Facts	Retention of facts	Comprehension of complex topics	Formulation of key issues	Independent yet collaborative thinking
Teacher Responsibilities:	Expound clearly	Know and judge answers	Elicit and guide thinking	Facilitate creative work	Monitor from afar
Student Responsibilities:	Listen and remember	Study and recite	Express own ideas	Invent and design	Invent and design
On-going Assessment and Evaluation:	Attending Multiple choice	Accurate? Multiple Choice	Changes in thinking? Integrative questions	Productive aspects? Integrative questions	Sense-making? Integrative questions
Teacher Questions:	Rhetorical	Test	Conceptual	Rare	None
Student Questions:	Rare or limited to end of class	Rare, may be viewed as threat	Welcomed	Occur frequently and spontaneously	Occur frequently and spontaneously

Note: From van Zee, Iwasyk, Simpson, & Wild (2001).

However, in order to be recognized as a member of a particular community, for example the science community, an individual must be able to use the ways of talking,

acting, and interacting that are particular to that community (Gee, 2005). It is through language use that a culture, in this case the culture of science, is made available to students (Newton et al., 1999). Thus, discourse is the tool for driving learning and competence within any given academic discourse is a goal of education (Pontecorvo, 1993). Learning science Discourse, then, is one goal of science education.

How do students learn to talk science? Science is a culture with specialized activities, such as experimentation, and particular practices, such as graphing (Lemke, 2000). Idiosyncrasies of the languages must be learned, and there are often translation problems. A word in science—impulse as used in physics, for example—may have a different meaning than that same word in the student's everyday discourse (Itza-Ortiz et al., 2003). Science Discourse is made accessible much the same way a foreign language is made accessible—through practice.

In most science classrooms this practice is not afforded the student. In fact, in most classrooms the discourse follows a predictable, teacher-centered interaction pattern. The teacher makes a "bid to start" which is ratified by the student(s). Then the teacher begins the thematic lesson intended to present the science information. The lesson is presented in a conversational pattern that follows an almost universal triad--IRE. The teacher asks a question (I), a student responds (R), and the teacher evaluates (E) the answer. The student is left to determine theme—what science is meant to be learned—on his or her own (Lemke, 1990).

This triadic dialogue is neither intrinsically good nor bad—its merits depend on the purpose it serves. The problem is its pervasive overuse. This communication pattern makes the science classroom a paradox. The most capable person, the teacher, does all

the talking and the novices, the students, have little or no opportunity to play with the discourse of science (Savinainen et al., 2005).

This IRE is not only nearly universal, it is resistant to change (Cazden & Beck, 2003). Despite all the educational research showing the importance of student discourse to their learning, academic talk among students is notably absent from the science classroom (Savinainen et al., 2005). Students engaged in lengthy discourse in classrooms is infrequent, yet the role of student discourse to the deep understanding of any subject is critical (Graesser et al., 2002). Giving students the opportunity to verbally "hash out" their learning with other students offers them opportunities to test out their ideas and talk themselves to understanding (Sperling as cited by Dunlap, 1999).

Science is not simply a collection of facts that result from unrefuted experimentation. Science involves construction of theories and explanations for observed events; and these explanations are open to challenges. What comes to be acceptable science only evolves after conflict and challenges to design, methodologies, conclusions, etc. occur. This is the "quality control" in science (Erduran, 2004).

While scientific communities have established social mechanisms for validating claims and providing opportunities for its members to question evidence and explanations, opportunities like these are not a given in science classrooms (Vellom, Anderson, & Palincsar, 1993). It is incumbent on educators to provide situations for students to work out precise understandings of scientific concepts and come to "own" scientific Discourse.

There are a number of reasons for providing opportunities for student-generated discourse in a science classroom. An initial reason for getting students to speak up in

science courses is to find out what it is they do or do not know about the subject at hand. Teachers attempt to bring students to an understanding of consensual knowledge—knowledge generally agreed upon by scientists—in a meaningful way. To be meaningful, learning must be built upon existing knowledge which students make apparent by articulating their thinking. Unless students are afforded the opportunity to let those around them know what they are thinking, what they know or are learning will remain a mystery. When students do talk in science classrooms, students and teachers have an opportunity to see if they are in agreement about what is being learned.

Another reason for encouraging student discourse in the science classroom is to afford students the chance to test out or validate their ideas in a (hopefully) comfortable environment. Students' discourse will reveal their conceptual understandings and their contributions are then available for consideration by fellow students. Students may find their understanding differs from other students prompting *an extended discourse*, which explores the reasoning behind the various viewpoints. This will provide all of the students opportunities to compare their understanding to others' and possibly prompt them to reconcile their different understandings effecting a conceptual change (Chin, 2001).

As students engage in science discourse and hear the questions and alternative views presented by their peers, their metacognitive skills can improve (Livingston, 1997). Metacognition—awareness of one's thinking processes—is essential for learning. Metacognition involves active control over thinking processes and includes the abilities to plan approaches to problems, monitor comprehension of material, and evaluate one's progress. When students are asked to solve a problem or respond to an extended

question, they are being asked to use metacognitive skills (Livingston, 1997). Discourse within the classroom, then, may help students gain insight into their reasoning thus strengthening their metacognitive skills.

When students verbalize their thoughts they make their thinking open for inspection and consideration by other members of the classroom. This may engender challenges to their reasoning. Warren and Rosebery (1995) found that students engaged in collaborative discussions had to consider and counter these challenges. This confronts the students with an additional repertoire of questions—the ones posed to them by their peers—to add to their own internal arsenal for application to future problems they might encounter. Students, through classroom discourse, gain new ways of looking at problems, which serves to enhance their collective metacognitive skills. Collaborative discourse has the net advantage of sharpening students' ability to think critically in a scientific context so they will not be easily duped in future encounters (Erduran, 2004) and enables students to generate new conceptual understandings—a form of conceptual change—by prompting them to organize or reorganize their existing fragmented, naïve concepts (Dawes, 2004).

Students may "see" observations differently from one another. That is, they may focus on different features of the same event resulting in differing mental models or concepts. What will be accepted by the group as the consensus knowledge will depend on the members' discourse about their observations (Driver & Leach, 1988). This parallels the actions of scientists as illustrated earlier in the negotiations undertaken by astronomers observing the same phenomenon and trying to develop an explanation for what they observed (Kelly & Green, 1998).

The discourse undertaken during collaboration will require participation by the group members, shifting some of the initiative for learning back to the student (Wells, 2000). Therefore, dialogic engagement is potentially motivating for students as it draws them into the problem (Savinainen et al., 2005). When students engage in these types of interchanges, the "interaction between the personal and the social dimensions promotes reflexivity, appropriation, and the development of knowledge, beliefs, and values" (Erduran, 2004). A community is a powerful force for effective learning and the collaborative group's discourse can be tremendously helpful to one another (Bruner, 1977).

While collaborating, the behavior of one member is influenced by the behavior of another member such that there are no one-way actions. Instead, negotiations occur among the members (Pontecorvo, 1993). Any learning that goes on within a group, then, is situated learning and is shared by the participants so the knowledge that results from the collaborative group can be considered co-constructed knowledge (Kelly & Green, 1998). Listening to and closely examining student discourse enables the researcher to look at the role of collective speech during this process of science-in-the-making (Kelly & Chen, 1999).

The discourse enacted by the group is explicit and therefore open to observation (Bearison, 1982). Students' private meanings are made public so students' emergent participation and patterns of thinking, which can be informative about their learning, can be followed (Ritchie, 2001). Examining student discourse can answer relevant questions about the participants' epistemologic stance on science (Hogan, 1999), it can describe what kinds of interactions occur within the group, what factors support and/or constrain

the group process, and what the outcomes of the group's collaborative efforts are (Kelly & Green, 1998).

Students learn from each other. Their interaction requires reflection, adaptation, reasoning, and decision-making—in other words, negotiation—to become established in relation to each other (Dawes, 2004). Negotiation can be viewed as a process by which students attempt to come to an agreement. But, in this study negotiation refers to negotiation of meaning. This is an ad hoc process of adjustments made by members of the group in order to come to a mutual understanding. In this study, student discourse was examined to reveal instances of concept negotiation that occurred during collaboration. Concept negotiation occurs when there is a mutual exchange of ideas that contributes to the conceptual content of a group conversation. Negotiation ensues until mutual understanding occurs (Kittleson & Southerland, 2004). The conceptual agreements shaped by the group discourse becomes the common knowledge of the group and is likely to heavily influence what each member of the group internalizes (Kelly & Green, 1998). If science educators can understand the discourse processes that surround negotiation, a model may be built for how concept negotiation may alter the conceptions of the group to affect science learning (Dillenbourg et al., 1996).

Negotiations, including concept negotiations, can be viewed from the standpoint of an argument. An argument is a series of statements presented in support of a claim or conclusion (Baergen, 2006). In its most basic form, Toulmin describes an argument as a *claim* made based on facts or *data* and supported by propositions or *warrants* that legitimize the claim/data connection. That is, the claim made is a logical claim based on the data observed because of some authorizing proposition. The data must be available

for the arguers to know. For the proposition, or warrant, to be taken as legitimate, it would have to be deemed valid by the arguers. *Qualifiers*, *rebuttals,* and *backing* complete the basic argument components. Qualifiers limit the strength of a claim, rebuttals refute the warrant(s) used for a claim, and backing strengthens the warrants made for a claim (Toulmin, 2003).

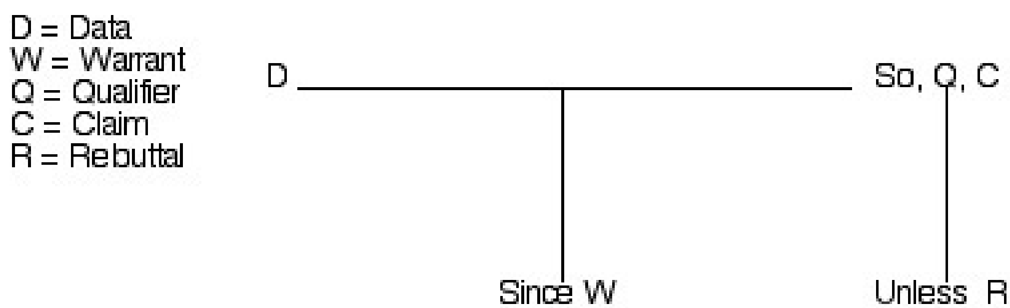


Figure 2. Toulmin's form of argument.

The basic argument pattern that Toulmin outlines is said to be field-invariant, that is, claims based on data supported by warrants is a feature common to arguments in any field such as a mathematics argument, a social argument, or a science argument. However, the standards applied to a claim and to the support of a claim -- the warrants, backing, and qualifiers -- are said to be field-dependent. In science, for example, there is a reliance on evidence that is testable and replicable to strengthen causal claims. Qualifiers might indicate those instances when the evidence presented (data) would not yield the conclusion drawn (claim).

Making and supporting knowledge claims, a goal of scientific inquiry, is an epistemic response to the question: How do you know something? (Toulmin, 2003) Argumentation about the appropriateness of experimental design, the legitimacy of

claims, and scientific explanations are *de rigueur* within the scientific community. Thus, the teaching of appropriate forms of argumentation in the science classroom would reflect what scientists do and enable students to become better judges of both the power and limitations of science (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000).

Listening to students when they enter into arguments reveals the students' present epistemic beliefs, what they consider grounds for knowledge. When students argue in science, the field-dependent parts of the arguments are based on the students' criteria, not necessarily criteria that would be acceptable to the scientific community. Jimenez-Aleixandre et al (2000) have described a set of epistemic operations (see Table 2) characteristic of scientific reasoning.

In learning the Discourse that is characteristic of science, students will need to learn the importance of, and how to apply a scientific epistemology to their reasoning. A component of successful science teaching is teaching the value of knowledge acquired through careful experimentation and subsequent argumentation (Carey & Smith, 1993). The school curriculum "… is the one place that society has set aside specifically for the purpose of systematically conveying to the public just what science is" (Rudolph, 2002, p.67). Studying student discourse within the context of scientific reasoning, then, reveals both where the student is and the direction he/she needs to move toward—what the students' conception of science is versus what society has deemed science via the curriculum.

Advances in science are driven by discourse in the form of debate, negotiation, and argumentation among scientists. Students need to understand this uncertainty in science in order to develop a critical approach to "important issues

Table 2

Epistemic Operations

Induction		Looking for patterns, regularities
Deduction		Identifying particular instances of rules, laws
Definition		Stating the meaning of a concept
Classifying		Grouping objects, organisms according to criteria
Appeal to	--analogy --exemplar/instance --attribute --authority	Appealing to analogies, instances or attributes as a means of explanation
Consistency	--with other knowledge --with experience --commitment to consistency --metaphysical (status object)	Factors of consistency, particular (with experience) or general (need for similar explanations
Plausibility		Predication or evaluation of own/others' knowledge

Note: From Jimenez-Aleixandre, Rodriguez, & Duschl (2000).

of science and technology" (NRC, 1996, p. 1). Promoting opportunities for student dialogue and then analyzing the strategies students use during the process is a significant component of science education (Simonneaux, 2001).

Conclusion

Based on the standard articulated by the NRC in the *National Science Education Standards* (1996) that "Teachers of science develop communities of science learners that

reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to learning"(p. 45), one aim of science educators is to provide contexts for students to try on this new identity as a scientist. Gee (2005) describes one function of discourse—language in use—as enabling an individual to enact a particular identity. In fact, Gee (2005) describes the ability to combine language with behaviors to enact a socially recognizable identity as a Discourse. So, science Discourse is a specialized way of talking and acting that reflects the values and identities associated with members of the social group known as scientists. This would imply, then, that replicating features of the activities of the scientific community in the classroom provides students the opportunity to practice science Discourse. Science Discourse can only be fully understood and adopted by students when they employ this Discourse to work out more precise understandings of the scientific concepts aimed for in the instructional setting (Vellom et al., 1993).

A collaborative group confronted with a challenging problem is a situation that is reflective of the scientific community. Members of the scientific community establish the norms and expectations for their group. For example, scientists place a heavy emphasis on the importance of evidence in backing claims. So too, a collaborative group in a science classroom establishes its cultural norms (Kelly & Green, 1998). Members' individual concepts are pooled and the discourse that ensues may lead to a consensus concept representing potential conceptual change and the co-construction of science knowledge. Students presented with the opportunity to engage in problematic collaboration are exposed to the very human, very messy, side of science—itself a learning experience (Kelly & Green, 1998).

Collaborative groups and the discourse they use during their work have been widely studied. However, these studies have focused on the benefits and drawbacks of collaboration to the individual's conceptual or cognitive development (Bearison, 1982; Dillenbourg et al., 1996; Kruger, 1993), and the influence of the group composition, size, membership, and participant disposition on the success of the group's collaboration (Azmitia & Montgomery, 1993; Bearison, 1982; Ellis, 1992; Hogan, 1999). In addition, much of the research has been done under special circumstances such as camps, extracurricular science programs, or programs with planned interventions, versus within the context and constraints of the normal classroom (Bearison, 1982; Duit, 2003; Wallace & Kang, 2004). "What works in special arrangements does not necessarily work in everyday practice" (Duit, 2003 p. 684).

This would suggest a fruitful line of inquiry to be the group processes that lead to the group's determination of what counts as scientific knowledge and values. What types of knowledge can be accessed, built, or changed from the group discourse (Pontecorvo, 1993)? The inherent social component of classroom learning means that understandings that students develop are due to or heavily influenced by the social context within which they occur. In other words, studies of collaboration must deal with the collaborative processes themselves not necessarily the effects of the processes (Tudge & Hogan, 1997).

Much remains to be understood about the nature of the interaction between members of a collaborative group (Kittleson & Southerland, 2004). Describing and examining student discourse enacted during the normal course of classroom work, can uncover the goals, agendas, and premises that influence what conceptual understanding is shaped by the group and the way this understanding develops (Kittleson & Southerland,

2004). Because discourse is language in use, examination of discourse includes what happens before, during, and after a discourse event. It can reveal shifts in reasoning within the group as well as the strategies used and social procedures enacted while developing the group constructs. Describing and examining the discourse will reveal the socially constructed nature of science knowledge—how members organize, retrieve, present, and manipulate their conceptual understandings. This type of research can help make sense of the interaction patterns within a group by describing the ways of thinking, acting, and interacting common to the group. It is these patterns that constrain and shape the meaning members will construct as a group (Gee, 2005).

Discourses, including science Discourse, assume resources and strategies are characteristic of the community in question. Careful examination of the discourse a community employs can be used as a tool for understanding one way that groups co-construct knowledge. Ultimately, if the discourse processes of a collaborative group can be understood, a model for how engaging in collaborative discourse may change students' science conceptual understanding can be built (Dillenbourg et al., 1996). Key to understanding these processes is a detailed and rich description of them as they are enacted among students.

CHAPTER 3

METHODOLOGY

Introduction

Qualitative research is useful for describing and answering questions about participants in a particular setting. Case studies focus on understanding a single entity or phenomenon (Gay & Airasian, 2003) and allow for generation of an in-depth picture of the selected case(s). This study employed a qualitative case study methodology to focus on student conceptual change during collaborative problem-solving activities in high school physics classes.

The goal of the study was to provide an in-depth description of student collaboration in a high school science classroom. Particularly, the focus was how these kinds of activities could lead to conceptual understandings by the members of the collaborating group. Studies of how collaboration in science contributes to conceptual change has been identified as an under-studied phenomenon in the science education research literature (Dillenbourg et al., 1998). Further, collaboration among students shifts the communication pattern within the classroom from teacher-centered to student-centered. Research into how changing communication patterns in the classroom can improve student learning has also been limited (Scott, Mortimer, & Agular, 2006).

An important data source for this study was audiotapes of the student discourse that occurred during the collaboration activities. While the NRC (1996) standards call for teachers to provide discourse opportunities for students in science classroom so they will

have the opportunity to learn how to present and defend scientific arguments, these opportunities are relatively rare occurrences especially within the naturalistic setting of an everyday, functioning high school classroom (Duit, 2003). Therefore, the descriptions generated by this study will add to the science education literature about the social construction of knowledge and the role of discourse in that construction. The study may further the understanding of group knowledge processing in high school science classes and suggest ways educators can positively support concept building in science.

Choosing the Research Methodology

Two major schools of thought that are employed in research design considerations are a positivist paradigm and a naturalistic paradigm (Lincoln & Guba, 1985).

The positivist paradigm is most readily conceptualized as the 'scientific method' which emphasizes facts, as determined through controlled observations, as being causes of behavior (Bogdan & Biklen, 2003). The basic premise of positivism is that there is a reality that can be discovered by breaking complex phenomena down into pieces, studying the pieces, then re-assembling the pieces into a whole. The researcher accomplishes this through detached observations. These detached observations are possible because the researcher has established an experimental design with controls that would exclude the possibility of the observer (a.k.a. the research scientist) imposing his or her values on the observations and thus the conclusions that are drawn (Fraenkel & Wallen, 2003).

The naturalistic paradigm, on the other hand, is characterized by research which describes processes as they unfold in a holistic manner with prediction and control as "unlikely outcomes" (Lincoln & Guba, 1985, p. 37). The naturalistic paradigm is based

on the notion that meanings are socially constructed, situated, negotiated, and characterized by multiple voices (LeCompte & Schensul, 1999). This type of research, often called qualitative research, involves a researcher entering into the actual setting that is to be studied because the context of the study is critical to understanding the actions observed. The data obtained in qualitative research is descriptive and is analyzed inductively with theory emerging as the study occurs (Bogdan & Biklen, 2003). Particularly, qualitative research is concerned with documenting processes and the meanings they generate for the people participating in the process under study (LeCompte & Schensul, 1999). One kind of qualitative design is that of case study in which a "population, process, problem, context, or phenomenon whose parameters and outcomes are unclear, unknown, or unexplored" is the focus of the research (LeCompte & Schensul, 1999, p. 83).

This study employed a qualitative research methodology because it was concerned with understanding behavior from the participants' frame of reference and generated data that described the people, activities, and conversations that formed the basis of data for this study. It was naturalistic in that the research took place within the natural confines of a school classroom while participants engaged in activities that were not specially set up for research but were a part of the required course work. Case study methodology was chosen because the focus of this study was to document a process—the collaboration that occurred during problem-solving in physics classes. This case study was instrumental in nature because the study potentially provides insights that may be applicable to more than this specific case. That is, this case study may shed light on

generally how collaboration shapes students' science understanding and provide insight into how students co-construct scientific concepts through their discourse.

Participants

Selection of participants

The selected group was looked at in depth and in context in order to better understand the relationship between group discourse and science knowledge construction. The selection of the group for study was based on its engagement in the kinds of activities that form the basis of this research as well as on the practical ability to engage with these students and their teacher. The case group chosen was representative of the kind of students that typically populate this level of physics and were noted (by their teacher) for interacting well in group situations. The final selection criteria depended on having received permission from the participants and their parents to study them as they worked in class.

The physics class that provided the case group for study was part of a large, suburban, public high school with a population of 2060 for the 2006-2007 school year, the year the data was taken. At the time the study was conducted, the student body at this high school was ethnically and racially diverse and the school was classified a majority minority school. Table 3 presents the racial/ethnic diversity of the school at the time of this study, in order of decreasing percentage of representation. The gender distribution at this high school was nearly equal. These identifications and statistics were provided by the school's administration and were part of the normal tracking information maintained by the school. The printouts provided to me by the school administration for these statistics are found in Appendix A. The source is not cited in order to protect the

Table 3

Racial/ethnic diversity of the study school

White	34.0%
Asian	24.3%
Hispanic	19.8%
Black	18.1%
Multi-racial and American Indian	3.1%

anonymity of the school.

Academically, the school's average SAT score for 2005-2006 (the year prior to this study and the most current statistics at the time of this study) was 1593. The same score for the nation was 1518, and for the county in which this high school resides it was 1541. The SAT scores were obtained by accessing the county public school website.

In the county where this high school was located, each student had to complete a biology, chemistry, and physics course sequence in order to graduate from high school. This county offered four levels of physics that students could be placed in after successfully completing biology and chemistry. Three of the four levels qualified students for the college preparatory diploma offered by the county. The remaining physics qualified the student for a technical diploma. Students were placed in physics based on their math placement, teacher recommendation, and, to some extent, student/parent self-selection. For example, students with the appropriate math background and teacher recommendations could have enrolled in one of three levels of physics and still have qualified for a college preparatory diploma. A fifth level of physics, AP Physics C, is calculus based and is taken as a science elective after

successful completion of one of the other physics offerings. While each physics group represented a different level of physics instruction, each level of physics was fairly homogeneous with regard to student ability because the students were placed in a particular physics level based on their math level. Some student/parent self-selection, usually selection for a less rigorous level, may have altered the student ability mix slightly.

The level of physics involved in this study was non-calculus based AP Physics B, populated by high performing high school juniors. The description and prerequisites applied to this course as described in the county curriculum catalog available to the teachers, parents, and students are:

> AP Physics B/Gifted AP Physics B: Prerequisite – Successful completion of Honors Chemistry or higher and Honors Algebra II or higher, concurrent enrollment in Precalculus or higher and teacher recommendation. This course is a rigorous mathematical approach to an in-depth study of matter in motion. Emphasis is placed on mechanics, sound, light, electricity, magnetism and modern physics. Students will be prepared to take the Advanced Placement Physics B exam upon completion of this course. (College Prep Diploma)

Description of participants and their engagement with school science:

The ethnic/racial distribution of the physics class that provided the participants for this study was 5 White, 8 Asians, and 3 Black students. The case group consisted of two males and two females, three of the members were Asian and one member was white. These participants earned a 3.5 average on their AP Physics exam as determined after the study was conducted. At the time the study data was taken, each of the participants had an A average for this physics course. Three of the four members of this group took an elective AP science their senior year and all four participants went on to be honor graduates, that is, they graduated with an overall grade point average over 90%. Three of

the four participants indicated plans to major in science in college. Two of the participants were members of their high school Science Olympiad team and competed with this team at the national level as seniors. The participants' level of academic accomplishment, their interest in participating in extracurricular science events, and enrolling in science classes beyond those required for graduation indicate these were motivated students with a particular interest in science.

These participants understood that they did not have to take part in this research. They expressed some self-consciousness about being observed and recorded by a teacher, albeit not their own teacher. However, these students understood that this kind of research could not happen without participants and they empathized with my need for their support. The participants seemed to me to be playful. When I told them I would have to give them pseudonyms, they asked me if they could choose their own. I agreed and one female student chose Larry, one female student chose Mary Lou, one male student chose Puppet Master, the name of a favorite game character, and the group named the second male Jimbo with a lot of joking surrounding the naming event. None of these names was related to their given names. This case study group was composed of those students in the AP Physics class that had indicated an interest in helping with a research event and also turned in the consent and assent forms required by the Institutional Review Board for participation in this study.

These students did not work in collaborative groups in science frequently. The following two questions were asked in a final interview with each of the participants:

1. How often do you work in groups in your physics class?
2. How are groups formed in this class?

The student responses to these questions indicated that they did not work in groups very often and when they did, it was most often it was with a single, self-selected partner.. The following are representative responses to questions one and two:

> Larry: Umm, like an average amount
>
> Mary Lou: Umm, not very often – usually it's like umm the whole class does it and then you work individually on problems and stuff

and

> Jimbo: Probably like every other week

The students expressed a strong desire to please their classroom teacher. It was clear they thought very highly of their teacher and wanted to do the kind of quality work that would make the teacher proud. In fact, the following exchange during the first activity illustrates this desire:

> Puppet Master: Yea, a little better *(referring to the graph that resulted from a trial*) will you check off on it? *(This question is directed to me as if I could approve/disapprove their work.)*
>
> Me: Well, do you like it?
>
> Jimbo: Yea, we love it, we love it *(in a mock enthusiastic voice that seems to indicate he knows the graph would not be good enough to satisfy his teacher)*
>
> Larry: *(indistinct words indicating to me she does not think the graph is acceptable.) Then she says:* Ok, let's try again.
>
> Jimbo: …One more time?
>
> Puppet Master: Shall we try one more? Oh yea, she'll say no *(again indicating they knew the existing graph would not be approved of by their teacher.)*

The students' personalities surfaced during the course of the study. Jimbo was the quiet one. He generally chose tasks that required him to run equipment but not interact too overtly. He generally made brief contributions to the conversations. Larry was the talker. She made the most verbal contributions and was the first to volunteer to do any jobs that needed doing. Mary Lou was the clarifier often asking questions about the

reasons for various procedures. Puppet Master was the mover often urging the group to hurry up so they could get through the assignment. However, when he disagreed with a conclusion or wondered whether the teacher would approve a particular activity he was willing to rethink the activity and try again.

Description of Activities

There were three lab activities observed for this case study. Each lab activity took place during an extended 90-minute class period. Each activity was designed to be completed within this extended class period. For the first two activities, the students received one lab instruction sheet to be shared by all members of the group but for the third activity, each group member received individual copies of the activity. This may be because the students did not have to provide written responses to the first two activities. For the first activity, the graphs generated on the computer were looked at and checked off by the teacher, for the second activity, the teacher observed the students' culminating run of the experiment, but for the third activity, the students were asked for their initial and final calculations as well as written responses to questions about the differences they found between their calculated data versus their actual experimental data. These activities are found in their entirety in Appendix B.

Activity 1: Graph Matching. The first activity, entitled *Graph Matching* (see Appendix B for the complete assignment), was a kinematics problem that had the participants recreate specified time-motion graphs using a motion detector attached to a hand-held computer. The participants were given pictures of six different time/motion graphs to recreate without any explicit instructions on how to accomplish the task. The participants generated the graphs using their own body movements. That is, they walked,

ran, stood still, and/or moved in particular directions, to generate the required graph. Unique to this activity was that the participants were not required to use any mathematical concepts to generate a prediction and accomplish their assigned task. , This activity required the students to recreate the graphs using their own body movements as part of the procedure. So the procedures that generated their graphs represented the students' conceptual understanding of time-motion graphs. The students did know how to work the Computer Based Lab (CBL) Motion Detector and had done a lab activity similar to this one with easier motion graphs to reproduce.

Activity 2: Projectile Motion. The second activity the participants undertook was a projectile motion activity (see Appendix B for the complete assignment). The purpose of this activity was to have the students apply their understanding of kinematics equations to predict exactly where on the ground a marble will land if it rolls off the edge of a table with a known horizontal velocity. The most important part of this task was for the participants to determine what the horizontal velocity of the marble would be as it left the table. For this, the students used two photogates associated with a CBL device to measure the average time it took the marble to travel a given distance. They then used this value in their kinematics equations to predict where the marble would land. After the students did the initial experimentation to obtain the marble's velocity and predict it's landing spot, their teacher gave them one chance to launch the marble based on their prediction. Success was determined by whether the marble landed in the predicted spot given a small variance allowance.

The participants were less familiar with this exercise than they were with the motion graphing exercises in Activity one. While they had done a similar graphing

activity with the Motion Detector, they had not done any laboratory-based exercises like this projectile motion one prior to doing this activity.

Activity 3: Series circuits. The third activity the students had to accomplish dealt with setting up a series circuit (see Appendix B for the complete activity). This activity had the students construct a series circuit that included two light bulbs with different resistances. The students measured the individual resistances and voltage drops across the light bulbs using an ammeter and voltmeter. This data was then used to calculate the theoretical values for total resistance, total current, and the voltage drop across each bulb if both of the bulbs were hooked together in a series circuit. The students then actually hooked up the indicated circuit, measured the voltage drop across each bulb, and used Ohm's law to generate experimental values for total resistance, current, and voltage drop in their circuit. Finally, the students compared the actual experimental values to the theoretical values generated by their initial calculations. The activity called for the students to compare these two sets of values and explain any differences. This activity was designed to support student understanding of Ohm's Law.

It should be noted that the activities the participants engaged in were confirmatory lab activities, typical of a science classroom (Dykstra, 2005). The teacher did not give the participants instructions but the written lab instructions given the participants were detailed and step-by-step.

Prior to each collaborative activity, the participants individually solved a problem similar to the one that would form the focus of the ensuing activity. Their teacher selected the pre-activity problem based on what the students had been taught in class. For the second and third activities, the students solved the pre-activity problem

individually while talking out their solution into their individual audio recorder. The students then solved this same problem together at the end and this was recorded. The change from the way the pre-activity problem was done as well as adding the post-activity group solution was done as an attempt to gather additional data about any conceptual change that may have occurred during the collaborative activity and if that change showed any commonality. This change was instigated by myself and did not represent a normal classroom activity the teacher would have planned. The problems the students solved and their individual and joint solutions can be found in their entirety in Appendix B.

Data Collection

This study was guided by a preliminary case study conducted by Julie M. Kittleson and Sherry A. Southerland (2004) that looked at the role of discourse in the group knowledge construction of mechanical engineering students completing a senior capstone design project. Due to this fact, a brief description of the study methodology employed by Kittleson and Southerland is included to identify a salient piece of data that will be used in this study.

In order to differentiate instances of knowledge construction from other forms of conversations that occur within the context of collaboration, Kittleson and Southerland (2004) developed the notion of concept negotiation as the hallmark of knowledge construction within the group. Collaboration involves the mutual exchange of ideas and negotiation enables members to reach a mutual understanding about shared ideas. This may generate consensual knowledge among the members. Thus, concept negotiation occurs when more than one participant contributes to the conceptual content of a group

conversation. Figure 3 situates Kittleson and Southerland's understanding of concept negotiation within the larger context of the total group discourse:

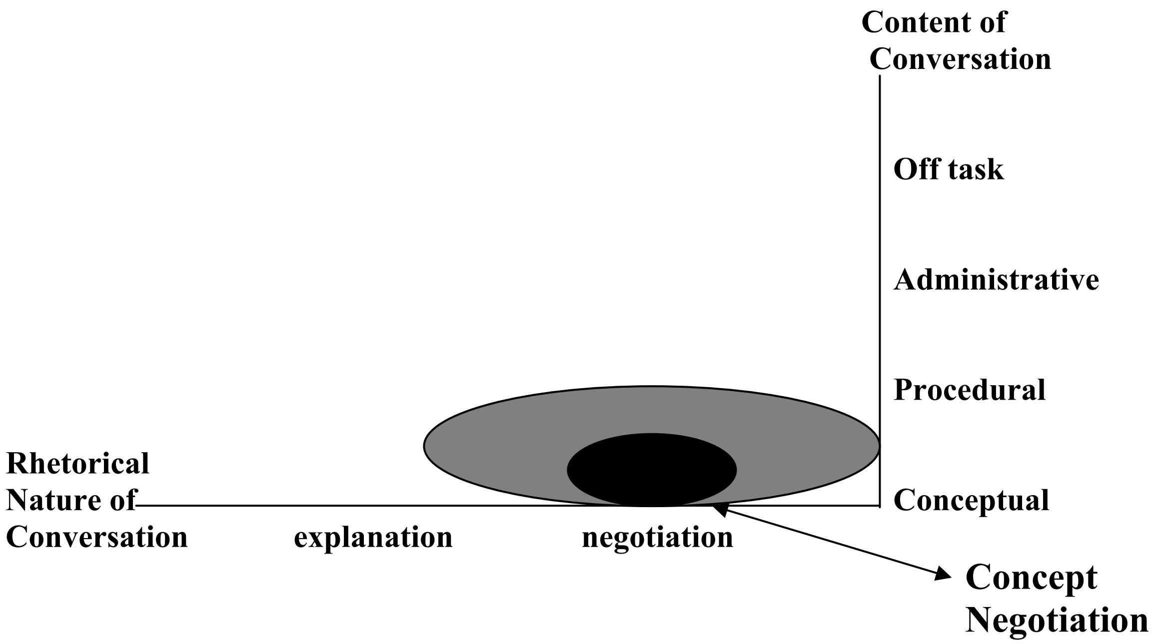


Figure 3: Concept negotiation in relation to other forms of interaction (Kittleson & Southerland, 2004, p. 271)

Kittleson and Southerland describe each of the categories of talk on each axis. On the vertical axis are four types of talk: *off task*, talk that does not address the task at hand such as talking about extracurricular activities; *administrative*, talk about the completion of a task such as discussion of deadlines; *procedural*, talk about the mechanics of the task such as how to set up the equipment to be used in an experiment; and *conceptual*, talk about the underlying science concepts related to the task such as the effects a variable may have on the outcome of the experiment. The horizontal axis describes the nature of the participation in the talk: *explanation*, when one person directs the conversation, and

negotiation, when more than one person contributes to the conversation, whether it is in agreement or disagreement. The discourse that falls at the intersection of negotiation and conceptual talk represents ideal concept negotiation. The larger oval represents an area of overlap where concept negotiation may include some procedural talk and/or explanation. Both of these kinds of conversations are considered efforts at knowledge construction by Kittleson & Southerland (2004). In this study, discourse episodes that reflected concept negotiation were identified as instances of potential conceptual development and change that occurred within the collaborative group.

In order to identify instances of concept negotiation, audiotapes of the participants during their collaborative work on assigned problems in the classroom as well as observations of the selected case group were made. Field notes based on these observations were taken to situate the activities within the context of the classroom. The notes included notations of student gestures, activities, interactions, and any tools and technologies the students used. Observations also included notations and inferences made about the students' values, attitudes, and emotions. Gee (2005) maintains that people enact various discourses, patterns of language in action, in order to establish an identity and/or to build an activity. The taped conversations and observation notes provided the data necessary to completely describe the kinds of activities the participants were building and the thinking processes they brought to bear on these activities.

As a naturalistic study, the case study was observed doing regular classroom activities. For this study, the particular activities that the participants were assigned were lab activities the teacher had planned as a review of concepts they had covered earlier in the course. The labs had originally been planned as a review for the AP Physics exam

and involved applying their physics understanding to the solution of three typical physics problems. Due to personal issues, the teacher rescheduled these activities. They were done after the AP exam as a review prior to the normal high school final exam. The case group members had not done these lab activities prior to this review, however, they had done a simpler version of the first activity, the graph matching activity, earlier in the school year.

Qualitative research is descriptive (Bogdan & Biklen, 2003) so the major source of data was audio-recordings of the participants' conversations that occurred while they worked on their activities as well as observation notes made by myself. Each participant had an individual audio-recorder that he/she controlled. There was also one general tape recorder set up to the side of the activity area as a back up. All of the members of the case group under study knew me because I taught at this school but each understood that I was not acting in the capacity of their teacher. The observations took place for the in-class duration of each assigned activity.

Prior to the collaborative events, I met with the participants' physics teacher. The purpose of this meeting was to determine what concepts she expected each activity to address and what she thought the participants should know and/or learn from each activity. At this point I decided that I should have the participants do a pre-activity problem that addressed the concepts the lab was supposed to support. I did this because I wanted to determine what the participants' initial conceptions were. The teacher chose the particular problems that were used because she was aware of what concepts the students would be expected to know.

Meaningful learning involves restructuring preexisting conceptions but "what learners know and how they build and revise that knowledge" may not be adequately addressed through traditional quantitative assessments. A more complete description of student conceptual frameworks may be obtained when students are provided the opportunity to explain or apply their understandings in their own words (Southerland, Smith, & Cummins, 2000, p. 72). So, after the first activity, I felt that it would be more informative if I had the participants do the pre-activity problem verbally as well as mechanically while being recorded so I could better understand their reasoning processes. I also felt that having the participants solve the same problem together at the end of the activity would help show if conceptual change took place and if the change showed commonality. Thus, I asked the participants to turn on their personal recorders and solve the pre-activity problems for activities 2 and 3 aloud while also writing out the solutions. I asked them to do it again as a group at the end of activities 2 and 3.

The pre and post-problem-solving was planned as a way of looking into the kinds of conceptual development and knowledge co-construction that occurred within the collaborative group. These activities were used to compare each individual's conceptual understanding to the group's apparent understanding as expressed in the solution presented at the end of the activity. The level of conceptual understanding as well as any commonality in the explanation made by members within a group highlighted the influence of concept negotiations on the development of science conceptual understanding within that group. The pre/post-activity problems can be found in Appendix B. The participants' written solutions can also be seen in Appendix B.

Field notes were made during and immediately after the observation period using a contact sheet (see Appendix B). The notes included a physical description of the participants' actions and demeanor within the group. The equipment used and how the participants went about their tasks was described. The participants' talk, including gestures and mannerisms, that occurred among the members of the group were noted. My own feelings and behaviors were noted as well. As the instrument of data collection, my behavior was noted to determine what effect, if any, it could have on the data collected.

The primary data source for this study was the participants' collaborative discourse and the context in which it occurred. The case group was audiotaped and the tapes supplemented with field notes. It is important to "make the subjects' words bountiful" (Bogdan & Biklen, 2003, p. 113) and the audiotapes supplied these words. The audiotapes were transcribed and subsequently coded. The audiotape files were downloaded to a computer and placed in protected files.

The final data were follow-up interviews of the members of the case group. Each participant that agreed to take part in the research had a final interview consisting of a set of questions that elicited reflection on the nature of the collaborative effort. Interviewing allowed me to check the accuracy of the impressions gained during the observation period of the study (Fraenkel & Wallen, 2003). Interviewing can bring out ideas that cannot be directly observed such as feelings and concerns (Lincoln & Guba, 1985) or the idiosyncratic meaning a group member may attach to some activity of the group.

The interview was semi-structured (Bogdan & Biklen, 2003). The set of questions was the same for each student but the interview included ad hoc questions that

were based on responses from the participants or observations made during the activities. The follow-up interview asked procedural questions as well as questions used to get the students' perspectives on their collaboration. The following questions were among the interview questions:

1. How often do you work in groups in your physics class?
2. How are the groups formed in your physics class?
3. What is working in a group like for you? (How do you feel about the way you learn physics when you work in a group?)
4. Was this lab new to you?

Following are sample ad hoc questions:

1. How was the group solution different from your original solution? Were any of the assumptions you made about the problem different than those made by the group?
2. What data were you confused about? What was unusual about the data? Why was the data confusing? Do you have any hypotheses about why the data was different than you expected it to be?
3. If you were to do the lab again is there anything you would do differently?

Table 4 outlines the data collected in this study and the procedures used to generate the data. Table 5 outlines the data collection methods and procedures and the purpose for each data type that had originally been planned for this study:

Analysis

Each individual participant's comments on their recorder were transcribed with each subsequent transcription superimposed on the previous one to obtain the total conversation. This maintained the integrity of each participant's contribution to the conversation but generated a complete record of the conversation. The general recording was used after complete transcription to ensure that the final transcript for each activity was compiled correctly with the order of speakers maintained. This manner of transcription produced a transcript--one for each activity--that maintained the

Table 4

Summary of student activities and corresponding data generated

Exercise →	*Graph Matching*	*Projectile Motion*	*Series circuit*
Preactivity	Students drew motion vs. time graphs for given scenarios.	Students individually solved given problem, talking and writing the solution.	Student individually solved given problem, talking and writing the solution.
Data obtained from preactivity:	Hard copy of graphs	Audio recordings Hard copy solutions	Audio recordings Hard copy solutions
Activity	Students attempt to duplicate required graphs using body motion	Students use motion detectors and data generated to predict where a rolled marble would land	Students use data generated to predict what would occur in a new series circuit
Data obtained from activity	Audio recordings Observations	Audio recordings Observations	Audio recordings Observations
Post activity	None	Students jointly solve the pre-activity problem	Students jointly solve the pre-activity problem
Data obtained from post activity	None	Audio recordings Observations Group solution.	Audio recordings Observations Group solution.
Post interview	General for all activities		

Table 5

Data Collection Methods Planned for the Study

Method	*Purpose*	*Target*	*Procedures for Collecting*	*Data Content*
Observation	Accurate description of context, content, and possible meaning of group discourse	Conversations and student interactions	Written descriptions of activities and their context, audiotapes of group discourse,	Description of physical settings, activities, interaction patterns, meanings, beliefs, and emotions displayed
Post project interview and problem solution	Obtain student perspective of experience and assess conceptual understanding	All members of the case groups	Audiorecording of semi-structured, individual interviews and problem solution	Member answers to open-ended questions and individual student solutions to problem
Audiovisual Methods	Make accurate audiotape records of student discourse during activities	Selected case groups	Targeted tape recording of case group conversations, Recorded solutions to post-project problem	Coded transcripts
Content analysis of text	Evidence for demonstrating conceptual understanding	Final report and/or presentations submitted by case groups as required by the teacher	Repeated observation, with development of themes to apply to written artifacts.	Group written or orally presented work

Adapted from LeCompte & Shensul, 1999, pp. 128-129.

conversational manner and tone the participants used as well as being an accurate record of their words. The speakers were associated with their utterances. Each line of the transcript was numbered for future referencing and retrieval.

This study was descriptive of the ways students acted and interacted while collaborating in high school science. The discourse patterns the students engaged in were closely examined. Kittleson and Southerland (2004) determined that conceptual development within a group would be best described by instances of concept negotiation—collaborative interactions that are conceptual nature and involve more than

one member of the group. They developed a set of coding descriptors that supports identification of these specific kinds of interactions. The transcripts of the discourse from this study were reviewed and initially coded using the descriptors from Kittleson and Southerland (2004). These initial codes are:

- Off-task talk (O): Talk that does not address the task at hand such as talking about extracurricular activities.
- Administrative talk (A): Talk that deals with the completion of a task such as discussion of deadlines.
- Procedural talk (P): Talk about the mechanics of the task such as how to set up an experiment.
- Conceptual talk (C): Talk about the underlying science concepts related to the task such as how to manipulate variables.

After the initial coding the same discourse was further coded for the following conversation pattern:

- Explanation (E): Talk that occurs when one person directs the conversation.
- Negotiation (N): Talk that is characterized by more than one person contributing to the conversation whether it is in agreement or disagreement (Kittleson & Southerland, 2004).

An example of the coding is shown in Table 6. This stretch of conversation was also coded separately by one of my colleagues experienced in coding research data, as a means of member checking. There was complete agreement on those stretches coded as C/N. I coded one sequence as off-task that the other coder coded as administrative, and I coded one sequence as administrative that he coded as procedural/explanation. My colleague coded several sequences of conversation as support for this analysis.

This initial a priori coding was used to identify those stretches of participant discourse that represented concept and procedural negotiation, the types of discourse cited by Kittleson and Southerland (2004) as evidence of knowledge construction. However, certain stretches of these negotiations were further analyzed from the

Table 6

Example of a priori coding system applied to a piece of conversation:

Name	*Transcribed Talk*	*Operation*
Puppet Master:	Hi Ms. *(teacher's name)*	O
Mary Lou:	Hi Ms. *(teacher's name),* You should be very ashamed of me right now. *The teacher had just come into the hallway to check and see if the students needed any more equipment. She also looked at the students' initial problem solutions at this time, which is what Mary Lou's comment refers to. Mary Lou sensed she had not responded correctly to the problems presented.*	O
Teacher:	I need to talk about this. *Referring to Mary Lou's solution.*	O
Mary Lou:	I don't remember!!! *(nervous embarrassment)*	O
Jimbo (hollers)	Mary Lou stop talking! *This was coded as administrative because the intent was to get the other students going on completing the task.*	A
Puppet Master:	Ok, Ok - Who wants to go first?	P
Larry:	What's your name? *This is directed to Puppet Master who had not selected his pseudonym yet.*	O
Jimbo:	I'll record it. *This indicated that Jimbo would record the data into the Motion Detector.*	A
Puppet Master:	It doesn't matter. *This back to Larry in response to her query.*	O
Larry:	It doesn't matter - Hey, It Doesn't Matter!	O
Mary Lou:	Hey Larry you wanna walk? *This sets up which of the students would provide the motion for the first graph.*	A
Larry:	Yes, I want to walk.	A
Puppet Master:	OK	A
Larry:	I so… want to walk the line	A
Jimbo:	Should I move this over more? *Referring to the placement of the Motion Detector.*	P/E

Name	*Transcribed Talk*	*Operation*
Larry:	Hey shouldn't we like walk how many meters we're walking right*? This segment refers to the picture of one of the assigned graphs and represents this student's understanding of what motion would be required to recreate the graph.*	P/C/N
Jimbo:	It doesn't matter. *(Conceptual response to Larry)*	P/C/N
Mary Lou:	Give in meters?	P/E
Puppet Master:	This is a position… Is this a position, time graph, or…?	C/N
Larry:	It's a position time graph.	C/N
Larry:	The curve shows velocity-remember?	C/N
Mary Lou:	Acceleration, the curve's acceleration straight line is velocity	C/N
Jimbo:	*(in background and spoken at the same time as Mary Lou)* No the curve's acceleration	C/N
Larry:	Oh, the curve's acceleration but the line is velocity	C/N
Puppet Master:	How can it be a position time when its (*noise obscures the rest*)	C/N
Jimbo:	Yea it's position time graph - it's velocity	C/N

standpoint of argumentation. Argumentation in science refers to the coordination of evidence and theory to support or refute a claim (Simon, Erduran, & Osborne, 2002). It is also a major strategy used by scientists to resolve questions, issues, and disputes. In fact, commitment to theory by scientists is the outcome of argumentation among the communities of scientists (Jimenez-Alexandre et al, 2000). For this study, analyzing parts of the participant discourse from the standpoint of argumentation, helped provide insight into the students' conceptual understanding of science processes since argumentation in science makes certain forms of knowledge relevant.

Thus, portions of the data that were identified as representative of procedure and/ or concept negotiation received a second and third coding. The second pass coded for the argument operation and the third pass coded for the epistemic operation each participant used in their conversational turns. The argumentation analysis follows Toulmin's (2003) pattern for characterizing the flow of an argument. Toulmin's components used here are:

(a) *Claims,* which are statements representing the conclusions to be established by the argument;

(b) *Data,* which are factual statements used to establish a particular claim;

(c) *Warrants,* which are statements that link and support the claim made based on the data given, the reasons given for a claim;

(d) *Qualifiers,* which are statements of conditions of exception to a claim; and

(e) *Rebuttals,* or statements of conditions that would negate the claim -- essentially a counter claim -- that is being established.

The conversations coded for argumentation were also coded for the epistemic operations the students employed during the argument sequence. Analyzing the student discourse for the epistemic operations they used gave attention to the kinds of thinking processes the students employed in their problem-solving. Characterizing the epistemic operations was based on work by Jimenez-Aleixandre et al (2000). The students' conversation was coded for:

(a) *induction,,* statements or actions that indicate students are looking for patterns;

(b) *deduction*, statements that indicate a student is using on a rule or law for understanding;

(c) *causality*, statements that reflect cause-effect relationships and prediction;

(d) *definition*, statements that give the meaning of a concept;

(e) *appeal,* to authority or some other factor considered authoritative;

(f) *consistency*, statements showing that the students expect a fit between what they observe and what they understand from theory or experience, and

(g) *plausibility*, statements that indicate acceptability or unacceptability of observed phenomena based on the students' prior knowledge.

Table 7 is an example of a stretch of discourse coded for argument and epistemic operations.

Table 7

Sample Coding for Argument and Epistemic Operations

753	Jimbo:	*(Indistinct)*...voltage escapes at a (*Indistinct)*...wires	Claim	Causality
754	Puppet Master:	Well what about V two *(Indistinct)*...voltage is increased	Qualifier	Plausibility
755	Larry:	Well ok because that was only a point zero three	Rebuttal Warrant	Causality
756 757	Puppet Master:	Yea yea ok it was only point zero(*indistinct but sounded like and seems to concur that the difference is not significant)*		Plausibility
758 759 760	Larry:	Like And it moved between cause at one point it said it did say two point nine nine two point nine eight It was just like you know unstable things maybe like (pause) yea so	Data Warrant	Causality
761	Jimbo:	Yea		Plausibility

After completing the field notes, I prepared a contact summary sheet (see Appendix B) addressing a series of focus questions to develop an overall summary of the contact (Miles & Huberman, 1984). This form was given an identifying heading with date, time, and circumstances and it included responses to the following questions:

1. What people, events, or situations were involved?
2. What were the main themes or issues in the contact?
3. Was there discourse that typified concept negotiation? What was this, how was it said, who said it, what words/phrases were used?
4. What new speculations were suggested by the contact?
5. Are there suggestions for subsequent field contact? These will be also be entered onto the next observation sheet so I will be reminded of these suggestions.

Trustworthiness

Maximizing trustworthiness in qualitative research renders the results credible and defensible (Golafshani, 2003). Four terms, credibility, transferability, dependability, and confirmability are applied to naturalistic inquiry as criteria for what counts as trustworthy and significant (Lincoln & Guba, 1985). In this study these criteria were addressed in a number of ways.

The case group was carefully observed for the duration of their activities. Persistent observation insured that relevant elements were identified, important atypical events were caught, and a thorough description of each activity was generated. Persistent observation is identified as necessary for valid qualitative research (Lincoln & Guba, 1985). A variety of methods were used to collect several different forms of data. If several forms of data support the same conclusions, the conclusions drawn have a better chance of being credible. Data collected from several sources protects against bias

because it is not likely that the multiple data sources will be biased in the same way (Gay & Airasian, 2003).

According to Lincoln and Guba (1985), a demonstration of credibility is sufficient to establish dependability. Both dependability and confirmability were accomplished using the concept of an "audit trail." Careful records of data taken, its reduction and analysis, development of findings and conclusions, process notes, and, reflexive notes were maintained. In-depth descriptions of the context of observations and conversations were made and careful documentation of the conversations by the case group members were made.

A major threat to valid qualitative research is observer bias, invalid information that results from the researcher's preconceived perspective (Gay & Airasian, 2003). The background a researcher brings to the research setting affects the lens though which events are viewed. To try to prevent observer bias, the bases for any inferences drawn were identified. The intent of any piece of discourse can only be completely known by the actual participants. As such, inferences made were supported as much as possible by using the participants' own words and/or written work. This allows the consumer of this research to agree with the inferences or have the data at hand to draw different but potentially valid inferences.

The presence of an observer may introduce changes in behaviors. This is especially so in this case study since I was a teacher in the school and represented an authority figure to the participants. I think the participants were initially self-conscious but as they became engaged in each activity, they appeared less self-conscious. For example, they engaged in some off-task talk in my presence and did not turn off their

recorders indicating they were not too self-conscious. However, this kind of research required my presence and so represents a potential flaw in this study.

Each naturalistic inquiry is contextual and unique so the transferability of the research rests on the extensive description of the case with all of its supporting data. The consumer uses this description and judges for him or herself whether this research is transferable, i.e., applicable to a different situation. "It is not the naturalist's task to provide an *index* of transferability; it *is* his or her responsibility to provide the *data base* that makes transferability judgments possible on the part of potential appliers" (Lincoln & Guba, 1985, p. 316, emphasis in original).

Ethical Considerations

Students' anonymity was preserved by immediately assigning a pseudonym to each student. The pseudonyms were used in my notes and transcriptions. The pseudonym for each student was the name used for the entire study. If any follow-up publications to this study occur, student anonymity will be maintained. The pseudonyms were recorded and immediately stored in a password-protected file. The parents and students were informed of this protection in the consent/assent forms.

Prior to the beginning of the study, each participant read an introductory paragraph into the audio-recorder that I used for voice recognition with the recordings that were part of the study itself. Although the participants had pseudonyms, they frequently slipped back into using their given names and these utterances were recorded. However, the sound files from the individual recordings were loaded onto a computer at the end of each day of recording and these files are protected.

The participants were not my own students; rather they were students of a physics teacher in the same science department as was I. This made it practicable to get to the appropriate classroom to take the data for this study. The activities the participants were given were assigned activities so the choice of another teacher's students was important in order to relieve the participants of any sense of coercion in their participation.

The participants, through my meeting with them prior to the study, were aware of the nature of the research, their level of involvement, and what would become of the findings from this study. They were also told that they could turn off the audio-recorder at any time--and taught how to do so-- in order that they could have "off the record" conversations. Informed consents from the parents as well as participant assents were obtained prior to beginning this study and these forms were filed. Beyond these usual documents, my greatest concern was to put the participants at ease. Since I was a teacher at the school where the research took place, I represented an authority figure. I tried to make the participants completely aware of my role and assured them that, like them, I was working in the capacity of a student. Still, they were initially self-conscious. They even asked my opinion about their work even though I had made it clear that I would not be judging their work and was not qualified to do so as I am not a physics teacher. The participants still deferred to me as an authority figure. At one point, one participant even asked me if she could be excused to go to the bathroom even though their teacher was right there. The participants got more comfortable as the study progressed and the students never purposely turned off the audio-recorders during the activities even when they were having off-task conversations.

Summary

To understand how collaboration may facilitate conceptual development—especially how the negotiation of meaning among the group members may influence what kinds of understanding students 'take away' from a science class—an appropriate methodology is one that is descriptive of the context within which the negotiations occur. A qualitative case study methodology was appropriate for this study because it supports in-depth description of processes as they unfold which is critical to understanding the actions observed and the meaning the participants may attach to these actions.

The participants in this case study were junior physics students attending a large, diverse suburban high school. The participants collaborated on activities assigned by their classroom teacher. The participants were aware of the research procedures and my role as researcher.

The data taken included audiotapes of participant discourse taken during their collaboration, field notes made during and after observations, a final interview, and written pre/post activity problems. The data taken was analyzed using an a priori coding system. Selected pieces of conversation were further coded for the argumentation and epistemic operations the participants enacted during their problem-solving activities. Inferences drawn were supported by relying on the participant discourse and written work for support.

This study provided insight into a process that may promote conceptual understanding in science. Orchestrating discourse events for students is not done frequently in the high school science classroom so the processes that occur are not well described. Of special concern in this study is what, if any, conceptual understanding

evolved because of the group process. A thorough description of the group collaboration with a thoughtful examination adds to the body of educational research. Collaboration in high school science provides students with opportunities for increased engagement in more authentic science experiences and may be a practical, less disconcerting starting point for teachers to move from traditional teaching practices to those that are more student-centered (Caprio & Micikas, 1997).

CHAPTER 4

RESULTS

The purpose of this research study was to explore the changes in science conceptual understandings that may take place when students have the opportunity to collaborate on solutions to science problems. The issue that forms the focus of this study is the documented lack of opportunity for students to engage in the science discourse that takes place during collaboration (Driver, et al, 2000; Dunlap, 1999; Kawanaka & Stigler, 1999; Lemke, 1990). Because the incidence of student science discourse in classrooms is low, the focus of the study is to examine the discourse that does occur when students collaborate and how this discourse affects student science understanding. The three guiding questions in this study focus on the conceptual development that may occur through collaboration in science:

1. How do the participating students engage in concept negotiation during their collaborative work in the science classroom?
2. How does participating in a collaborative group activity in science facilitate conceptual development in students?
3. How do concept negotiations undertaken during collaborative work in the science classroom contribute to a conceptual understanding that is common to the group?

Discourse is the situated, purposeful use of language (Wells, 2000) and as such is the tool members of a group use to establish the roles, relationships, and obligations that

define membership within any cultural group (Gee, 2005). Central to this study is the premise that students learn from each other and that this learning occurs at least partly through the kind of discourse that requires give and take by collaborating participants.

A kind of conversation that can promote learning is exemplified by concept negotiation. Concept negotiation can be viewed as a process by which collaborators attempt to come to a mutual conceptual agreement through an ad hoc process of adjustments made by members of the group as they exchange ideas and articulate their own understandings. In this study, the discourse that took place during three in-class laboratory experiments was examined to reveal instances of concept negotiation between members of a group. The conceptual agreements shaped by the group discourse may become the common conceptual agreements of the group and influence what each member of the group internalizes as science (Kelly & Green, 1998). Describing the discourse processes that occur during collaborative work may contribute to a model for how concept negotiation and other types of naturally occurring conversations can influence conceptual development and change and thus affect science learning (Dillenbourg et al., 1996). Collaborative inquiry provides a context for thinking and talking about science. For example, when students have to negotiate conflicts in evidence or use data in explanations they share and coordinate their science knowledge (Rosebery, et al., 1992).

This study is a description and analysis of the discourse that took place during three student collaborative laboratory experiments. For each of these experiments, instances of concept and procedure negotiations were identified. Some of the instances of negotiation were characterized by discourse that could be identified as argumentation,

which is a type of conversation that requires collective speech that consists of making and justifying claims. The field-dependent nature of the justifications used to support claims made in the argument can be examined for the epistemic operations the students use in their reasoning. Analyzing student discourse such as that presented here can give insights into how appropriately students use science talk, and how student learning is shaped by such conversations. This chapter presents the data in light of the questions that are the focus of this study.

Focus Questions:

Focus question 1: How do the participating students engage in concept negotiation during their collaborative work in the science classroom?

Two features of these lab experiments proved important in determining how students engaged in concept negotiation. The first feature was that each experiment required the engaged participation of each member of the group and the second feature was that each experiment required the participants to make a prediction. Each of these features will be discussed.

Physical Engagement

The participating students were given tasks for which they could not just subdivide the labor, work separately to generate their respective piece and then put the pieces together into a product. Rather, each task required the participants to physically participate as well as share their personal conceptual understanding of the task components. This kind of engagement elicited procedural negotiations that linked procedure to concepts. The following conversation sequences illustrate this link:

Segment I.

Puppet Master:	We need tape.
Larry:	No, take a dry erase marker and just mark the floor.
Mary Lou:	Alright, good job, Larry. See if I can remember this *thing (unclear whether Mary Lou is referring to the equipment or the kinematics concepts she is confronted with).*

Segment II.

Puppet Master:	May I see the graph?
Larry:	2 meters, 2 meters, 2.5, 2.5
Jimbo:	Hoooo - Youre gonna hafta walk backwards
Puppet Master:	Yea, I got that
Jimbo:	Ok. Just letting you know
Puppet Master:	So wait
Larry:	2.5
Puppet Master:	Hmm
Larry:	Ok Puppet Master, you see this orange line?
Puppet Master:	Yea
Larry:	That's 2.5 meter
Puppet Master:	Ok
Larry:	Wha…!
Mary Lou:	Ok so what's the first graph look like?

Segment III.

Puppet Master:	So, would I like, start doing then slowly get faster or something? Like faster or what?
Larry:	Yea, faster, faster (snapping her fingers to emphasize speed)
Jimbo:	Move back, move back
Larry:	You need your …see cuz you need your Y max as .5 and your scale as .5 so you're going to need to measure out 2.5 meters and cuz yea…
Puppet Master:	Ok
Larry:	Yea so so measure out 2.5 meters

Segment IV.

Mary Lou:	Oh the time--the time it takes to travel between the two photogates?
Jimbo:	Lemme see the meter stick. Yea *(said in response to Mary Lou's question)*

Mary Lou:	Where's the photo *(utters something at same time as Larry's utterances above - sort of an outburst by each that is concurrent). Were the photogates just used to see like t (t is understood by the students to stand for the variable time).*
Larry:	Like the calculator and photogates you'll be using will measure time
Jimbo:	Noo ok *(at first disagreeing then seeming to understand what Larry means and agreeing)*
Mary Lou:	Each photogate is gonna take a velocity or is it like ?
Larry:	No no no *(quickly)* it's going to take it because
Jimbo:	Noo its gonna take distance It's gonna take where it is at the time and we determine the difference in time and the difference between the photogates velocity
Mary Lou:	Oh

Each of these conversation segments was coded as procedural negotiations. Segment I represents procedural statements alone. However, segments II, III, and IV were coincidentally coded as concept negotiation. In segment II, the participants were clarifying just what kind of conceptual understandings are needed to solve the problem at hand and what procedures will accomplish the task. For example, Jimbo says "Hooo -- You're gonna hafta walk backwards." In segment III the participants were expressing their conceptual understanding of kinematics when they direct the "mover's" actions as when Larry says, "Yea, faster, faster". In segment IV, the participants were negotiating the procedures surrounding the use of the photogates, that is, what data they would generate, and how would this data be used in the experiment. This is illustrated when Mary Lou asks, "Each photogate is gonna take a velocity -- or is it like?"

The procedural tasks were parceled out by the students in a cooperative manner, that is, each participant took on responsibility for a part of the procedure. For example, in the graph recreation lab activity (Activity one), Jimbo took on the task of operating the

motion detector while Mary Lou and Larry measured out and marked the course area. Puppet Master tried to move the task along by asking: "Ok, ok, who wants to go first?"

In the projectile motion lab (Activity two), again Jimbo set himself up to operate the motion detectors. Larry read the activity instructions out loud while Puppet Master and Mary Lou obtained the meter sticks for measuring and set up the ramp on which to roll the marble. A similar pattern of physical cooperation emerged with the third activity, the series circuit lab: Larry read the instructions out loud and Mary Lou, Jimbo, and Puppet Master all worked to set up the equipment.

In all of the activities, each student had something to do and the tasks could not easily move forward without each member's participation. What sets the activities these participants engaged in apart and fosters the kind of collaboration that promotes concept negotiation is that the action to be carried out physically required multiple people—someone had to operate the machines while someone else had to perform the motion, for example. However, beyond physical cooperation, each participant had to understand what each of the other members would do and what information each part of the lab activity generated. This generated conversations that could be viewed as negotiation, not for conceptual understanding, but for procedural understanding. For example, in the preceding exchanges in segment III, Mary Lou, Larry, and Jimbo negotiate their understanding of what data the photogates would give them and for what this data would be used.

According to Kittleson & Southerland (2004), this conversation typifies the intersection of concept and procedural negotiations (see Figure 2) and that can contribute to knowledge construction within a collaborative group. This conversation involved

more than one member of a group exchanging ideas and negotiating a mutual understanding of these ideas. Mary Lou opens this segment by trying to clarify what the photogates measure. She is actually on the right track, as each photogate measures the time the marble passes. However, when Jimbo and Larry both respond affirmatively, Mary Lou asks whether the photogates are just used to measure the time she is indicating that she is not clear how this data will be used to get the velocity of the marble. Larry and Jimbo try to explain that the difference between photogate readings will give the time it takes the marble to travel the distance between the two photogates. Mary Lou is still puzzled and asks if each photogate is going to take a velocity. Both Larry and Jimbo jump in, but it is Jimbo who provides the most complete explanation of how the photogates work to provide the time data for the experiment's calculations: The difference in the times recorded by each photogate as the marble passes, divided into the distance between the two photogates will give the marble's velocity. This explanation is confirmed by Larry and seems to be understood by Mary Lou, as indicated by her "Oh." The concept of velocity seemed to be understood by all participants, but it took negotiation--

Jimbo:	Noo
Mary Lou:	Each photogate is gonna take a velocity or is it like
Larry:	Noo it's gonna take the distance. Its gonna take where it is at the time and we determine the difference in time
Mary Lou:	Oh

--to make it clear how the procedures would generate the necessary data.

So, the physical engagement of each participant meant that each person contributed to the execution of the activity. In order to accomplish this, each member had to understand what the procedures were, what data would be generated by each

procedure, and how this data would be used. This physical engagement elicited procedural negotiations by the participants and these negotiations linked the students' procedural and conceptual understanding. In these particular activities, procedural and conceptual negotiation were linked and both contributed to the students science talk.

Prediction

The second feature shared by each activity that contributed to conceptual or procedural negotiations, was that each task required a *prediction* about the outcome of each experiment. In order to accomplish the required tasks and generate a prediction, each student had to make his/her preexisting knowledge apparent to the other participants and they all had to come to a meeting of the minds about what procedures would achieve their goal and allow them to test their prediction. That is, the participants had to make their prior knowledge clear and bring that into alignment with each other's understanding in order to successfully complete their experiments.

In the following exchange, the students are figuring out exactly what they are to accomplish and trying out their initial understanding by bouncing their ideas off the other members of the group.

Puppet master:	This is a position - is this a position, time graph, or…?
Larry:	It's a position time graph. The curve shows velocity- remember?
Mary Lou:	Acceleration, the curve's acceleration…straight line…is velocity
Jimbo:	*(in background at the same time as Mary Lou)* No the curve's acceleration.
Larry:	Oh, the curve's acceleration but the line is velocity
Puppet Master:	How can it be a position time when it…
Jimbo:	Yea it's position time graph. It's velocity.
Larry:	Ms. [Teacher's name] is this position time graphs right?
Ms. [Teacher]:	Yes they are all position time graphs

These statements were coded as concept negotiation. To get started, the group had to understand each other as well as the task at hand. “Is this a position time graph?” While phrased as a question seems more a search for concept confirmation. This kind of science talk at the outset of each activity, was a search for a common understanding of the concepts necessary to undertake the task—“The curve shows velocity—remember?” The participants asked these kinds of orienting questions of each other as a way of determining a starting point in mutual understanding.

This kind of discourse brings to light each student’s preexisting conceptions in relation to the others’ conceptual understandings. For example, Larry’s incorrect identification of velocity as a curved line is brought to light and corrected by Mary Lou and Jimbo. At this point, the group is able to proceed without further discussion of the difference between acceleration and velocity. This is sufficient to clarify Larry’s understanding of acceleration versus velocity.

A different function of procedural negotiations is seen with the following questions from the beginning of the second and third activities respectively.

Mary Lou:	Anyway. Let’s find the exact spot - So we’re looking for v not v actually, d actually?
Puppet Master:	Yea, so the ammeter tells you the current right?
Mary Lou and Jimbo	*(simultaneously)*: Yea
Mary Lou adds:	in amperes

These questions were coded as procedural because they refer to steps that had to be accomplished during the activities. However, it did not seem as though the participants were actually looking for an answer or negotiating what procedures to enact. Rather, it appeared the students that asked these questions knew the answer and were looking for reassurance, or perhaps were simply thinking out loud.

In the conversation below there was conceptual talk between several participants, but it was almost parallel talk rather than negotiation because each student seemed to be orienting him or herself to his or her understanding of both the task at hand and what horizontal velocity means. It did not seem that the students were actually negotiating their understanding:

Larry:	Horizontal velocity is the velocity that goes in a horizontal direction
Jimbo:	and it never changes
Larry:	Never (softly) – Unless theres a
Jimbo:	well
Larry:	force applied
Mary Lou:	a force on it…Like wind, wind could add like
Jimbo:	but this is Physics B there wouldn't be any wind (I think this is said either because wind calculations would be above the level of this course or because this Physics doesn't cover whatever physics deals with wind)
Larry:	Like Applied force.
Mary Lou:	Right
Larry:	Like Applied Force, Like if Jimbo's velocity just changed
Mary Lou:	but that would be like an impulse if it went like that

Negotiations—conceptual and procedural—begin with collaborative activities that require each person to make known his or her initial understandings from both a conceptual and procedural standpoint. From a conceptual standpoint, participants would articulate their definitional understanding of the concepts to be used in the activity—Horizontal velocity is..., for example. And from a procedural standpoint the students would articulate the purpose of various steps -Yea, so the ammeter tells you current, right--for example. Science discourse ensues as students hear each other's contributions. Thus, both procedural and conceptual negotiations contribute to science discourse.

As the participants worked through their activities, conversations based on their experimental observations would result in concept and procedural negotiations. These negotiations occurred as the participants would do an experimental run and then assess its quality. The following disagreement sequence resulted from building on experimental observations:

Jimbo:	It's fine
Mary Lou:	Noo.. It's like not no its not *(emphatically in relation to a discussion about whether the graph they had generated would meet their teacher's standards)*

Jimbo's assessment that the generated graph is fine is emphatically disagreed with by Mary Lou. This indicates that each participant had different standards of acceptability. Jimbo capitulates and this was followed by a new experimental run and an exchange about how to appropriately change the movement to achieve the desired graph shape:

Jimbo:	GO go go go go go *(to hurry the movement)*
Larry:	How's it look? *(Said as she is doing the movement)*
Puppet Master:	Noo - You're too close to it at the beginning…
Larry:	Oh God
Puppet Master:	But if you stood further away then yea that's fine.
Jimbo:	Just do the same thing you did last time…Just stand further away.
Larry:	Yea oh yea this thing is a little off too *(pointing to another part of the curve generated she walks to position to try again)* Ok

Noises of another experimental run:

Mary Lou:	Was it …..
Puppet Master:	No you should stand
Jimbo:	Puppet Master, that was fine
Mary Lou:	It does, it really does. *(Indicating the graph and how it is an acceptable match to the one they are trying to recreate.)*

Puppet Master:	Would she check off on it? *(Again referring to whether their teacher would have approved of their product.)*
Jimbo:	Yea- Good job Larry!
Larry:	Yea - it's a little jagged
Jimbo:	Yea-she would approve that
Larry:	Yea
Jimbo:	Cuz the slopes fine
Puppet Master:	Yea let's try the other one.
Larry:	Yea
Puppet Master:	Hang on hang on hang on
Larry:	Yea Especially right there where I took my first step. I'm not even
Larry:	Oh, this thing

These statements, coded as both conceptual and procedural negotiations, required students to articulate their understandings and seemed centered on how to generate the desired product. These types of conversations were more prevalent in the first activity, since generating graphs that matched the standard required a combination of understanding velocity and acceleration and a bit of trial and error. The participants would generate a graph, look at it, determine among themselves whether is was a close enough match to the standard, and then decide how to adjust their movements to more closely match the required graph.

The students applied different personal standards to the success of this graph. For example, Puppet Master and Jimbo disagree about the success of the graph but when Mary Lou agrees with Jimbo about its acceptability and Mary Lou, Jimbo, and Larry decide the teacher would be satisfied, Puppet Master agrees that the graph is acceptable. This is the final conversation the students had about the J-shaped graph. Larry, Mary Lou, and Jimbo seem to have reached consensus that the graph they have generated was

appropriate and would win the teacher's approval. Puppet Master is not so sure ("Hang on, hang on…"), but capitulates in the interest of moving along with the assignment.

Conceptual Disagreement

The last two descriptors of how students enter into concept negotiation revolve around conceptual disagreement. The conversation sequence below closely followed the second activity's opening conversation, as the participants were setting up the equipment for the projectile motion activity. The discussion revolves around Puppet Master's confusion over the need for two photogates--versus one photogate--to measure the velocity of the marble's take-off speed.

Larry:	*(reading)* The purpose of this lab is to determine exactly where on the ground a marble will land if it rolls off
Puppet Master:	so you guys, why do we need two photogates? You
Larry:	the edge
Puppet Master:	only need one
Larry:	Of a lab table with a known horizontal horizontal velocity. No! Read the lab, Puppet master, read the lab, read the lab ok? A marble will… Ya know if you look at the picture it says: Photogate number one and photogate number two
Jimbo:	uh uh *(directed at Puppet Master)* You're gonna measure the distance between this and then your gonna use a calculator to calculate the time
Larry:	Yea
Jimbo:	Ya gotta get velocity
Puppet Master:	No but all we need so we don't have like ah… alright never mind I'll just read it.

Larry and Jimbo try to explain to Puppet Master the purpose of the two photogates, but are exasperated by his confusion and blame his confusion on a need to read the provided information in the lab--which he agrees to do. However, the argument picks up again when Puppet Master reasserts the need for only one photogate. It would appear that Puppet Master mistakenly thinks that the photogate will measure the velocity,

thus only one photogate at the end of the launch table will provide the necessary data. Puppet Master's confusion is finally resolved by Mary Lou who had exhibited a similar misunderstanding just a few minutes before. Apparently, understanding the need for average constant velocity resonated with Puppet Master and helped him see the need for two photogates.

This is an instance of concept and procedure negotiation that occurs when several members of the group share an understanding that is not shared by all. The participants appear to have a common conceptual understanding of velocity but not a common procedural understanding of the need for two photogates. This generates exasperation among the participants.

The students continue with the activity. Larry is reading the lab instructions out loud when Puppet Master again brings up his confusion about the need for two photogates:

Puppet Master:	Here, we don't need this- since all we need was
Mary Lou:	(inserts at end of above) we need the distance
Puppet Master:	(emphatically) All we need is this, we have the distance here (said impatiently)
Mary Lou:	Right
Puppet Master:	d equals
Larry:	We need the horizontal velocity (insistently)
Puppet Master:	Yea and the thingy here
Larry:	We're trying to find (indistinct). Exactly! The two photo things
Puppet Master:	So we only need one
Jimbo:	No you need two -- Because you're gonna determine the velocity
Puppet Master:	Why do we
Jimbo:	We need two because you can't just measure velocity
Larry:	(Emphatically and concurrent with above). You need two Cuz One calculates One at like one time and the other at another time

Puppet Master:	Oh, ok
Larry:	and then you measure the distance V equals the distance of the thing you measured here divided by time
Puppet Master:	No we don't Ok. Whoa, whoa calm down, calm down!
Larry:	Yea yea yea (softly) Yea, Puppet Master (more emphatically)
Mary Lou:	Find the average constant velocity (softly in background)
Larry:	(softly) Yea
Puppet Master:	That's yea that's that was the answer I was looking for
Larry:	What?
Mary Lou:	Average constant velocity?
Puppet Master:	Yes

This conversation highlights several ideas. First, the participants do not share a common understanding. Jimbo, Mary Lou, and Larry all seemed to understand the need for two photogates but Puppet Master did not. The second idea highlighted by this conversation flows from the first. Because all of the participants did not share a common understanding, negotiations—in this case procedural negotiations—had to take place to decide what was valid knowledge and it took several versions of explanations to bring Puppet Master around to the group's conceptual understanding.

Conversations that were procedural or conceptual both contributed to student understanding of the activity requirements. How and what kinds of negotiation occurs, then, is dependent on providing opportunities for conversations to occur among students. Furthermore, how these conversations are generated is heavily influenced by the kinds of activities required of the students. The activities these students participated in required that they read, communicate, negotiate task procedures, review their procedures, evaluate their success, and accept or reject their work. Figure 4 is a graphic representation of the flow from collaboration to the two types of negotiation most often engaged in by the students in this case study. Examples of discourse pieces that illustrate

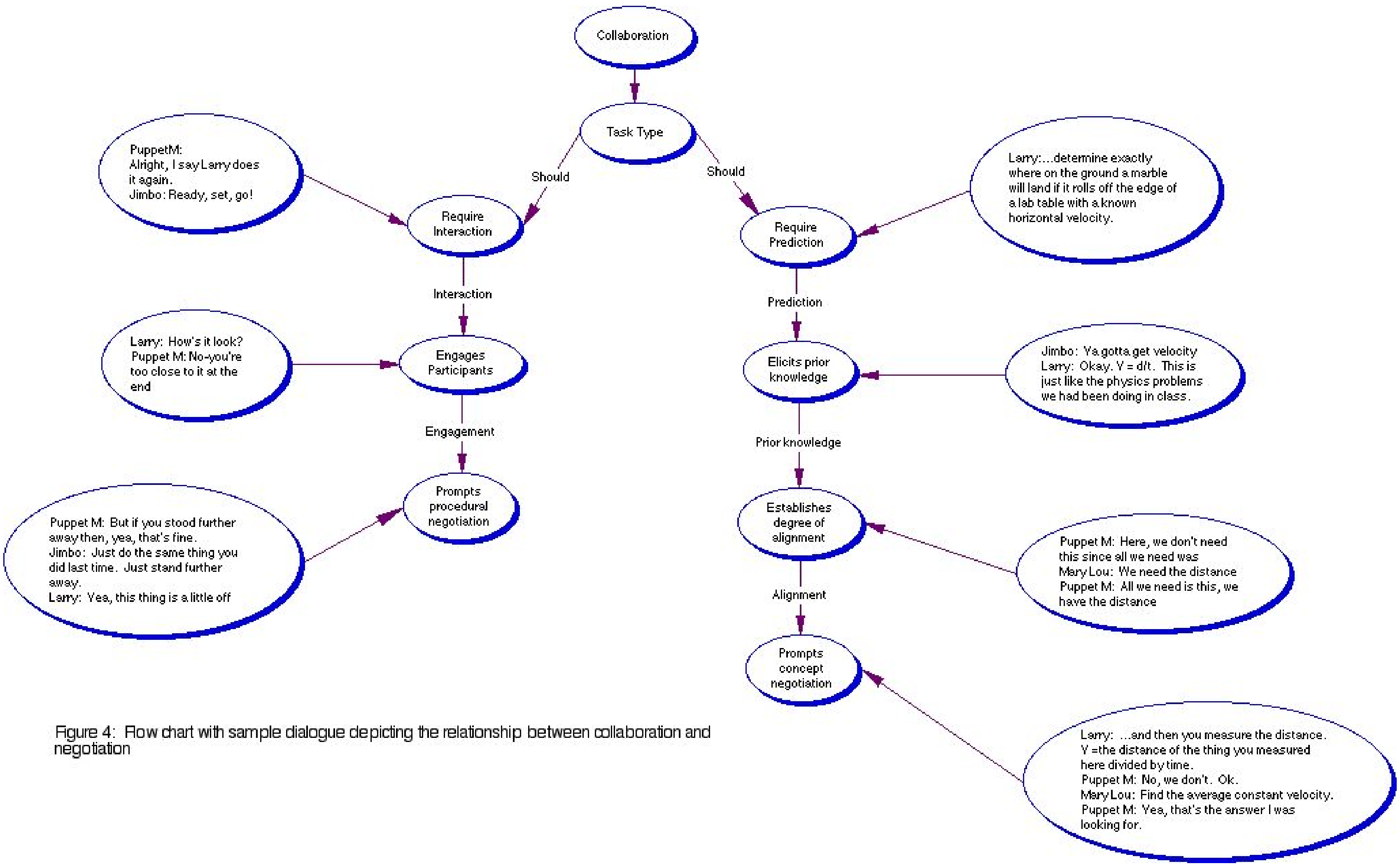


Figure 4: Flow chart with sample dialogue depicting the relationship between collaboration and negotiation

the key components of each step are included in the graphic.

It is through conversation that students share, develop, and maybe change their science conceptual understanding. In this study, the activity elements that generated conversations included the interdependence of all the group members for the planning and execution of the activity, the need for the members to make themselves understood to each other, and a level of motivation, in this case, provided by the element of prediction. The students were engaged, generating explanations, and communicating their ideas. These are features described as essential components of science learning and classroom inquiry as well as indicators of science discourse (NRC, 2000).

Focus question 2: How does participating in a collaborative group activity in science facilitate conceptual development in students?

Concepts are perceived regularities in ideas or events. Researchers have noted that a common precursor to conceptual change is a dissonant or anomalous event--something that does not fit with existing understandings (Posner, et al, 1982). In the following series of student conversations recorded during activity three, the participants wrestle with just such a dissonant event. The participants generated data that did not fit Ohm's Law as explained to them by their teacher. Their conversations are viewed in the context of an argument in which the students essentially argue with their data with claims that their data is wrong.

Arguments can be viewed from a variety of perspectives, but a rhetorical perspective emphasizes arguments as a form of communication (Inch & Warnick, 2002). Argumentation is a reasoning tool and is a major strategy used by scientists to resolve questions, issues, and disputes. Argumentation in the classroom allows students the

opportunity to see the messy side of science versus just the cleaned up material they read about in their science textbooks.. As these students present and defend or support their claims they use a variety of epistemic operations that are characteristic of science (Jimenez-Alexandre et al., 2000) thus giving an indication of their level of scientific sophistication.

The following argumentation sequence occurred when data taken during a circuit building lab yielded anomalous results (see Appendix B for complete activity). This particular sequence was chosen to analyze because each member of the group agreed that the data they had taken were wrong but they did not agree on why it was wrong or what should be the correct response to the problem raised. Thus, this conversation highlights each participant's thinking. Table 8 is a recreation of the group's theoretical and measured data for this activity:

Table 8

Theoretical versus measured values for a series circuit

	Theoretical	Measured (with the meters)
I (total)	0.09 A	.108
V_1	1.88 V	1.55
V_2	2.98 V	3.01

The group's *measured* data for the current and volts, using Ohm's Law, yielded the following values for resistance:

$R_1 = V_1/I = 1.55V/.108\ A = 14.4\ \Omega$ versus the *theoretical* value of $20.93\ \Omega$

$R_2 = V_2/I = 3.01V/.108\ A = 27.9\ \Omega$ versus the *theoretical* value of $33.12\ \Omega$

The two pieces of data that initiated the argument sequence were the measured values for the total current (I) and the measured voltage drop reading, V_2. Both of these measured data, according to the students' expressed understanding, should have been the same value as or a little less than, the theoretical value, but not more than the theoretical value. The students do not simply accept these values. A lengthy conversation ensues as the students try to puzzle through their unexpected data.

This lengthy discourse among the students is treated as an argument sequence and is broken into four parts. Each of the parts demonstrates different components of this argument. The first section is the initial discovery of the anomalous data and the realization that it is inconsistent with their classroom understanding of Ohm's Law. The second segment is the proposal of various theories to explain the anomalous data. The third section occurs when the students discover yet more inconsistent data deepening their confusion. The fourth and final sequence is the resolution of the problem.

The data is presented coded for the argument operation and the epistemic operation each student uses in their conversational turn. The argumentation analysis follows Toulmin's (2003) pattern for characterizing the flow of an argument. Toulmin's components used here are: (a) *Claims* which are statements representing the conclusions to be established by the argument here the claim that the data obtained is implausible; (b) *Data* which are factual statements used to establish a particular claim, in this sequence, the anomalous experimental data obtained; (c) *Warrants* which are statements that link and support the claim made based on the data given, the reasons the students give for

their claim; (d) *Qualifiers,* which are statements of conditions of exception to a claim; and (e) *Rebuttals* or statements of conditions that would negate the claim that is being established.

The conversation was also coded for epistemic operations. Characterizing the epistemic operations was based on work by Jimenez-Aleixandre, et al (2000). The students' conversation was coded for *induction, deduction*, c*ausality*, d*efinition*, a*ppeal* c*onsistency*, and p*lausibility* (see Chapter 3).

In the first section of the argument sequence, there are three parallel arguments being advanced. For each argument, the data and the claim are the same. The data is the measured current. The claim is that the measured current (0.108 amps) should not have a greater value than the calculated value for the theoretical current (0.09 amps). What differs within each argument is how each student proceeds from data to claim. The warrants and backing offered by the students as support for the claim that there is a mismatch between the experimental and theoretical data is different. The differences are seen in the varied warrants each student uses to try to resolve the disconnect and reflects each student's personal epistemic commitments. Argumentation is a reasoning strategy and its elements -- data, claims, warrants, backing, and qualifiers -- are consistent from one field type to another—that is, they are field invariant. However, what counts as justifiable warrants, backing, or data are field dependent (Jimenez-Aleixandre, et al., 2000). Thus, evaluating the students' conversation for the epistemic operations they bring to bear in their argument highlights what the students consider important field-dependent elements in a scientific argument.

Table 9

Initiation of argument sequence: Discovery of anomalous data

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
558	Larry:	[Reading from the student lab handout]How does the measured total current compare to		
559		what you thought the current should be?		
560	Mary Lou:	It's higher	Data	
561	Jimbo:	It's greater	Data	
562	Larry:	It umm the measured value is greater than the uhhh	Data	
563	Mary Lou:	Actual is greater	Data	
564	Larry:	The measured value is greater than the theoretical value	Data	
566	Jimbo:	Why?	Claim	Consistency
567	Larry:	Ok , let's go back to our equations Ok	Warrant	Appeal
568	Mary Lou:	I equals V over R [something indis]	Warrant	Appeal
569	Larry:	Using Ohm's law V equals IR	Warrant	Appeal
570	Mary Lou:	(in background and indistinct) didn't have that yet		
571	Larry:	Thennn		
573	Puppet Master:	What the heck? The should	Rebuttal	Consistency
574	Jimbo:	Would this mean [indistinct] that resistance was lower	Qualifier	Consistency
575	Puppet Master:	No the resistance should have been greater cuz there's resistance in the wire	Rebuttal Warrant	Causality
576	Jimbo:	I know		Causality
577	Larry:	Ok lemme see ok V equals IR and therefore, total current equals V over R. If its LESS then no the measured is actually more than	Warrant	Appeal
578		it so that means that		
579	Puppet Master:	It doesn't make any sense at all	Claim	Consistency/ Plausibility
580	Jimbo:	It just that means resistance is supposed to be lower but that doesn't make [indistinct]	Claim	Consistency/ Plausibility
581	Larry:	The resistance was either	Warrant (cont)	
582	Puppet Master:	But remember there's resistance in the wire	Rebuttal	Plausibility
583	Larry:	Lower	Warrant (cont)	
584	Puppet Master:	so should be greater so it doesn't I don't get it	Rebuttal (cont)	Plausibility
585	Larry:	Yea		Plausibility
586	Mary Lou:	It should be lower (puzzled)	Claim	Plausibility
588	Puppet Master:	It should be actually greater	Rebuttal	Plausibility
589	Larry:	I don't Noo		Plausibility
590	Jimbo:	Did you mess with this?	Qualifier	Causality
591	Mary Lou:	Oh wait beca…	Warrant (incomplete)	

Initial discovery of anomalous data

Jimbo's question (line 566) is an inferred claim that the measured value for current should not be more than the theoretical value. This prompted all the students to see the mismatch. The students had made their theoretical calculations using Ohm's Law as they had been taught and had practiced in class. Jimbo's classroom understanding extended to the fact that actual measurements should be the same as or perhaps lower than calculated values, but that the actual value was higher was inconsistent with his understanding of electricity and experimentation. These arguments can be visualized in Figure 5 below.

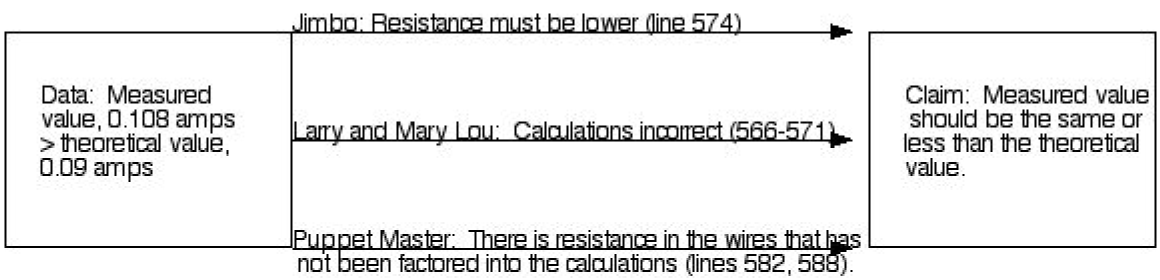


Figure 5: Three parallel warrants for the claim that the data is implausible

Though Jimbo catches the inconsistency in the data his claim that the data is implausible is reflected in his question, "Why?", the warrant he proposes is not stated. Rather, the warrant is phrased more as a question (line 574, 580) and is tentative. Jimbo, probably relying on his understanding of Ohm's Law, offers lower resistance in the experimental set up as rationale to explain the increased measured value for the current.

Larry and Mary Lou recognize and concur with the claim but their warrant is that their calculations are incorrect. So they set about recalculating to provide backing for their warrant. Puppet Master gives the most complete warrant for the common claim

(lines 579, 582, 584, 586). He notes that the wires have inherent resistance which was not factored into the group's original calculations. The resistance of the wires would increase the resistance values in the calculations thus *lowering* the value of the measured current. There is a brief exchange between Mary Lou (line 586) "it should be lower," and Puppet Master (line 588) "it should be greater," that seems to show a difference in understanding but Mary Lou was talking about the measured value for amperes whereas Puppet Master was talking about resistance. This line of argument did not go any further than these two lines so it is hard to tell if there was a fundamental disagreement in conceptual understanding or if there was simply abbreviated conversation with "it" standing in for two different nouns.

While these participants express a common claim, their epistemic approaches to an explanation varied. Jimbo voiced his claim based on a commitment to consistency, that is, what they measured was inconsistent with expectations. This became the common understanding; however, different tacks were taken to identify the cause of the inconsistency. Larry and Mary Lou placed a heavy reliance on appeals to authority: Rather than look at the experiment or set up for answers, both of these students resorted to the authority of the mathematical relationships, expressed by Ohm's Law (lines 567 and 568) . Puppet Master understood the mathematical relationships but his epistemic commitment was to plausibility, a reflection of what kinds of values he expected based on what he understood the experiment should do to the values. Puppet Master (line 575) points out "resistance should have been greater, cuz there's resistance in the wires."

By the end of this initial part of the argument, all of the participants seem to move from their initial commitments to Puppet Master's warrant. They see the plausibility of

the wires contributing resistance thus rendering the data questionable (lines 579 through 589). Figure 6 summarizes this opening argument sequence.

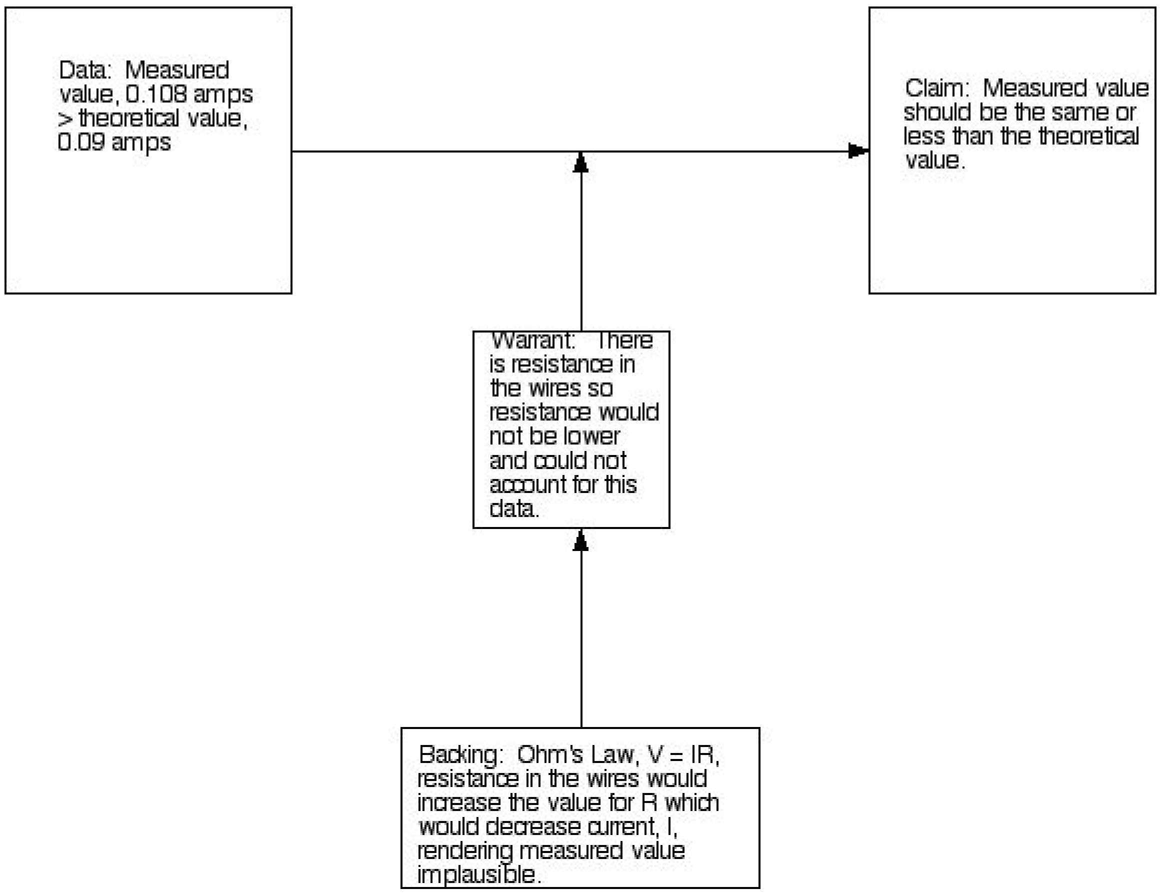


Figure 6: Argument status at end of section one with a common warrant cited

However, the end of this segment of the argument demonstrated that all of the group members' realized that there was a data to theory mismatch and this was sufficient to call their work into question. All four members are confused at this point as indicated by such statements as: "It should be lower" (Mary Lou, line 586), "It should be actually greater" (Puppet Master, 586), and "Did you mess with this?" (Jimbo, line 590) . While there is common conceptual agreement that their data is wrong and the problem lies with

the resistance, none of the participants brought up changes in voltage that could have affected their measured values. Also at this point, none of the participants questioned their experimental procedures or the physical set up of the circuit, which was set up according to very specific directions given on the lab sheet provided by the teacher.

Proposed causes for anomalous data

The second part of the argument is represented in Table 10. The participants are proposing theories for what could have generated the implausible data.

Table 10

Argument section 2: Theoretical proposals for anomalous data

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
598	Mary Lou:	I have a I have a theory	Claim	Induction
599	Larry:	What		
600	Mary Lou:	Because how many cords you used originally	Claim (cont)	
601	Larry:	(Interjects) The button you press just kidding		
602	Puppet Master:	Doesn't matter they're adding to the total resistance	Rebuttal	Deduction
603	Mary Lou:	It actually DOES because it would increase the resistance	Warrant	Causality
604	Puppet Master:	Yea, which would decrease the voltage (response to above)	Rebuttal	Deduction
605	Larry:	What's the hey hey what's the total		
606	---	Meanwhile Puppet Master and Mary Lou are continuing the argument		
607	Larry:	Hey hey Can you take off the volts and see what the total voltage of this thing is right now	Rebuttal	Causality
609	Mary Lou:	(indistinct) total resistance	Warrant (cont)	Causality
610	Puppet Master:	Something indistinct said with above		Causality
611 612	Larry:	Maybe we like accidentally touched it in all that right? There's always the possibility	Rebuttal (continued)	Causality
	---	*The students unhook the power source from the circuit and check the power source.*		
615	Larry:	Yea it's 4.86 right now that's why Our voltage is	Data Warrant	Causality
616	Mary Lou:	Ok		

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
617	Jimbo:	Nooo that doesn't make sense though	Claim	Consistency/ Plausibility
618	Puppet Master:	Our voltage decreased which means our current also should've decreased	Data Claim	Appeal
619	Mary Lou:	(interrupting above) Nooo It directly related (exasperated)	Claim (incomplete)	Appeal
620	Puppet Master:	Everything's saying that our voltage is decreasing	Data	Consistency
621	Larry:	But our our resistance increased maybe it -- that means	Qualifier	Causality
622	Mary Lou:	(Indistinct) how did that happen(?)	Claim (continued)	Consistency/ Plausibility
623	Puppet Master:	If our resistance increased	Warrant to implied claim	Consistency
624	Mary Lou:	Can we end in a confusion?		Plausibility
626	Mary Lou:	Cause we don't know		Plausibility
627	Larry:	We are confused		Plausibility
628	Mary Lou:	We don't know We are confused		Plausibility
630	Puppet Master:	Ok		
631	Larry:	we are confused		Plausibility
633	Larry:	Cuz it the theoretically the measured should be lower because we didn't account	Claim Warrant	Causality
634	Puppet Master:	It should be lower (in midst of above)	Claim	Plausibility
635	Larry:	For the resistance in the wire	Warrant	Causality
636 637	Puppet Master:	Cause the wires have resistance	Warrant	Causality
638 639	Mary Lou:	IS lower our theoretical IS lower	Claim	Causality
640	Larry:	No no no our measured measured is supposed to be lower. We are confuzzled.	Claim	Consistency
641	Mary Lou:	Right (concedes to Larry after recheck of numbers)		
642	Jimbo:	You actually write that?		
643	Mary Lou:	(Interjected in above and indistinct) more resistance		
644	Larry:	We are just confused now		Plausibility
645	Puppet Master:	There's more resistance so there should be less current	Claim Warrant	Causality
646	Mary Lou:	and that's indirectly related to the current	Warrant	Appeal
647 648	Larry:	Why? Our voltage should be greater maybe the resistance should be Lower hmmmm	Qualifier	Causality
649	Puppet Master:	resistance doesn't change	Claim	Appeal
650	Larry:	Yea ok how		Plausibility
651	Puppet Master:	So That's always the same so that's that's not it	Claim	Causality

The significance of this segment of the argument is that it was the first time mention is made of volts and their potential contribution to the confounding data. Larry (lines 605, 607, 611-14) seizes on this idea. Perhaps the voltage delivered to the system is not what it was when they first measured it. She even goes so far as to suggest that the voltage delivered by the power source be re-measured. The new data, 4.86 V, unfortunately, is lower than the participants' original voltage reading (4.99V). This makes the high current reading even more implausible. Jimbo (line 617), Puppet Master (line 618), and Mary Lou (line 619) all express exasperation.

An initial claim is made by Mary Lou (lines 600, 603, and 609) that the number of cords used in the set up increases the amount of resistance in the system. It is significant that this claim is made over several interruptions. Mary Lou is not able to get her whole claim and warrant spoken without a rebuttal by Puppet Master, (lines 602, 604), asserting that the increased resistance would decrease the voltage and resistance.

This segment ends with two opposing warrants to explain the high current reading (See Figure 7). One warrant is that there was more resistance in the set up due to the extra wires, thus, there should have been a lower measured current because resistance is indirectly related to current. This conclusion was supported by the voltage data retake value. The opposing warrant was that the voltage should be greater and the resistance should be lower. This segment of the argument ends with Puppet Master committed to the notion that there was an increased resistance due to the set up and that resistance does not change (lines 645, 651), but Larry is beginning to consider alternative explanations (line 647).

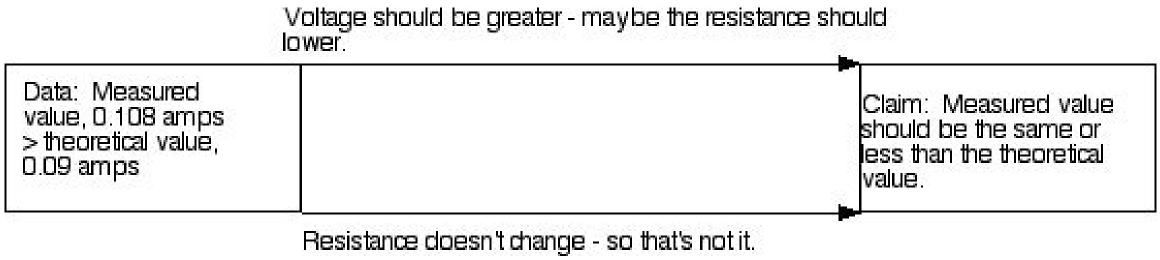


Figure 7: Argument status at end of section two indicating two opposing warrants for the claim.

Though the expressions of confusion and exasperation cannot be coded in terms of an argument, they contribute to the idea that the students are doing science. The students are talking science--engaging in a debate to which they bring their epistemic commitments. What they really understand science to be is data consistent with theory. That is, they are looking for plausible reasons to explain the inconsistent data. The participants were able to articulate how the different variables in the experiment could effectively change the measured values. This is illustrated by Puppet Master in line 618 (Our voltage decreased which means our current also should've decreased). The participants came to this exercise with a strong pre-commitment to Ohm's Law, so they wanted their data to be consistent with Ohm's Law. That the data was not consistent with Ohm's Law makes the data wrong. What the students seem to lack is the scientific maturity (Carey and Smith, 1993) to question the experiment or its set up. This is consistent with findings such as those in a review by Carey and Smith (1993) that indicate that students often view knowledge unproblematically. That is, there is one right answer to a set of observations. Also, this same review showed that students do not associate experiments with theories and that anomalous data may call upon them to generate and test a new theory.

Science demands evidence, this group's evidence is wrong (in their minds), but they seem unable to move beyond this realization. The participants come tantalizingly close to evaluating their explanations and considering alternative explanations when Larry suggests that maybe the voltage did not remain constant. However, even when the students took a second measurement of the voltage, it was taken strictly across the power source itself without accounting for the lights and ammeter. The value they got for this re-measure of the voltage was lower than their initial voltage setting thus further confounding the data. If the voltage at the source had changed such that it affected their data, then the voltage reading should have gone up not down.

The participants generated theories about why their data was not as expected. However, they were not following up on the theories they suggested and never devised a system for testing those theories they did come up with.

Discovery of more inconsistent data

In the third section of this argument, shown in Table 11, the participants decided to go on to the next lab question without resolving their confusion. However, they discovered more inconsistent data.

This part of the argument might be called, *grasping at straws*. The confusion over the different voltage measurements overwhelmed the participants. With one measured voltage too high, although only a little, and one value very low, the participants cannot use any of their existing conceptual framework to explain the disparity. The voltage that is 0.03 V too high seems to be within an acceptable margin of error such that it can be overlooked (line 706) but the value that is 0.33 V low is not acceptable. Further, that these values are off in opposite directions puts the participants in total confusion.

Table 11

Argument section 3: Second confounding data set

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
652	Larry:	Let's see (reading) how do the measured voltage drops from the above compare to the		
653		value you calculated voltage drop should be from part (indistinct and drops voice) Ok one of	Data	Consistency
654		them is lower one of them is higher - how does that work out? (silence a second) Well,		
655		you could account that these resistance of these bulbs have been used for too long and	Claim	Causality
656		like when that happens doesn't it like the resistance like decrease (indistinct) messed with too	Warrant	
657		much? So you know theoretically maybe the resistance IS lower in these bulbs cuz its	Claim Warrant	
658		been used so much. How's that sound?		
660	Jimbo:	Sounds good		
661	Larry:	Sounds good right?		
662	Puppet Master:	whispers something		
663	Mary Lou:	What was that? Like		
664	Larry:	Maybe like you know the bulbs when you use them too much like you know like	Claim	Causality
665		resistors if you use them too much they start to wear out	Warrant	
667	Puppet Master:	Alright, Guys we have a problem here	Claim	Consistency
669	Larry:	What		
670	Mary Lou:	If it decreased the resistance it should make the thing decrease (indistinct)	Claim	Appeal
671	Larry:	what what what		
673	Puppet Master:	You know how our voltage is greater so for v one ok so our voltage increased	Warrant	Plausibility
674		right? So I mean our current increased so we		Consistency
675		should have a greater voltage but v one we have less voltage	Warrant	
676	Mary Lou:	There's just gotta be flaws somewhere we [indistinct]	Claim	Plausibility
677	Larry:	(interjecting) There's no flaws somewhere there is	Counter claim	Plausibility

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
678	Jimbo:	Why? human error	Counter claim	Plausibility
679	Larry:	Like cuz you know	Claim (implied)	Plausibility
680	Puppet Master:	Again, I'm perplexed		Plausibility
681	Larry:	Well ok for the number five I can say maybe the resistance resistors were worn out ya	Claim Warrant	Causality
682		know? Cause that can change the resistance of it [indistinct] maybe got a little more	Warrant	
683		resistance there but for uhh prides (indistinct) sake there's ehhh		Plausibility
684	Puppet Master:	It's human error that's I dunno	Claim	Causality
686	Puppet Master:	Cuz I mean like I don't cuz		Plausibility
687	Mary Lou:	Its experimental flaws	Claim	Causality
688	Puppet Master:	the current was greater than	Claim (continued)	Plausibility
689	Mary Lou:	but what kind of experimental flaws?	Qualifier	Causality
690 691	Puppet Master:	what we theoretically measured so current equals voltage times resistance So it makes sense that voltage should be greater	Warrant Warrant	Appeal
692		since resistance is constant throughout the entire thing (This is said while the following	Claim	
693		goes on and is completed concurrent with MARY LOU: No cuz statement below)		
695	Larry:	Which which voltage did we	Qualifier	Causality
696	Mary Lou:	Is it completely constant is the power supply completely constant(?)	Qualifier	Causality
699		No cuz because when we measured the the umm whenever we measured something the		
700		number would be going up and down so		
701	Puppet Master:	It would only increase or decrease by a hundredth of a de a hundredth of a thing	Claim	Plausibility
702		so that wouldn't be it		
703	Mary Lou:	Gosh, why is this so difficult?		

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
704	Larry:	Can I see an eraser?		
705	Puppet Master:	Whereas our answers differ a tenth	Warrant	Plausibility
706	Larry:	Our like ok maybe ya can't account for the tenth ya know cuz those but Point three	Warrant	Causality
707		that's quite a lot to be off Maybe that resistors' been used too much its been	Claim	
708		tampered with		
709	Jimbo:	I like her answer		
710	Larry:	But I I eh eh (indistinct sounds of doubt)	Qualifier	Plausibility
711	Mary Lou:	That means it would decrease causing the and the current's going to be the same soo	Warrant	Causality
712	Larry:	(interrupting Mary Lou above) Ok when you saw the bulbs which bulb was brighter	Warrant	Causality
713	Mary Lou:	(Indistinct)…Oh wait that works (excited) cause V equals IR	Warrant	Appeal
714	Puppet Master: & Jimbo:	Fatman	Data	Causality
715	Mary Lou:	no no look it look it more	Warrant	Appeal
716	Jimbo:	(Indistinct)…That works	Claim	Plausibility
717	Mary Lou:	wait wait hold on		Appeal (cont)
718	Larry:	But wait that one was brighter that one that works out well no well	Data	Causality
719	Mary Lou:	(talking excitedly but indistinctly) …one second one second I got something to say		
720		Man I want to say something (desperate for the floor)		
721	Puppet Master:	When all of us have something to say you talk over us (admonishing)		
722	Jimbo:	just let her talk		
723	Puppet Master:	nooo nooo		
724	Mary Lou:	I'm I'm sorry. I apologize I fail at life		
725	Jimbo:	Mary Lou go Mary Lou go!		

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
726 727	Mary Lou:	So what Larry was saying about the resistance dropping because V equals IR so umm the voltage is directly related to the resistance so because	Warrant	Appeal
728	Puppet Master:	but the resistance stays the same	Rebuttal	Consistency
729 730	Mary Lou:	so if the resistance has worn away	Warrant	Causality
731 732 733	Puppet Master:	Resis How can it ok we measured it at the beginning how can it wear away in a matter of minutes to where it affects our answers three hundredths I mean yea three tenths	Rebuttal Warrant	Plausibility
734	Larry:	Ok like when you calculate it you are assuming	Warrant	Causality
735	Puppet Master:	I understand it wears out over time but not in a matter of minutes	Claim Warrant	Plausibility
736 737	Larry:	Yea yea but like ok lets say when we calculate it we assume it is perfect everything is perfect	Claim Warrant	Causality
738	Puppet Master:	Yea		Plausibility
739 740	Larry:	Maybe that is the flaw this is not a perfect thing this is not perfect	Claim Warrant	Causality

A level of understanding of the nature of experimentation was demonstrated when Larry said: "Yea… yea but like ok lets say when we calculate it we assume it is perfect everything is perfect. Maybe that is the flaw. This is not a perfect thing this is not perfect." Larry comes close to understanding that the flaw could be with the system set up. While she drew the wrong conclusion about the resistance wearing out in the wire it was a fairly big leap, conceptually, to understand that there could be a flaw in the system rather than things working out perfectly using calculations alone.

Why did Larry ask about which bulb was brighter? It could be that Larry was making some inarticulated connection in her mind about brightness and the power of the bulb. Perhaps she was considering that the brightness was an indicator of having more resistance and, conversely, that the dimmer bulb would have less resistance. Perhaps she was grasping at some thought about the brightness of the bulb having something to do with what's going on, and the brightness being evidence that is above and beyond the data being taken. Here is another theory that the participants did not explore that might have explained what happened. Brightness is related to power (Watts = I^2R), which the participants would have known about, but they did not articulate and/or act on this understanding.

The participants seemed to realize that .03V (1%) difference for V_2 is not significant. They did realize that .33V difference for V_1 *was* significant (line 706 and 707). Their confusion was about the fact that one value went down as compared to theoretical and one essentially did not change. In the previous argument, they checked the supply voltage and it changed, but that should have made the voltages at the bulbs change in the same direction but these values changed in opposite directions (line 654). The participants question what could make one bulb voltage change and not the other (line 706). They seemed to be zeroing in on an argument that isolates the attribute that is not shared by both bulbs. This would be that something is happening to the resistance, and it is happening differently in one bulb than another (line 718) .

This argument sequence demonstrates how participation in a collaborative group promotes important conceptual understanding of the problem. To say that if all of the experimental data is different than the theoretical in the same direction and conclude that

could be because of one thing would be obvious. But the fact that the data on one of the bulbs changed significantly and the other did not (and even changed in the opposite direction slightly) means that the change has to be due to one of the other factors, and that factor is one that is assumed to be constant. So, the participants deduce that they have to challenge their assumption that the resistance of the bulb has to remain constant based on their data. It is like the participants are saying "Oh come on, it is like the resistance is changing." It would have been wonderful if they had taken this notion further and taken some more data from throughout the circuit, or done some simple experiments to test out this theory.

So the students grasps at straws. "So you know theoretically maybe the resistance IS lower in these bulbs cuz it's been used so much. How's that sound? Sounds good (line 657 and 660)." Puppet Master does not accept that the resistance "wore out"—it does not wear out in a few minutes (line 735). But what the participants didn't pick up on was the question of whether resistance is constant as the current changes through the circuit. They were thinking along those lines while questioning the relative brightness of the two bulbs, but didn't quite make the connection.

The participants could have made some comparisons about the relative brightness of the light bulbs. The participants talked a lot about what could have caused the inconsistent data they got. They generated some theories about the reason for their inconsistent data. The students did not redo the experiment or try out the theories they generated such as checking to see if the resistance across the bulbs had changed over the course of their experiment. Their discourse helped them identify the problem but did not help them come to a solution.

Resolution

The last argument section, section four, is found in Table 12. The participants' frustration and confusion was apparent and their conversation indicated they were tiring of the puzzle and were ready to give up. The participants do want to know the answer because they approach the teacher about an answer (line 781) but they are not motivated enough to stick with the problem.

Table 12

Argument section 4: Resolution of the problem

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
741	Puppet Master:	I I really don't get it I'm confused		Plausibility
742	Mary Lou:	Did it *(Indistinct)*		
743	Larry:	There are going to be flaws maybe these wires	Claim	Causality
744		have been used too much there has been like something bad battery	Warrant	
745	Jimbo:	It's cuz the ammeter took some of the voltage	Claim	Causality
746	Larry:	Yea, Yea the		
747		ammeter took some of the voltage there was voltage dropped across the ammeter *(liking*	Warrant	Plausibility
748		*this solution)*		
749	Puppet Master:	True true *(softly, dubiously)*		Plausibility
750	Mary Lou:	Yea		Plausibility
751	Larry:	Right?	Claim	Plausibility
752	Puppet Master:	Yea Wait hang on	Qualifier	Plausibility
753	Jimbo:	*(Indistinct)*…voltage escapes at a *(Indistinct)*…wires	Claim	Causality
754	Puppet Master:	Well what about V two *(Indistinct)*…voltage is increased	Qualifier	Plausibility

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
755	Larry:	Well ok because that was only a point zero three	Rebuttal Warrant	Causality
756	Puppet Master:	Yea yea ok it was only point zero *(indistinct but sounded like and seems to concur that*		Plausibility
757		*the difference is not significant)*		
758	Larry:	Like And it moved between cause at one point it said it did say two point nine nine	Data	Causality
759		two point nine eight It was just like you know unstable things maybe like *(pause)*		
760		yea so	Warrant	
761	Jimbo:	Yea		Plausibility
764	Mary Lou:	So we		
777	Mary Lou:	Actually It doesn't make sense though	Claim	Plausibility
778	Larry:	Can we ask you later? *(speaking to their teacher who had come into the room)*		
779	Puppet Master:	But we can't ask Ms *(Teacher)*		
781	Larry:	No no Can we ask you later cuz I'm I just wanna know		
785	Mary Lou:	*(interjecting)*our data's weird	Claim	Plausibility
786	Puppet Master:	*(Indistinct)* one person one person one person		
787	Teacher:	I wanna look at the data I just wanna look at the data Where (to herself looking over the		
788		students' data) theoretical measured theoretical		
790	Mary Lou:	You are confused? *(to teacher)*		
791	Teacher:	No I'm not I'm just looking at it and I like the trend That's all I'm saying		
802	Larry:	Ok ok ok well ok ok the ammeter takes some of the the ammeter well it depends on	Warrant	Causality
803		Like maybe when you hooked it up like it the voltage dropped like	Warrant	
805	Puppet Master:	I just wrote down [indistinct] to human error I've given up	Claim	Causality

Line	*Name*	*Transcribed Talk*	*Argument Operation*	*Epistemic Operation*
806	Larry:	let's jus put ammeter takes some of the voltage *(while writing)* Ammeter takes voltage too	Warrant	Causality
808	Puppet Master:	Oh whoa I've given up		
809	Mary Lou:	*(Indistinct)* already		
810	Larry:	Cuz lets just say like you know it probably was maybe that's uh how the current goes	Claim	Causality
811	Jimbo:	Ok we're done		
812	Mary Lou:	ok good		
813	Larry:	Thank you very much		

This sequence introduces two important ideas for this argument. The first idea was offered by Larry as an explanation for the anomalous data. Her hypothesis that maybe voltage did not change but that "resistance IS lower in these bulbs cuz its been used so much…if you use them too much they start to wear out (lines 657, 658, and 665)" resurfaces as "…these wires have been used too much (line 744)."

The second idea is that the students were ready to grasp at straws and latch onto any explanation. Jimbo chimed in that the "ammeter took some of the voltage (line 746, 747)" and "voltage escapes at … wires (line 753)". Larry pointed out that one voltage was off so little it could be accounted for by "unstable things (line 760)." It is significant that Puppet Master does not capitulate his position on resistance. He maintained that the resistors would not have worn out in a matter of a few minutes and they were not the cause of the change in voltage. He is, however, tired of the frustrating work and ready to quit. Evaluation of some or all of the plausible explanations is within the students' level of expertise and knowledge, but they do not explore their explanations. Except for

Puppet Master, the answers the students put on their lab sheets reflected an abandonment of their epistemic commitments to causality and plausibility.

Each participant had been given a lab sheet for this activity that required the participants to record their data, generate and record their prediction, and then take actual data to compare with their predicted value. The activity ended with a series of questions about the lab activity. Question five in the lab handout was: How does the *measured* total current compare to what you thought the current should be (your calculated value, from Part 3)? **If it differs, WHY?** (emphasis and bold in original, see Appendix B for the complete assignment). The students did not give the same answers to this question and did not necessarily give the same answer as they had articulated during the argument sequence. Larry and Mary Lou both attributed the unusual values to "resistors have worn out." Jimbo's answer is in contrast to his verbal contribution to the argument. Jimbo replied "sounds good (line 660)" in response to Larry's worn out resistor suggestion but he actually answered on his lab sheet "There is no explanation." Apparently Jimbo did not really find worn out resistors a plausible explanation. Puppet Master's response is consistent with his argument stance "there is some resistance in the wires that we couldn't measure." (For complete responses see Appendix B). For lab question six on the student handout, the students were to compare their measured voltage drops to their calculated (theoretical) drops and account for any differences. Jimbo, Larry, and Mary Lou attribute the unusual differences to the ammeter taking some of the voltage. Mary Lou adds a generic "there's going to be flaws." The summary of the entire argument sequence is visualized in Figure 8:

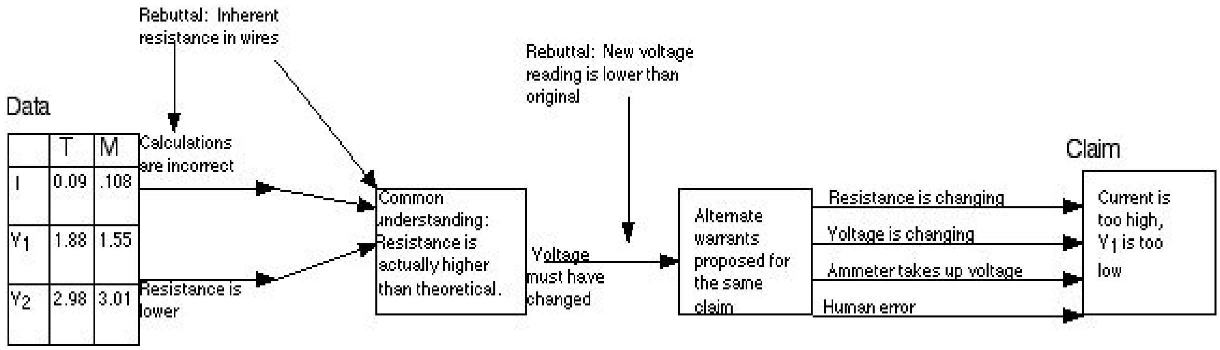


Figure 8: Flow chart of initial argument sequence over anomalous data

The flow chart shows the students coming together over the common understanding that there is resistance in the wire. Their understanding of Ohm's Law is that this resistance would have made the measured current value be less than the theoretical and the measured voltage drop greater than the theoretical. When the experiment did not yield these results, the students diverged in their proposed explanations.

Viewing the discourse sequence surrounding the anomalous data from the standpoint of the argumentation and epistemic operations that the students used in their discourse highlighted the science processes the students understand and/or apply to scientific questions. Figures 9 and 10 summarize the frequency of use of the argumentation and epistemic elements employed by the students during this entire argument sequence. These graphs show that the students used relatively limited argument and epistemic elements. Over 70% of argument elements consisted of claims and warrants and over 70% of epistemic elements were causality and plausibility.

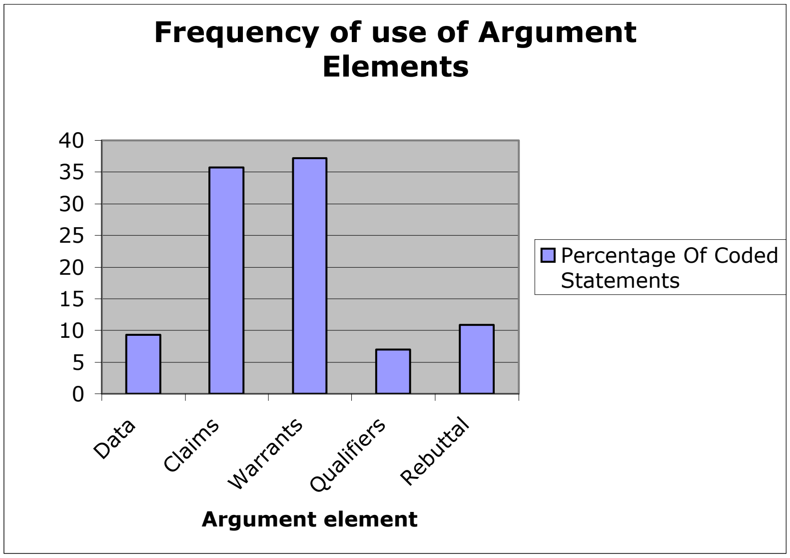


Figure 9: Summary of the student argument element total usage frequency, expressed as a percentage of coded statements

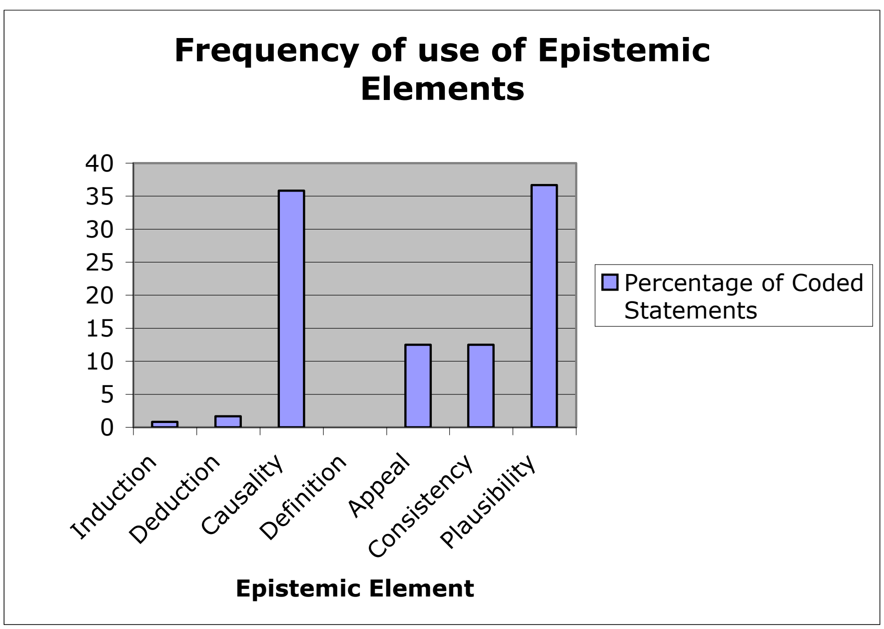


Figure 10: Summary of the student total epistemic element usage frequency, expressed as a percentage of coded statements

Focus question 3: How do concept negotiations undertaken during collaborative work in the science classroom contribute to a conceptual understanding that is common to the group?

In this case study, prior to undertaking each collaborative activity, the participants solved a problem similar to the one that would form the focus of the ensuing activity. At my request, their teacher selected the pre-activity problem based on what the participants had been taught in class. For the second and third activities, the students solved the pre-activity problem individually while talking out their solution into their individual audio recorder. The students then solved this same problem together at the end. This was a change from the first activity and an attempt to gather additional data about any conceptual change that might occur during the collaborative activity and if that change showed any commonality. So, for the projectile motion and the series circuit labs, the students individually solved a teacher-selected problem, collaborated on the lab experiment, then collaborated on solving the same teacher-selected problem after doing the lab.

Comparisons of students' initial conceptual understanding

These participants came from a similar educational background and they came into this study from the same physics class. As such, one consideration is that all of the students in this group were students in the same class with the same teacher performing the same tasks during the development of their initial understanding. In fact, during the final interview when Puppet Master was asked if he had made any assumptions (about his individually solved problems) that were different from the other students he replied:

> No, I mean we all had, the group had the same teacher so we were taught the same way. Yea, we all had the same idea - assumptions. All that… I just messed up on that one part.

The graph-matching lab was preceded by the participants individually solving several time/motion graphs. By looking at the graphs the participants generated prior to their collaboration, it can be seen that the students did not necessarily begin their time/motion activity with the same conceptual understanding..

The following are the directions and the graphs the participants generated prior to the first collaborative activity:

> Sketch the velocity-time graph for an iguana slowing down at a uniform rate while moving in the positive direction.

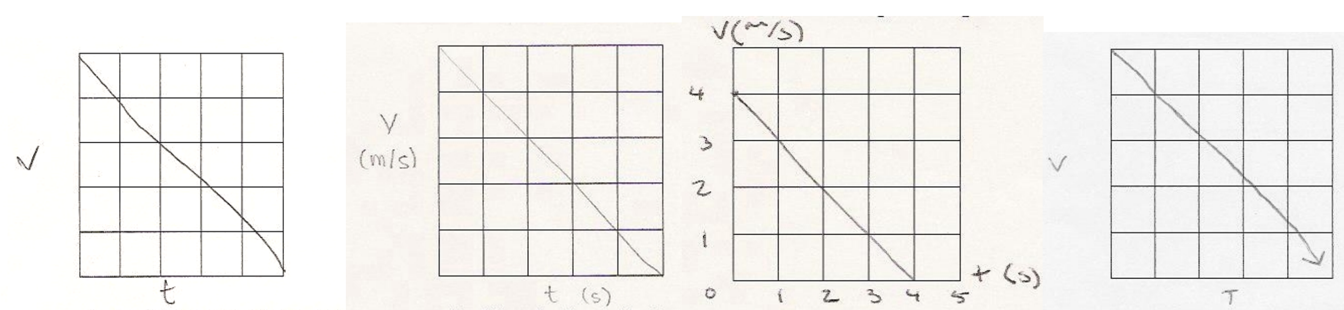
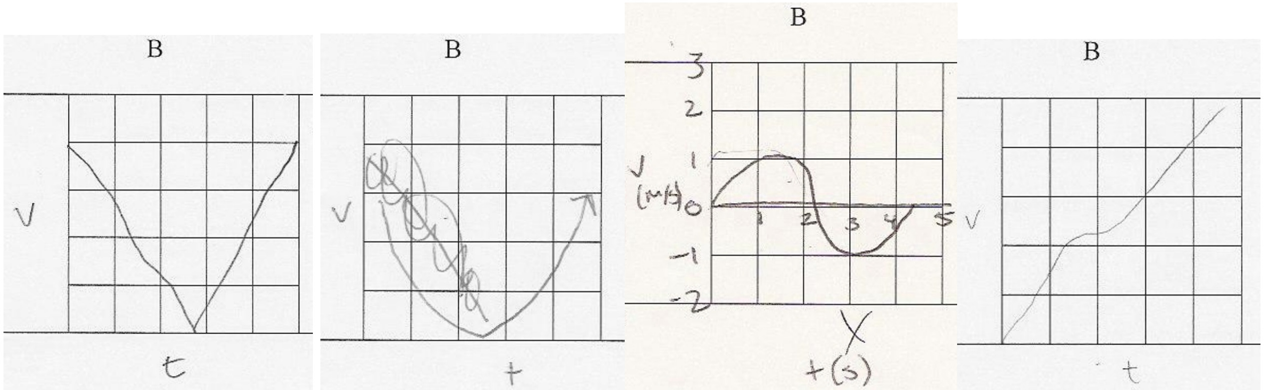


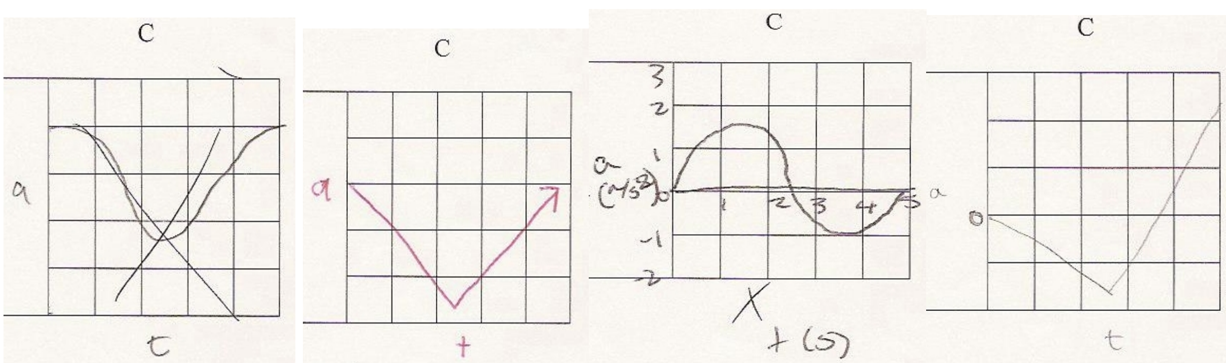
Figure 11: Student graphs - Pre-lab question 1, velocity vs. time.

> Sketch the…velocity-time (graph B), and the acceleration-time (Graph C) graphs for the following motion:
>
> A ball is given a quick shove up an incline plane. It rolls freely up the plane until it reaches its maximum height and then begins to roll back down the ramp.



Jimbo Puppet master Mary Lou Larry

Figure 12: Student graphs - Pre-lab problem 3, velocity versus time.



Jimbo Puppet Master Mary Lou Larry

Figure 13: Student graphs - Pre-lab problem 3, acceleration versus time.

This exercise showed what the students understood about time versus motion based on classroom learning, but not influenced by their collaboration on the motion replication activity. In viewing the graphs, it can be seen that the participants produced some inconsistencies in their solutions. For example, Figure 11, which shows the uniform slowing of an iguana, all of the participants had nearly identical graphs.

However, the pre-lab graphs indicating the relationship between velocity and time and acceleration and time that were generated by the students based on the directions to shove a ball up an incline plane show differences in student understanding. Figure 12 shows the graph responses for velocity versus time. Jimbo and Puppet Master drew very similar representations with the motion shown as a line decreasing to a point and then increasing. Mary Lou's graph is a sine wave and Larry's graph shows an irregularly drawn direct relationship between velocity and time.

On graph C (Figure 13), acceleration versus time, Puppet Master and Larry's representations are similar with deceleration to a point and then acceleration. Mary Lou repeated her sine wave and Jimbo crossed out his drawing. Although his drawing was similar to Puppet Master's and Larry's, it can be inferred that crossing it out indicated Jimbo had decided that this drawing was incorrect.

The participants all seemed to understand the most basic time/motion graph as indicated in Figure 11, the only graphs that the students consistently drew correctly. The students did not have a consistent and correct understanding of the more difficult time/motion graphs. Particularly, the students did not distinguish between velocity and acceleration versus time.

The different renditions of the time motion graphs for question 3B and 3C indicate a difference in the conceptual understanding each student took from the classroom teaching about acceleration and velocity. None of the graphs in Figures 12 and 13 are completely correct. The students were unsure of themselves with these particular graphing problems. For example, Mary Lou confessed to her teacher how ashamed the teacher would be of Mary Lou once she (the teacher) saw her solutions: "Hi

Ms. (Teacher's name), you should be very ashamed of me right now. I don't remember!" It can be inferred from this statement that the participants thought they should know how to do these sorts of graphs.

Comparison of final conceptual understanding

That the participants would come out of each event with a common, correct, or changed conceptual understanding is not a given. For example, the second collaborative activity, projectile motion, was preceded by each student solving the same projectile motion problem and talking through their solutions (which were recorded) as they worked the problem. All four of the students solved the problem using the same set of equations. A significant difference was that Puppet Master assigned an initial vertical velocity of 5 m/s. This value was actually the horizontal velocity. During the group solution at the end, Puppet Master discovered his mistake in the following exchange:

Puppet Master:	No no no no no *(quickly)* Since we're finding horizontal distance you'd use v-i five *(meaning initial velocity)*
Jimbo:	No, we're finding vertical We're using vertical to find the time because we know vertical is zero meters per second
Puppet Master:	Oh we're finding Yea yea yea zero zero zero
Jimbo:	So v is equal to negative 78.4 cause it's going down And then acceleration is 9 point 8 so that gives us a time of 4 s
Puppet Master:	Wait then I was wrong then oops

This represents a common, correct, conceptual outcome that resulted from the group's collaboration.

However, it is apparent in the responses the students gave to the lab questions associated with the circuit labs that a common, correct conceptual outcome might not happen. The circuit data did not match expectations and the argument about the reasons remained unresolved. In answering questions five and six, which called for an

explanation of any differences between the calculated and measured values for the current and voltage drop, the students variously answered

Jimbo:	5) There is no explanation. 6) Ammeter takes some of the voltage.
Larry:	5) …maybe resistors have been worn out 6)…ammeter takes voltage
Mary Lou:	5) …b/c resistance could have worn out 6) are going to be flaws
Puppet Master:	5) …there is some resistance in the wires that we couldn't measure 6)…human error

The students were given final interviews the day after the last of the three activities and asked about the anomalous data. Their responses indicate they do not share a common understanding of this lab experiment. The students remained puzzled about the data but also committed to Ohm's Law. The students were asked: What do you think caused the unusual data and is there anything you would do differently if you were to do the lab again? The following responses were given:

Larry: Well, I was thinking …Maybe it wasn't really the value that we calculated and it might have been worn out.

(In response to what she would do differently) I don't think so cuz like you know we like data didn't really match up but it was probably cuz like the experiment…yea (indicating some sort of inherent experimental error)

Mary Lou: Umm at the end we were trying to figure out the flaw…I remember trying to work with that a lot after she said cuz I hadn't thought about it first and because I actually had no idea. I was just thinking basically little flaws that we had made. I didn't know specifically…Some were higher some were lower (referring to measured data)… Like the first one because… we were trying to figure out why the resistance dropped so much…because it can't really wear away that quickly and we were trying to take into account resistance of the wire. What probably happened was because they…wires in the set up because there were two light bulbs coming in another wire…that probably added more resistance and uh but they were trying to

figure out why the resistance no the voltage- measured because when the resistance goes down, the voltage goes down because they're directly related so we just couldn't figure how this second voltage went up and it was confusing and how can it drop like .3.

(In response to what she would do differently) I really don't know because, I mean, it was like a very step by step lab and it was a good process of finding information. It's just for some reason the resistance was we probably would hafta like somehow test and see umm I don't know (chuckles self-consciously and trails off).

Jimbo: Like uh the stuff that seemed unusual was like our theoretical along with the measured …Yea, if the resistance is larger the measured should be lower but ours was actually higher than our theoretical. Well what we think is that like one of us might have like hit the dial on the voltage and that would have lowered it which means like I guess the voltage would be lowered and the resistance would be higher.

(In response to the interviewer asking about the resistors wearing out hypothesis) I guessed it would be like legitimate because resistors do like uh wear out with time but Puppet Master is also right by saying umm that it was only like a few minutes within a few minutes.

(In response to what he might do differently) Uh, I think we the lab went pretty well I guess it's just like Oh umm I really don't know. I guess the equipment we were using like the ammeter and voltmeter the numbers kept changing.

Puppet Master: Well, our theoretical current was less than our measured current…If the resistance is increased, current is inversely proportional to the resistance so if the resistance increased the current should decrease…And it went up so that I don't know why it went up.

(In response to a prompt by the interviewer about others' proposed explanations) Yea that the resistance that the resistors themselves wore out during the time. I can understand that but not in a matter of minutes. They're gonna wear out in time but not from when we measured the resistance over cycles uh a few minutes later at the end of the lab when we measured the current the one that was worn out in a manner of minutes where it'll affect our answer that much.

(In response to what might he do differently) I guess be more careful with our measurements and I would have rounded up to like thousands.

> Cause we rounded to hundreds. I would try thousands cause that would have affected our answers.

The responses given to the question about the anomalous data represent disagreement over the reasons for the unexpected data. Larry stayed with her assertion that “it (resistance)…have been worn out.” Mary Lou, though she had answered that the resistance had worn out on her lab sheet, changed her mind by the interview “…because it can’t really wear away that quickly…”and Jimbo concurred, “… Puppet Master is also right …it was only like a few minutes…”

In looking at the solutions the students provided for the problems they did before and after the projectile motion and series circuit labs, it was noted that the students did not necessarily incorporate what they learned during the collaboration into their group solution after the lab. The students did, however, do a more rigorous job on the solutions they worked out together.

For example, each student solved the projectile motion problem prior to the activity in much the same way as the group did at the end. However, the students, even working together at the end, did not incorporate what they had learned during the activity into their ending solution. The students were not successful in getting the marble to land within the target area. They were very disappointed by this, even trying to convince the teacher to give them another chance to try to get the marble to land in the target area. They discussed briefly with their teacher why their experimental run was unsuccessful:

> Teacher: Missed it Hey, but ya know what, lemme ask you this: Why do you think it actually hit in front of where you thought?
>
> Larry: FRICTION
>
> Puppet Master: Yea, Air resistance. So we were right! (This is in reference to a statement made at the outset of the activity by Larry and agreed to by all of the others, that they could neglect wind and other factors that might change the horizontal velocity)

Larry: Air resistance and friction (more to herself) cuz when we do physics its
Puppet Master: Yea, like friction and all that air resistance

The collective solution to this projectile motion problem was more explicitly done than any of the individual solutions in that more steps were included in the collective solution than were present in any individual solution. The group work had a more complete drawing (see Appendix B) and the equations were clearly laid out suggesting that, as a group, more rigor was implemented than each individual working alone implemented. Although the participants had discussed with their teacher why their experimental run failed they solved the final problem without including consideration of the experimental elements suggested by this conversation.

In the group solution (see Appendix B), the students made no reference to friction and air resistance and their potential effects on the projectile motion of the object as they had discussed with their teacher. This could well be because the students separated the problem they were given ostensibly to solve with mathematics from an experiment that put the same concepts into action. The students showed an epistemological commitment to the authority of mathematic equations versus what they could actually observe in practice. This was the same sort of issue the students had when they encountered their anomalous data in the circuits experiment. The students maintained a reliance on mathematical solutions in spite of the mismatch to their actual results. The participants did not make the leap from reliance on theoretical authority via equations to experimental reality.

A similar pattern of thoroughness in the group solution versus the individual solutions was apparent in the series circuit problem. Jimbo recited all of the formulas he

used as he performed these calculations but actually only wrote out two of the three formulas that applied to the solutions. His written solution did not indicate for which part of the problem he was using each of the equations, and he showed little mathematical work (see Appendix B for complete student work). Jimbo also used an equation to solve for the power of each resistor that was different from the equations used by the other students to solve for power. Mary Lou and Larry, working independently, wrote out three equations, labeled the parts of the problems, but showed no mathematical work. Puppet Master wrote out three equations that he physically associated with the part of the problem for which they would be used, but also showed no mathematical work and had some confusion about what units to use for power. All of the participants indicated verbally what they were doing with the equations—multiplying, dividing, rearranging the equation—but did not show a set up for that work.

Only Jimbo and Larry drew the schematic of the circuit indicated by the problem. The group solution to this problem, like the group solution to the projectile motion problem, included a more completely labeled schematic. As the group proceeded with their solution, Larry made a comment that drawing the diagram was an onerous task:

> Ooh man I didn't like this part cause you had to label like thirty different parts. It was so annoying.

The group solution included all three equations necessary for the solution as well as the rearrangement of one of the equations to be used for the fourth part of the problem. In addition, the appearance of the Σ, sigma, as an indicator to sum the individual resistances appears only in the group solution. As with the individual solutions, the group solution showed no actual mathematical set ups. Perhaps the group problem was more completely laid out because of the need to visualize what each group member was

thinking. This would not have been necessary while working alone. In addition, each member may have had different ideas about what constituted a good solution presentation, and so, more work was presented because each student wanted to include what he or she thought was important.

During these activities, the students used language that was particular to science. This usage seemed to be universally understood by the participants so it probably had its origins in their classroom experience. For example, in the following exchange Larry initially gets acceleration and velocity reversed but is easily corrected by Mary Lou and Jimbo indicating Larry knew they were correct based on their common classroom experience:

Puppet Master:	This is a position. Is this a position, time graph, or…?
Larry:	It's a position time graph. The curve shows velocity-remember?
Mary Lou:	Acceleration, the curve's acceleration straight line is velocity
Jimbo:	(in background and coincidental with Mary Lou) No the curve's acceleration
Larry:	Oh, the curve's acceleration but the line is velocity

Though the participants used common science language that they had learned in class, it was not always precisely used. The above exchange shows a definitional understanding of the distinction between velocity and acceleration but not a functional understanding of that distinction. In the following conversation the students show an incomplete separation of the concepts of acceleration and velocity. The meshing of velocity and acceleration into a single concept of speed is a common occurrence among physics students:

Mary Lou:	Just hafta have like slower in through here (more indistinct)
Puppet Master:	Yea you hafta time it
Mary Lou:	like slower in through here and slower accelerate right

Larry:	Yea, but that's pretty good
Larry:	youuuur (drawn out)
Puppet Master:	Let's do it again Just (Overlaps above)
Larry:	your acceleration your acceleration does not need to be
Jimbo:	you need to increase your velocity
Larry:	so high Yea
Jimbo:	decrease
Larry:	you're going
Puppet Master:	Just slow down just slow the whole thing down
Jimbo:	(quickly and vehemently) Ready Get set Go
Larry:	the velocity - slow it down

The interchangeable use of velocity, acceleration, and slow does not hinder the students successful completion of this graph matching nor does it act as a barrier to understanding the directions they give to each other during the execution of the graph matching. The participants did not have to draw the graphs for their time motion activity because the graphing calculator drew the graph based on their movements. The participants had the teacher look at the calculator display and check off their graphs. The participants could also keep trying if their graph did not meet with their satisfaction. This was not the case in their solution to the initial problem they were given to draw as shown in Figures 12 and 13. For example, Figure 12 shows Jimbo and Puppet Master in agreement in their understanding of velocity versus time but Mary Lou and Larry neither agreeing with Jimbo and Puppet Master or each other. In Figure 13 -- acceleration versus time --Puppet Master and Larry are in agreement, Jimbo is not sure, and Mary Lou's graph is distinctly different. Incomplete functional understanding of the difference between velocity and acceleration did prove to be a barrier to successfully graphing the differences prior to the outset of this activity.

Another time the students had a definitional understanding that did not transfer to experimental reality:

Mary Lou:	Because, remember the cords have resistance
Larry:	cuz this is before it goes through the wires. The wires have resistance so what is the total uh (Line 354)
Larry:	No cuz there's a resistance in the cords too (Line 508)

Both of these participants made the above statements *prior* to obtaining the anomalous data. When the observed data did not match the expected data they did either did not remember this concept or did not remain committed to this understanding.

The students frequently assessed their own progress in each of the assigned activities. This was done informally and the assessments were generally expressed as positive or negative statements. In conversations during the activities, the students often agreed or disagreed with each other. For example, during a run in the graph matching activity, there was give and take of a positive and negative nature. The following is an excerpt from a graph matching run that illustrates real time self-assessment:

Larry:	One one thousand, two one thousand
Mary Lou:	I think… You're holding it too low
Mary Lou:	Did she not wait long enough?
Noises of a run	
Jimbo:	That's better that's fine
Mary Lou:	Was it (?)
Puppet Master:	NO you should stand you should
Jimbo:	Puppet Master, that was fine
Mary Lou:	It does, it really does
Puppet Master:	Would she check off on it?
Jimbo:	Yea Good job Larry!

This stretch of negotiation shows the participants observing, comparing, analyzing, and evaluating their data until they agreed on their product. These ad hoc conversations

occurred throughout each activity and contributed to a conceptual agreement common to the group.

This case study was an in-depth look at a group of high school juniors as they collaborated on the solutions to three physics lab experiments. The participants were audiotaped, observation notes were taken, and artifacts in the form of written problem solutions were obtained. The audio data was examined for instances of concept negotiation and portions of these data were further analyzed for argumentation elements and for the epistemic elements the students employed while collaborating. The problem solutions were reviewed for evidence of conceptual agreement. All of the data were examined for evidence of conceptual change. Examination and analysis of the data in light of the research questions points to the following assertions:

1. Students engaged in extended, productive science discourse during their collaboration. Students were “doing” and “talking” science.
2. The students held and maintained a naïve understanding of science as a means of generating knowledge.
3. Students’ allegiance to their normative science represented a strong misconception that prevented conceptual change.

These assertions will be discussed in Chapter 5. Their relevance to this study in particular and science education in general will be also be discussed.

CHAPTER 5

DISCUSSION

Introduction

Examination of the discourse surrounding student collaboration can shed light on what science conceptual understanding students come into an experience with (Kelly & Chen, 1999), what their view of science as a way of learning or knowing about their world is (Hogan, 1999), and how each of these does or does not mature as a result of collaboration. Another key point in examining student collaboration is to add to the limited body of research about whether changing classroom communication patterns can improve student learning (Scott et al, 2006).

Examination of the data from this case study generated three major assertions:

1. Students engaged in extended, productive science discourse during their collaboration. Students were "doing" and "talking" science.
2. The students held and maintained a naïve understanding of science as a means of generating knowledge
3. Students' allegiance to their normative science represented a strong misconception that prevented conceptual change.

Each assertion will be presented and discussed in terms of this study's theoretical framework. The implications of this research for science education and suggested areas for future research efforts will follow. The final section of this chapter will present some personal reflections on the research conducted.

Assertion 1: Students engaged in extended, productive science discourse during their collaboration. Students were doing and talking science.

Examination of the conversations among the students as well as observations made of the students in this case study showed that collaboration is an effective vehicle to prompt the kind of science discourse that will engage students, may help students learn science, and can reveal to teachers what science the students know.

Two elements of collaboration are identified as instrumental in promoting this kind of discourse and engagement in science. These two elements are the physical engagement of the students and the element of prediction each activity required. The physical engagement pressed the students into verbalizing their procedural understandings so that each participant knew what each part of the activity would generate in terms of the problem's solution. Prediction elicited the student's existing science understanding in the form of prior conceptual knowledge, because the students had to articulate what they knew in order to make a correct prediction. These conceptual and procedural negotiations played a significant part in generating engaged science discourse that brought out both consistencies and inconsistencies in student understanding. These two elements established a structure for "productive disciplinary engagement …by giving students authority and holding students accountable to others" (Scott et al., 2006, p. 607). As a result, these students, during the course of their collaboration, utilized many components of science talk providing them with substantial, realistic practice talking science.

Using and practicing science talk

In the first activity these students worked on, they observed the graphic results of their movements, compared the generated graph to a standard, evaluated their graph's fit with the standard, discussed what changes needed to be made to the graphs in the experiment, designed an experiment, and followed their procedures. Students made predictions, tested hypotheses, and presented arguments, all discourse elements Lemke (1990) identifies as components of language-in-context that mark "talking science." These students used most of these components of science talk, as well as others, at some point during the course of each of their collaborations.

Collaboration requires discussion and in this case group, the discussion acted both as a tool for the students to use as a means of making their thinking apparent and as a tool for growing their personal science understanding. These particular collaborative activities did more than just provide the opportunity for students to contribute their conceptual understandings through their discourse—it required their conceptual contributions. The nature of the activities undertaken meant that all of the group members had to be both physically involved in the task of setting up and running the experiments and verbally involved in evaluating the results. The importance of understanding a procedure in order to understand what data would be generated and how this data would be used represents an intersection between procedural and conceptual negotiations, two opportunities for science talk to take place. When students were carrying out these types of conversations they were talking science while working out their knowledge construction. Each member contributed his or her frame of reference to the execution of these activities via science talk. This is in keeping with research that

knowledge construction occurs when participants bring their personal frame of reference to bear on a problem and talk their way through a problem (Kelly & Green, 1998, Lemke, 1990).

Though the students talked science, they did not necessarily employ all science terms precisely. Science uses words more precisely and sometimes with different meanings than the same word in the everyday vernacular. Impulse as used in physics, for example, has a different meaning than that same word in everyday discourse (Itza-Ortiz et al., 2003). This imprecision can lead to confusion as students mesh together the everyday meaning of a word with the more particular science meaning. This is the case with the case group in this study. These students meshed together the terms *speed*, *velocity,* and *acceleration* using the words interchangeably. When the students' terminology was aimed at recreating a graph that all the students had examples of before them, the imprecise use of velocity, acceleration, and speed, did not cause a misunderstanding among the group members, nor did it result in an incorrectly formed graph of the required motion.

This is not the case in the graphs drawn by the students aimed at having the students distinguish between velocity and acceleration. In the problems the students were given at the outset of this activity, when the students were asked to draw velocity time graphs then acceleration time graphs for the same scenario, only one student changed his/her drawing to distinguish velocity from acceleration (see Figures 12 and 13). This indicates that the students' imprecise use of these terms extended to an incomplete understanding of the differences in the meaning of these terms.

The imprecise use of science terms is one of the primary reasons for students to engage in science discourse. While affording the students practice in science talk it also makes flaws in their thinking and reasoning apparent. This represents an opportunity for the teacher to discover what science concepts the students can correctly apply in a practical problem-solving situation.

Students talk indicated an epistemic stance in keeping with scientific epistemology

The students' talk that emerged in response to anomalous data indicated they held an epistemic stance in keeping with a scientific epistemology. For example, the students recognized the importance of causality and plausibility in science. This is demonstrated by the frequency of the use of these two epistemic elements in their conversations. Seventy percent of the coded statements that followed the anomalous data fell into the epistemic categories of causality and plausibility (see Figures 9 and 10). The students recognized that their experimental data did not match the expected values. This showed that the students came into this process with a view that science is not capricious. They knew to look for data consistent with theory, and when their generated data was inconsistent with theory the data was rendered implausible and there must be a cause for the inconsistency.

Research shows that it is often anomalous data that generates the greatest debates and subsequent changes in science understanding (Chin, 2001; Kittleson & Southerland, 2004; Posner et al., 1982). For example, anomalous data paved the way for acceptance of a heliocentric universe (Stern, 2004) and the discovery of RNA interference (2008). The students in this case study—as in a community of scientists—had their most extensive discussion following anomalous data. These students employed predominantly two

argument elements—claims and warrants—and two epistemic elements - plausibility and causality. The sort of discourse that surrounds anomalous data, then, is a window into what students understand science is.

Discourse reveals prior knowledge

An important component of the student discourse at the beginning of each activity included orientation questions as each member sought to come to an agreed-upon start up understanding. When students share this orientation talk they are making their prior knowledge apparent. This is an important first step in conceptual change and suggests that the discourse that occurs during collaboration will help students articulate what they know. Sometimes the initial talk the students engaged in took the form of parallel talk, talk that did not seem to seek a response. Each student verbalized his or her own understanding of the activity requirements. Though this parallel talk did not seem to be conversation, it still revealed each member's understanding and afforded each student the opportunity to compare his or her understanding with others' and in a number of instances, caused a participant to revise his or her thinking. As Warren and Rosebery (1995) point out, the students' had to hear, consider, and counter others' thinking and this parallel talk represents this kind of opportunity.

Each activity the students worked on required them to make a prediction about the outcome of their actions. The component of prediction required in each of the activities pressed the students into communication and engagement. This communication generated science talk that revealed students' prior knowledge, what epistemic elements they applied to their science understanding, and provided a medium for practice in talking science. Such questions as, "Why do we need two photogates?" revealed what these

students knew about the equipment they would use, what data it would generate, and how this data would be used to try out their predictions.

Collaboration promotes productive engagement

A conclusion to be drawn from this finding is that collaboration that requires physical engagement and prediction prompts extensive science discourse. This discourse reveals the students' science conceptual understandings as well as their science process understandings. The nature of the kind of collaboration the students in this case study undertook, required their active participation thus shifting some of the initiative for learning back to the student. Therefore, collaborative engagement is motivating for students as it draws them into the problem. When students engage in these types of activities, the "interaction between the personal and the social dimensions promotes reflexivity, appropriation, and the development of knowledge, beliefs, and values" (Erduran, 2004). Figure 14 illustrates the connection between activity type and the two types of negotiations the students in this study employed during their collaboration. This flow chart is a model for the kinds of classroom activities that encourage productive science discourse. If the task given the students requires interaction, procedural negotiations will occur and if the task requires a prediction, concept negotiation will occur. Together these negotiations provide the students with practice in science discourse and the potential for conceptual modifications and growth as well as opportunities for the teacher to see the students' enacted understanding of science concepts.

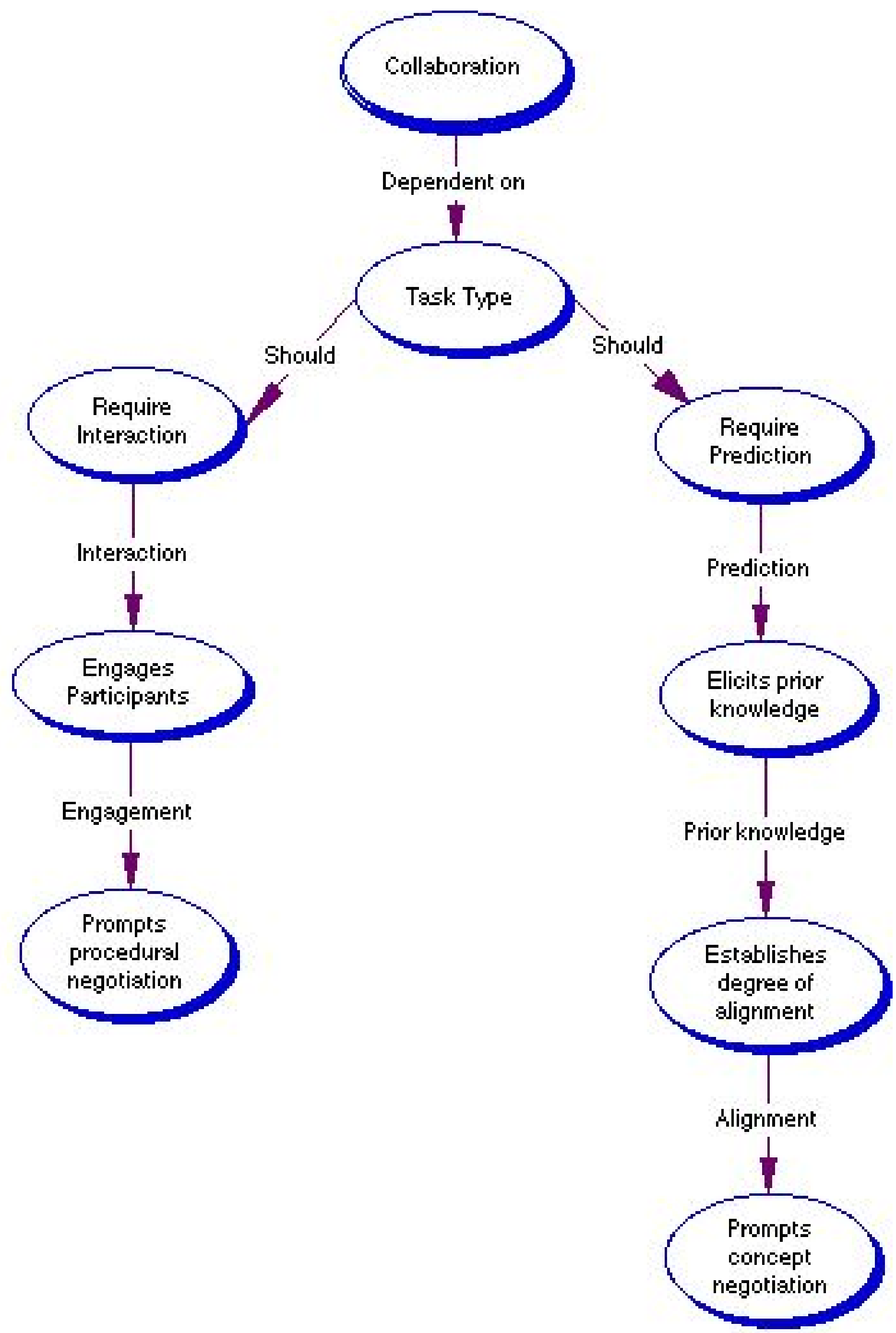


Figure 14: Flow chart depicting the relationship between collaboration and negotiation

Assertion 2: The students held and maintained a naïve understanding of science as a means of generating knowledge.

The students in this study displayed a naïve understanding of science as a process for making sense of observations during the argument sequence surrounding the series circuit activity. The students proposed alternative theories in the form of claims--the data is due to incorrect math, changing voltage--to account for the discrepant data. Also, the students acknowledged each others' proposed theories as viable possibilities. They did not set out to test any of these alternative theories. The students used their untested theories as answers on their lab response sheets as their rationale to account for the differences that occurred between their predicted values and their experimental data.

Students' level of science epistemology

Carey and Smith (1993), in a summary review of data from several sources, looked at the relationship between students' understanding of the nature of scientific knowledge and their personal epistemology. Specifically, this review was looking at the variance between these two ideas and how this variance might affect conceptual change. This review identified two contrasting epistemologies and three levels of understanding of the nature of science.

The two contrasting epistemologies were: Knowledge unproblematic and knowledge problematic. These authors summarize knowledge unproblematic as an epistemology that believes there is one objective reality that can be understood through observation. That is, there is only one right answer to a set of observations. Conversely, knowledge problematic allows for multiple theories about observations and these multiple theories allow for potentially multiple valid interpretations of observations.

The participants' epistemology seemed to be beyond knowledge unproblematic because they did propose alternative theories in the form of claims. That is, they knew there might be more than one explanation for the unexplained data. They did not, however, move fully into knowledge problematic because they did not set out to test these alternative theories. Their theories remained conjectures.

Within the argument, the students made claims and warrants which are typical practices reflective of scientific argumentation. However, the students did not generate evidence to back their claims, a key component of successful science argumentation. Indeed, the entire argument sequence was based on the results of one run of the experiment. The students had sufficient time to rerun their experiment, although they were not given instructions to do this. These students did not consider the outcome of a single experiment as insufficient grounds for a knowledge claim.

The students made some initial measurements and then used the values they obtained as if they were constants for calculating what values they expected to get in the final, completed circuit. Part of an understanding of science is that the mathematical solutions obtained under ideal situations may not match the data of an actual experiment and in these activities; the values they used in their calculations were, themselves, data. This means that the experimental set up itself can change the predicted outcome and, thus, needs to be considered. The students did not take into account that the values they obtained to use as variables in their prediction might not remain the same from one set up to another, that is, from the set up they used to obtain the initial values to the series circuit set up. The measurement of the resistance of a single bulb might change when this same bulb is connected in a series circuit. Perhaps the students did not understand that this

does not make either the law under investigation wrong or the data they obtained wrong. This would be a point at which the teacher could step in to prompt a more sophisticated response to the data mismatch such as a conversation that revolved around the procedures they were using and how these procedures might change the values they obtained.

Carey and Smith (1993) tentatively identify three levels of understanding that students exhibit about the nature of science. Level 1 understanding sees discovery of facts and answers as the goal of science. Level 2 understanding is described as follows:

> Students make an explicit distinction between ideas and experiments. The motivation for experimentation is to test an idea to see if it is right. There is an understanding that the results of an experiment may lead to the abandonment or revision of an idea. However, an idea is still a guess; it is not a prediction or derivable from a general theory. (Indeed, students may not yet have the general idea of a theory.) There is yet no appreciation that the revised idea must now encompass all the data, the new and the old, and that if a prediction is falsified, the theory may have to be revised (p 248)

Level 3 adds to level two an appreciation of the relation between the results of an experiment *especially unexpected ones* (emphasis added) and the theory leading to the prediction. And, in the instance of using models as a means of testing ideas, that models can be manipulated and tested as a way of investigating ideas.

Bartholomew, Osborne, & Ratcliffe (2004) also describe characteristics that demonstrate an understanding of the nature of science. One theme these authors identified as core to this understanding is "scientific methods and critical testing." This nature of science attribute states:

> Pupils should be taught that science uses the experimental method to test ideas, and, in particular, about certain basic techniques such as the use of controls. It should be made clear that *the outcome of a single experiment is rarely sufficient to establish a knowledge claim* (p. 657, emphasis added).

This research describes what it means to have a mature scientific epistemology and understanding of the nature of science. Especially relevant to this study is that a mature view of science would enable experimenters to see the value in devising models to test theories and would not accept the results of a single experiment as fact.

While a premise of this study was that concept negotiation among students was a vehicle to conceptual change, conversations that included explanation and procedural talk can also contribute to conceptual change. Figure 3, shows ideal concept negotiation occurs at the intersection of negotiation and conceptual types of talk but that concept negotiation can also occur at the intersection of negotiation and procedural types of talk. An example of the overlap of negotiation and procedural talk occurred during the graph matching activity.

The students in this case group were very successful with their graph matching activity. A good deal of their conversation during this activity was coded as procedural. In the graphing activity, the students readily matched their physical procedures to their graph results and constantly adjusted their procedures to obtain the desired results. This kind of visual prompt was not available in their circuit lab. The students would have had to understand that their experimental set up could have been manipulated just like their experimental movements had been in the graphing activity. This may be because the series circuit was a more abstract model than the graph matching activity. An understanding that models can be manipulated and tested as a way of investigating ideas is indicative of a sophisticated view of the nature of science (Carey & Smith, 1993). These students did not seem to see this circuit set up as a model for testing ideas about Ohm's Law.

Anther aspect of student collaboration that indicated a naïve view of science is that students did not propose reworking the circuit experiment either by redoing the procedure as given to see if it generated consistent data, or by varying components of the experiment systematically to determine the effects of each component on the data. Either of these steps might have produced data that could have provided a counter to the anomalous data or understandable support for the data they did generate. Simon et al, (2002) point out that one aspect of a good argument is not accepting unsupported claims. These students did not generate support for their claims. In fact, data based argument statements represented fewer than 10% of the argument elements used by the students during the series circuit activity (see Figure 9). This is an area of concern since science education is expected to help students understand the importance of and employ valid evidence in their arguments.

The behavior these students exhibited appeared to be characteristic of what Carey and Smith (1993) describe as a level 2 understanding of the nature of science. That is, the students did not step back, develop a theory about their problem, and generate a systematic experiment or series of experiments that might lead them to a solution. For the second and third activities, these students relied on the outcome of a single experiment to establish a knowledge claim. Only the first assignment, the graph matching assignment, prompted the students to retry failed experiments. The nature of this assignment with immediate feedback tied to the experiment prompted and supported easy repetitions. In more abstract, conceptual experiments with problematic feedback, generating multiple trials or a series of theory-based experiments might have to be

explicitly prompted and supported until the students take on this level of sophistication themselves.

The students talked about possible reasons for the inconsistencies of their data. For example, the students did check the voltmeter to see if it was giving the same reading as it had at the outset of the experiment but its reading had changed in the wrong direction furthering their confusion. Plus the check reading was across the voltmeter alone not as it had been set up in the circuit. The coded discourse sequence for this argument included several proposals for what might have caused the anomalous data—but nowhere do the students propose an experimental approach to generating data to support any of the proposed causes for the anomaly. A study by Hogan and Maglicate cited by Simon et al (2002), found that students were poor at coordinating evidence (data) and theory (claim). Further, Simon et al, found that enacting a valid argument does not come naturally to students and must be taught as a skill. This points to the need to establish argumentation specifically the science field dependent elements of data as evidence as a core part of a science curriculum and to collaboration on problematic experiments as a reasonable framework for the curriculum.

The students initiated and maintained an argument sequence over a fairly lengthy time frame. They were genuinely puzzled by the data and wanted to understand why it was “wrong”. Statements such as “Why is this so difficult (Mary Lou)?” and (to the teacher) “Can we ask you later cuz I’m I just wanna know (Larry)” indicated genuine interest in understanding what was happening. These students were not disinterested or lazy.

Did the science processes that might have answered their question simply escape their thinking? When the students were interviewed after these activities, their responses to the question about what might have caused the unusual data, their answers still lacked reference to experimental procedures as a possible cause. In fact, Mary Lou indicated she would not do anything different (if she were to do the experiment again) "because, I mean, it was like a very step by step lab and it was a good process of finding information." Puppet Master simply indicated he would "be more careful with our measurements and…I would have rounded up to like thousands." The students had a very defined procedure to follow. The students did not seem to think about deviating from the procedure given to them..

The students' inability to see how their *process* affected their *answer* was confined to the two activities that generated predicted answers based on abstract mathematical models. For example, the students could not get past Ohm's Law calculations as the sole rationale for the data expected, and they did not incorporate the teacher's feedback about the effects of friction and wind resistance into their post-problem calculations for the projectile motion problem after their failed attempt to land a marble exactly. However, in the graph production activity, the first activity the students did, the students had to rely on the visual (the CBL screen graph) produced as a result of their movements to determine whether they were right or wrong. They could "see" to adjust their experiments to generate the graph they sought. This is akin to multiple experimental trials with predictions based on ad hoc theories the students proposed about the effects of their movements. Chances are, if the students had tinkered with their projectile motion and circuitry experiments in a similar fashion, they would have figured

out how to land the marble correctly and how their circuit set up may have affected their theoretical values. As students work through such problems, they are reconstructing the theoretical models rather than just supporting the existent model through confirmatory activities. This type of dynamic approach to science learning-one in which experimentation and language play key roles in linking student science learning to book science—has been proposed by Izquierdo-Aymerich and Aduriz-Bravo (2003) as having tremendous potential for teaching students how to think in terms of theories as a means to understand the world.

A premise of this study was that conceptual change could occur when a conversation between collaborators occurred. The graphic of potential interactions between collaborators (Figure 2) shows that intersections between procedural talk and negotiation or explanation may also reflect joint knowledge construction. The conceptual conversations that occurred during the argumentation sequence negatively affected students' procedural negotiation. That is, there were conceptual negotiations about the reasons for the anomalous data. In this case, looking at the procedures they had followed might have proven fruitful but procedural talk rarely occurred during the series circuit activity.

The result of the circuit lab shows that there was confusion between conceptual understanding of what was taught in class (viewed unproblematically as "truth" by the students) and the broader view of what procedural factors could influence the expected outcome. That is, the students continually cited Ohm's Law in their efforts to understand their data. This law, learned in class, was viewed as the one right answer to their dilemma, like the unproblematic epistemology described by Carey and Smith (1993).

Perhaps there is a developmental maturity to be reached before coming to an understanding of the ways of science. Certainly, the meta-analysis of literature about people's understanding of the nature of scientific knowledge conducted by Carey and Smith (1993) points to maturity and education as contributors to a sophisticated scientific epistemology. However, these same authors do not believe the levels are developmental and that these levels could be influenced with the right science curriculum. These students remained naïve in their understanding of the nature of science—that is, they did not think systematically enough to consider retracing their steps. Perhaps fatigue set in, or, perhaps, the problem situation was too difficult for them to get at in the length of time given them without any outside (teacher) scaffolding.

Some considerations, here, include the following: Was this problem too difficult for the students to examine? I do not think this is the case, as they had a pretty good grasp on the mathematics involved and also made some valid causal suggestions for their results. This would indicate the presence of intellectual ability.

Did the students lack the perseverance necessary to follow through on their problem? The students had time to retrace their steps and their talk indicated they wanted to understand the process and what had caused their unexpected results. Their talk also extended for longer than a rerun of their experiment would have taken. These two factors would eliminate time and apathy as the reason they did not follow through on their problem. Perhaps their inaction occurred simply because of their naïve epistemology—they did not see the experimental set up as problematic or changeable. These students may not have understood that they actually had the ability to find an answer and so, did not see persevering as fruitful. Or, they saw this as a school exercise to be done as is. To

know to enact more scientific initiative would mean that the students would have been taught at some point that they were expected to go beyond what was on the lab sheet.

The students went on to answer the questions associated with the lab activity based on their argumentation sequence, without providing any support from data-driven evidence. The lab questions ask the students if their measured values "…differ from what you thought the current/voltage drop should be. If it differs, WHY?" The questions do not explicitly require that the students back their answers with evidence, though this is implied by the emphatic why. Since the students did not enact any follow up procedures to try to determine why their data was wrong, they did not have any data to offer in support of their answers.

By the end of the argumentation sequence, the students, with the exception of Puppet Master, had indicated agreement with Larry's proposed causal explanation for the high current reading that the resistors "wore out." However, the students' written answers did not all concur with this (apparently) accepted proposed reason, indicating that they did not really carry that proposal forward as agreed-upon science

These students entered into lengthy discussions, an important component of learning science, and revealed some understanding of the nature of science. For example, they expected plausibility as demonstrated by their surprise at the data they obtained during the circuitry lab. Like practicing scientists, the students raised issues and challenges while looking for a reason for their data. The students saw the relationship between ideas and experiments, as in Level 2 science, but did not move to the next level by generating and testing theories to answer questions. Generating theories to answer their questions is the link that would have prompted the data generating questions

necessary for resolving their problem. The students could do this when they saw their actions making a difference--as in the graph matching activity—but not when they did not see what actions they could take. Thus their understanding of the nature of science remained limited. The students had a level of understanding of science processes but did not link that understanding to what they could do for themselves to resolve their problem.

Assertion 3: Students' allegiance to their normative science represented a misconception that prevented conceptual change.

The students in this study entered into extended science discourse. The procedure and concept negotiations the students participated in were typical of knowledge construction as defined by Kittleson and Southerland (2004). However, conceptual understanding occurs when an individual or group has an integrated picture of processes and events versus a disconnected collection of fragmented ideas (Fisher, 2000). The students' understanding of some of the science concepts they used in their problem-solving activities indicated fragmented understanding, a form of misconception.

The students in this case group held fast to the "rightness" of science laws --especially the mathematics involved in those laws—that they had been taught in their class. This allegiance acted as a kind of misconception. Vosniadou (1996) describes inert knowledge as bits of information that students encounter and store but are accessible only in very limited situations. The students encountered discrepancies in their projectile motion activity and their series circuit activity and their classroom understanding of kinematics and Ohm's Law did not provide them with knowledge capable of solving these problems.

For example, in the projectile motion activity, the students used the appropriate kinematics equation to calculate where the marble would land when it rolled off the edge of the table. At one point, prior to starting this activity, Larry had indicated -- and the others had agreed -- that they could neglect friction, air resistance, and other factors in their calculations as being physics not required at this level. Thus the students carried out their prediction without considering these factors. The marble did not fall into their predicted target area. The teacher monitored this part of the activity and carried out a brief discussion with the students after their failure. This discussion reminded the students of the need to consider friction and air resistance in deciding where their marble would fall.

The students figuratively kicked themselves for not giving these factors consideration thus costing them a good prediction for the marble landing. However, this realization did not stick. Immediately after completing this activity, the students collectively solved a projectile motion problem essentially identical to the marble experiment. The students fell right back into reliance on their mathematical model. Their solution to the post-activity problem was strictly a mathematical solution with no consideration of the effects of wind resistance or friction on the predicted landing site, counter to the realization they had just admitted to their teacher. Perhaps the math involving these additional factors was not something the students were equipped to handle, but a statement indicating that they understood the effects of these factors on the projected object would have indicated transfer of the knowledge gained from the actual experimental results coupled with the brief teacher discussion afterwards. No such statement was given, even though, on the whole, the problem the students collaborated on

after the experiment was more completely and explicitly laid out as compared to the ones they had solved individually prior to beginning the activity.

A similar falter in the transfer of science understanding occurred during the circuitry lab. The students were all well versed in Ohm's Law—the basis of the lab activity—and how to complete calculations involving this concept. In fact, the students' general talk at the beginning of the activity indicated that they were pleased that this was a series circuit activity because they knew Ohm's law so well they felt like they could move through the experiment quickly and easily. However, when their procedure generated experimental values for the total current and voltage drop that did not match the calculated values, i.e., the theoretical values, the students were puzzled and could not reconcile the difference using their classroom understanding.

The extensive science talk that surrounded the anomalous data in this case study did not generate conceptual change. In fact, though the students seemed to end their argument sequence in agreement that the resistors had worn out, the student responses to the lab questions as well as the interviews indicate that the students had not really accepted this explanation for the data. This is both good and bad. The idea of resistors wearing out over the brief period of an experimental run is not in keeping with normative science. So, the students have not accepted *wrong* science. However, they did not generate any plausible alternatives.

The fact that the students thought the data they got was wrong in the first place is an indication of their commitment to the authority of Ohm's Law. Students' proposed explanations for their data were indicative of their allegiance to the mathematics of Ohm's Law. That is, their proposed explanations placed blame for the anomalous data on

"flaws" rather than on some rational explanation. And while their argument was with the data generated, the students did not see that they needed additional or different data as evidence to back their proposed causal claims. The students understood science processes sufficiently to realize their data was unacceptable. However, the students were too committed to their mathematical understanding of Ohm's Law to allow for explanations for anomalous data besides those variables directly involved with a straightforward mathematical application of Ohm's Law. The same allegiance to calculations learned in the classroom showed up in the students' handling of the projectile motion activity.

Certainly the anomalous data was a result of some change in one of the variables of Ohm's Law, but probably a change that was a result of the experimental set up. The students never gave consideration to set up issues. The students were dependent on the credibility of their classroom, mathematical version of Ohm's Law versus seeing the fundamental aspects of the *science process* and its potential to provide insight and answers. This dependence on an "undebatable set of facts" represents a barrier to these students preventing them from considering alternative explanations for their anomalous data (Settlage & Sabik, 1997). Had these students actually investigated their data in a scientific manner, what would have happened to their understanding of Ohm's Law? I feel their understanding would have been much more powerful than the "plug and chug" mathematical understanding they entered and left this activity with. If students are actively investigating and documenting observations -- like they did during the graph matching experiments -- while learning theory, they are engaged in knowledge construction (Settlage & Sabik, 1997).

Sometimes a conceptual or procedural misunderstanding did change as a result of interaction with the group. With group prompting, Puppet Master readily understood his error in the use of the initial velocity of an object as the vertical velocity versus the horizontal velocity. Larry easily accepted the group's correction of velocity as a straight line and acceleration as a curved line. That these corrections were so easily accepted seems to suggest that each idea was not so much a misconception as a memory lapse and, so, easily accepted and changed. However, if the collaboration had not made these lapses apparent to Puppet Master and Larry, they may have remained incorrect in their minds and perhaps be carried forward to future learning. Procedural misunderstandings were most readily corrected in the graph matching activity when incorrect actions were immediately visible to all participants.

The argument sequence that occurred at the outset of the projectile motion activity showed that Puppet Master had an incomplete procedural understanding of the need for two motion detectors to determine the speed of the projectile. This conceptual/procedural modification took longer and involved more group discourse than the velocity/acceleration changes did before Puppet Master caught on.

That the students would come *out* of their collaborations sharing a common and/or correct conceptual understanding is not a given. This is readily apparent in the responses the students gave to the lab questions associated with the circuit labs. The circuit lab data did not match student expectations and their argument about the reasons for this remained unresolved. However, with the exception of Puppet Master, the group members ultimately agreed *verbally* that the "resistors wore out" and that was the reason for the high current reading. The students also agreed that the ammeter took some of the voltage and

that was the reason for the unexpected lower voltage reading. This apparent conceptual agreement was not carried over into the students' responses on their individual lab sheets or in their interview responses. Only Larry and Mary Lou retained a commitment to "the resistors wore out" theory on their written lab responses and Mary Lou did not retain that commitment when interviewed at the end of the study.

It is clear from these responses, especially when matched with the written responses, that the students did not take away a common conceptual understanding of their series circuit activity. The written answers indicated that worn out resistors was an implausible explanation for two of the four students and the post-interview showed that the student that had put worn out resistors as a reason for the high current reading changed her mind from the end of the activity to the next day when the interview took place. The students did not share a common understanding (or misunderstanding) of what had occurred during this lab activity.

None of the students' responses was in keeping with normative science. That is, their responses were not supported by evidence in the form of data. The responses were either very general as in, "are going to be flaws" or "human error," or incorrect as in "resistance could have worn out" or "there was some resistance in the wire we couldn't measure." None of the responses, which represent the claims these students are making in response to this activity, cite evidence to support their claims. An integral part of the discourse of science is the importance of evidence as backing to support proposed claims.

A component of the third assertion of this study is that the students did not necessarily start and/or end each activity conceptually on the same page. In the projectile motion and series circuit activities, the students started each activity by individually

solving a problem their teacher had determined was like those the activity would conceptually support. These problems were ones the teacher expected the students to be able to solve for their final exam. Before doing activities two and three, the students solved each problem individually talking out their explanation into their individual recorder as well as writing out their solutions. The students then solved the same problems together at the end while being recorded. The students' individual solutions were compared to the group solution.

While not exactly indicative of a common conceptual understanding, the written group solutions to the problems that the students had done individually were more completely and rigorously laid out. For example, in the group solution to the circuit problem, the group included all three equations necessary for the solution as well as the rearrangement of one of these equations to be used for the solution of the fourth part of the problem. None of the individual solutions showed such a complete layout. In addition, the appearance of the symbol Σ, sigma, as an indicator to sum the individual resistances appears only in the group solution. Perhaps the group problem was more rigorously done because of the need to "see" what each group member was thinking. This would not have been necessary while working alone. In addition, each member may have had different ideas about what constituted a good solution presentation. Like Larry and Puppet Master being easily prompted to remember the difference between acceleration and velocity and horizontal versus vertical acceleration during the lab experience, collaboration prompts idea sharing. In more extensive problem-solving, then collaboration might support more extended responses. A possibility is that it can foster a more in-depth approach to problem solving.

A premise of this study was that students, through their discourse during collaboration, could undergo conceptual modification and their final conceptual understanding would be what the group considered valid scientific knowledge (Kelly & Green, 1998). Among the varying descriptors of conceptual change, one proposed by Ivarsson, Schoultz, and Saljo (Suping, 2003) is that conceptual change is the appropriation of intellectual tools and the use of these tools in different contexts. This would indicate that the students, if they had understood science as a process for generating knowledge, would have applied the tools of experimentation to the problem of the discrepant data generated in the circuit lab. Instead, the science they understood stood in the way of seeking more reasoned answers. The students acted as novices who did not know enough to be able to distinguish between important or unimportant information or evaluate the relevance of information (Chinn, 1998). The students did not move forward along the continuum of understanding science processes and so, in the case of Ohm's Law and the series circuit, a conceptual change did not occur.

Posner et al (1982) maintained that an individual student must encounter an event that is not explained by his/her existing conceptual framework and there must be discoveries or insights available that do explain the anomaly. In this instance, the students would have had to generate their own discovery or insight, and this required them to exercise an understanding of the nature of scientific processes. That this did not occur in this instance seems to indicate a naïve practical epistemology with regard to scientific processes. There appears to be a discrepancy between the students' practical epistemology—that is, what science they enact themselves—versus what science they would say they understand scientists to enact. These students have been taught about

how science is conducted but this teaching did not translate into action. The students did not act as the scientists in this case. These students could probably have given an accounting of the kinds of activities scientists carry out but this description would not dovetail with what they enacted in their own inquiry.

Implications for Science Education

One implication for science education is that collaboration is a necessary component of effective science education. However, the collaboration should be structured to encourage the use of field dependent argumentation elements that extend beyond reliance on unsubstantiated claims and over dependence on the authority of normative science as learned in their classrooms. Another implication is that science education should include pressing students to more mature levels of science epistemology. With a more mature scientific epistemology, students would not need to be told to explore consistencies, they would naturally expect to explore inconsistencies.

Collaboration is a necessary component of science education

Collaboration did foster student discourse. By definition, collaboration means working together to solve a problem. There is no pre-set division of labor; instead the participants distribute and coordinate the tasks and develop a shared view of the nature and extent of the problem they have to tackle (Dillenbourg et al., 1996). The activities these students completed required them to physically work together. In doing so, they coordinated their tasks. Collaboration cast the students into the role of actively engaged learner within the social context of other actively engaged learners. For the teacher planning a curriculum that includes collaboration, the choice of activity enacted is very important.

Collaboration leads to an exchange of ideas among members of the group. This was true of the discourse enacted by this student group. It was useful in making apparent to each other -and to observers of the activities—discrepancies in their understanding. Nystrand and Gamoran as cited by Dunlap (1999) point out that high quality discourse occurs when the talk takes on the aspect of normal conversation, with speakers negotiating the content and engaging in turn-taking. This natural conversational discourse is difficult to achieve in adult-student collaboration such as teacher-directed discourse, but is more likely to occur in peer collaborative groups As research suggests, the teacher's absence made the discourse naturalistic (Hogan, et al., 1999), lacking the tension that is often engendered by the presence of a teacher. This is not to say the students working collaboratively never had contentious moments. It is, simply, that these moments were natural outcroppings of their work and not a function of being nervous about having the right answer for the teacher.

Collaboration is potential teaching strategy for establishing a classroom culture of learners who value each other's contributions and requires engagement of all participants. In a science classroom, collaboration can be similar to the activities carried out by scientists as the students negotiate common procedural and conceptual understandings. The caveat is that the choice of the experience makes the difference between successful collaboration and simply getting the job done. Research suggests that the learning experience must be made up of authentic questions. The component of prediction present in each of these activities represented an authentic question (in the form of a problem to solve) for these students. In addition, physical interdependence in the enactment of the

activity was key to student engagement. It was not easy for the students to sit idly by while their cohorts did the work.

Argumentation is such an integral skill to successful science learning and communication that it is worthwhile to challenge students with activities that have the potential to engender arguments. Activities that have the potential to produce unexpected results can be an especially useful prompt that starts argumentation. This will provide the teacher with the opportunity to monitor and improve how the students shape their argument. The students in this study relied heavily on the argument elements warrants and claims with few references to data or backing elements.

One implication for teaching is to foster the kinds of collaboration that promotes negotiations among the students. These activities engage students in discourse that provides a window into student conceptual understanding. Collaboration, then presents natural opportunities for teachers to take stock of student misconceptions, incomplete conceptions, and naïve science understandings.

For example, this research showed that the students had an incomplete functional understanding of science as a way of solving problems. In most science classrooms each science subject is taught as discrete units with the scientific method taught as a unit near the beginning of each science course. Even if the classroom teacher has a good working idea of science processes and teaches science as a tool the student can use to mediate his/her own learning it may not mean the students will appropriate this learning. This is especially true if these process ideas are presented as a discrete unit that is over and done with after testing. The students will not necessarily extend what they have learned in this

discrete unit across the discipline under different contexts. The teacher will need to make science process skills an expectation of every lesson.

Positivist learners working in collaborative groups tend to show decreased engagement. Positivists are learners who emphasized learning as recreating a reality (Hogan, 1999). These students were positivists recreating a reality with their lab activity. But, they also remained engaged in their lab work for an extended period, not a typical positivist action. My take on this is that there is a continuum of positivism. One form of conceptual change is the movement along a conceptual continuum from a novice position to an expert position. These students were certainly not at the beginning of this continuum -- their engagement and attempts to bring classroom knowledge to bear on their problem is evidence of this. An initiative for education, then, would be to push students forward on this continuum knowing that its progress may be something like a halting two steps forward one step backward progression. The ideas of science need reiteration, practice, and reinforcement. There needs to be multiple opportunities for students to confront lessons that require them to personally use science processes such as experimental repetitions, theorizing and hypothesizing, data generation, and argumentation.

In the projectile motion activity, the students had one shot to get their marble in the correct spot. At the outset of this activity, the students had discarded the effects of friction and air resistance as not relevant to their solution. However, after their failed shot, the teacher reminded them of these components. This seems to highlight a disconnect between what the teacher expected the students to understand and what they expected of themselves. When the students were reminded about these effects, the

students were not surprised. It could be inferred from this, that the teacher had addressed the implications of these components at some point in class. One of the teacher's directives in the lab was that the she would take away any marbles she heard landing before the one shot so clearly the teacher expected the students to be successful without practice. That the concepts of wind resistance and friction were dismissed by the students but expected by the teacher indicates a disconnect between teacher expectations and student appropriation.

Guide students toward a more mature scientific epistemology

In the circuit activity, the students failed to enact science processes that would potentially solve their problem. When asked to explain any differences between the theoretical and actual data, their explanations were simplistic and unsupported by data. This suggests a need for the teacher to step away from the specific concept being taught (Ohm's Law) and step up teaching scientific processes.

Teachers need to foster an ongoing working understanding of science as a personally usable way to find answers. Science as a process should be continually applied throughout a course, ideally throughout all science courses. Science as process cannot be simply a unit taught and completed at the beginning of the year. Science taught in this manner is inert, consisting of bits of information that students encounter and store but are accessible only in very limited situations (Vosniadou, 1996). This was demonstrated when these students got stuck on their circuit problem. This inability to employ what they were taught in one context, such as the "scientific method" or the effects of friction on movement, shows a naïve, fragmented understanding of scientific

processes, a form of misconception. This, like any misconception, needs to be identified and addressed in an ongoing manner.

It has long been a tenet of education that student preconceptions need to be assessed prior to any teaching episode. However, preconceptions are not the only conceptions that need to be assessed. Assessment should include preassessment, post assessment, and on-going assessment to ensure that new concepts are being constructed appropriately. To effectively mediate student learning, students' knowledge construction needs to be continually assessed so breakdowns are quickly spotted and addressed. For example, the circuit lab required the students to explain any differences between their calculated (theoretical) and measured values. Their responses were unsupported in any scientific way. This would have been the time for the teacher to take action.

The following student competencies were noted as necessary outcomes of mathematics education but it could be argued that these goals are subject neutral (Fuson, Kalchman, & Bransford, 2005, p. 218)

1. Conceptual understanding—comprehension of mathematical concepts, operations, and relations
2. Procedural fluency—skill in carrying out procedures flexibly, accurately, efficiently, and appropriately
3. Strategic competence—ability to formulate, represent, and solve mathematical problems
4. Adaptive reasoning—capacity for logical thought, reflection, explanation, and justification (emphasis added)
5. Productive disposition—habitual inclination to see mathematics as sensible, useful, and worthwhile, *coupled with a belief in diligence and one's own efficacy* (emphasis added)

"Science" could be effectively substituted for "mathematics" throughout this list.

The students in this case group fell down on their adaptive reasoning and productive disposition. Ongoing assessment during the circuit activity would have made this

apparent to the teacher. The teacher would then have the opportunity to step away from Ohm's Law (or whatever the scientific knowledge under question is) per se and bring to the fore what students can do to resolve their problem.

Teachers are encouraged to mediate student learning and in science this means both their specific content knowledge as well as their ways of knowing (Magnusson & Palinscar, 2005). Rather than having the students complete this lab activity in one period, it would be fruitful to have this activity restructured to be the springboard for teaching science processes. Klayman and Ha (1987) suggest a "positive test strategy" as a means of solving problems. This would have the students take the solutions they propose, prioritize these potential solutions, test each one, and determine if any of the solutions provides strong explanatory and predictive potential. This kind of activity provides confirming evidence for their hypothesis but may or may not provide disproving evidence. As such, it is not classic science but is a practical method for searching for a real-life solution to the problem presented. Research suggests that students design better experiments after they have been explicitly taught that the purpose of an experiment is to isolate causal relationships (Sandoval, 2003).

A shortfall of the activities that these students completed was the minimal requirements for written explanations for what they were doing, what they found out, or what they accomplished. Other than mathematical solutions to pre- and post-problems, the students had no writing requirements for the first two activities. The graphs produced in the first activity were not downloaded, they were checked off by the teacher. In addition, the circuit activity only required a one-line response to explain their results.

What if, for example, the circuit lab activity could be set up as a two-tier activity? The question set required by the students could extend the conclusion question to include: Why was the data different than expected? *Present an argument with data to support your response***.** That each student gave different responses from each other and from what they had substantively agreed upon at the end of the lab is also significant. What would the answer to the circuit lab had been if the activity had required a single, unified, group response? This research showed that students working together provided a more thoroughly laid out solution to a problem. If this had been the first tier of this activity, the teacher would have the opportunity to review the more extensive (but fewer) responses and dialogue with the students about how their work looks. Does it look good, off base, or interesting; show me more to prove what you claim. If the work is off base, go back and try again. The students would then review their work and cycle through the activity again to satisfy the points of the mid-experiment. Have the different groups within a classroom present their initial findings. Are the findings the same between groups? Different? A larger group's discourse would press the students to defend their findings and provide the opportunity for a teacher to stress the need to link data to explanations.

This two-tier sequence with teacher scaffolding would press the students for more reflection, explanation, and justification, thus making more demands on the students. If classroom activities such as these occur frequently enough within a course, the students will naturally begin to make connections between science processes and their ability to solve a real problem. This would move students toward the desired goal of belief in diligence and one's own efficacy.

The activities observed in this study were done during extended class periods of ninety minutes each. This should have provided an opportunity for the students to reflect and enact changes as needed. The students were operating at a scientific level as evidenced by their search for consistency, plausibility, and causality, but they were drowning in the higher-level aspects of science processes. These students had one assessment episode for each activity. Whether this was usual is not known. In the post study interviews the students did indicate that lab activities were not a very common occurrence in their classroom. Informal or formal support of these activities as sticking points occur and are observed by the teacher may have prompted conceptual development in students.

Remillard and Geist (2002) use the term "openings in the curriculum" to denote those instances during instruction in which things do not go as planned or directed by the curriculum. These openings may become apparent when teachers observe students' misunderstanding during planned activities. Teachers can optimize these openings by analyzing student work and thinking, weighing possible options for proceeding, and taking some action. Deciding what teaching to do next by interpreting students' understanding with respect to the goals for the students represents an opportunity for teachers to improve their own efficacy and for students to undergo conceptual change. When teachers find themselves and their students in one of these "openings" it can become a teachable moment with a sort of pay it forward component in that the teacher addresses a student's misunderstanding quickly and is also better prepared for the next time he/she teaches this curriculum.

Implications for Future Science Education Research

Extend research into science practical epistemology

Research into students' reasoning regarding scientific experimentation, interpretation of data, and engaging in scientific argument identifies some common conceptual pitfalls for students. For example, in spite of all of the times students have been taught the scientific method, not all students see experimentation as a means of testing their hypotheses. For example, the students in this study indicated in their post interview that they thought this lab was "a good process of finding information."

Sandoval (2005) characterizes the epistemology of science in the following questions: What do we know? How do we know what we know? And why do we believe it? (p. 638). In a further distinction, Sandoval separates practical epistemology from formal science epistemology. Practical epistemology can be described as the working set of ideas an individual (in this case, the students under study) has about how they generate knowledge (in this case science knowledge). Practical epistemology is distinguished from formal (science) epistemology which describes the ideas students have about how scientific knowledge is generated by professional scientists. That the students in this research could not see the value of devising experiments to test their causal hypotheses suggests that even these very capable students held a naïve practical epistemology about how science knowledge is generated. They did not see themselves as scientists.

Studies support the notion that students' hold different levels of epistemology and that the level changes over time. For example, Evans and Ravert (2007),) in a study of epistemic beliefs among undergraduate and graduate students, found that lower level

undergraduate students “valued questions with one right answer and perceived little value in knowledge supplied by classmates”(p. 12). Further, these authors found:

> …group collaboration to solve ill-defined problems may work well with upper-level and graduate students, but may lead to unintended distress and have limited effectiveness with freshman and sophomores. Likewise, relying on peer-based learning to take place…may be especially challenging and/or require greater scaffolding with younger students who perceive the instructor as sole possessor-of-knowledge (p. 12).

In a study of introductory college physics students, Hammer (1994) found he could classify students’ beliefs about learning as authority-driven or concept-driven. Authority-driven learners see physics as a collection of topics consisting of facts and formulas delivered by an authority. Concept-driven learners, on the other hand, see physics as a coherent system of concepts that can be applied across different contexts and modified using one’s own judgment. Understanding these differing epistemologies can provide insight into what can be expected from students. For example, if a student does not expect a coherent understanding of physics concepts from his or her coursework but, rather, expects to memorize formulas that are applied in discrete contexts, then he or she may expend little effort in seeking coherent answers to problems that arise. More of this type of learner’s effort will be expended trying to match the proper formula to the particular class of problem it is to be used for (Hammer, 1994). The students in this case study acted as authority-driven learners as exhibited by their heavy reliance on the rightness of Ohm’s Law. The students expected their results to confirm the validity of the law. When it did not, perhaps they were not able to move forward because they were not epistemologically ready to modify their understanding of a scientific law (Ohm’s Law).

A series of studies cited by Carey and Smith (1993) highlights students' naïve epistemologies with respect to science processes. In one study, students showed limited abilities to confront confounding evidence with hypotheses that could be tested (much like the students in this case study). The students studied, except for graduate students, simply abandoned those hypotheses that were at variance with the data. Another study (Grosslight et al as cited by Carey & Smith, 1993) of students up through grade 11 found that students could be classified into three levels with respect to scientific epistemology. These levels describe a scientific epistemology continuum from science provides answers to incorporation of theory and model testing. Carey and Smith (1993) found that up through grade 11—the highest grade tested—none of the students were classified at Level 3. However, all professional scientists interviewed scored at Level 3. Maybe the inability to grasp Level 3 ideas, considered formal scientific epistemology, may constrain students' success in science.

Student epistemology may differ from scientists' and the students will enact their personal epistemology in doing their school science. Furthermore, students do not reflect consciously upon the reasoning they use. Therefore, students' personal epistemology may not be determined by asking de-contextualized questions about what science is, how scientists work, how is knowledge generated (Leach et al., 2000). There might not be congruence between how students respond to these research-based instruments and how the students actually approach a learning situation (Hammer, 1994). Students' real, enacted epistemology can only be accessed by observing the students as they actually participate in science. Students' beliefs about knowledge and learning in science may have a direct bearing on what they learn, and these beliefs are a "difficult target"

(Hammer, 1994, p. 155) for research. However, descriptive studies of students' practical epistemologies can be used to describe how "the encounters made by students in the classroom change their undertakings and what they learn" (Wickman, 2006).

So, this suggests that student thinking about how one learns science will have to be explored through the lens of real-time, school-based activities. What kinds of practical epistemologies would correlate positively with those that reflect the nature of scientific epistemology?

This kind of research has the potential of uncovering what kind of science education needs to be enacted to foster these views. Hammer (1994) suggests case studies of students in an ongoing course with direct reflective accounts from the students as an effective means for identifying students' epistemologies. Hammer contends that the students could be asked to reflect on problems they have solved in a conversational manner that highlights what the students consider relevant.

The research cited above is based on examining individual epistemologies. It can be expected that the individual student will bring his/her own beliefs about learning into a collaborative problem-solving event. The individuals' beliefs may mesh with, clash with, or be set aside as irrelevant in the process of group problem solving. Studies of the discourse within collaborative groups working on science problems provides a context that could reveal students' common beliefs about how they learn, as well as what beliefs are at odds with each other or with a scientific epistemology. How does this affect the work the students accomplish together? Looking at the beliefs that the students bring to bear on a problem, especially the domain specific epistemologies that are characteristic of

and valued by the scientific community, can be a springboard to developing a means of moving students' along the continuum from naïve to sophisticated science thinker.

Reform documents call for:

> teachers of science [to] develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning ... [and that] students [are] to explain and justify their understanding, argue from data and defend their conclusions, and critically assess and challenge the scientific explanations of one another (NRC, 1996, p. 32, 50)

Just as a collaborative group working together brings their individual intellectual histories to the task to ultimately determine what counts as science (Kelly & Green, 1998), so, too, the group will develop and use a collective epistemology based on: What do we know, how do we know it, and why do we believe it? Looking at direct accounts of the collective epistemology that is enacted by a collaborating group is a potential area for research. Unproductive, misdirected epistemologies need to be understood and identified and the role of inquiry teaching in developing productive processes in students needs to be clarified.

Perseverance

A second area of interest for research is the notion of *perseverance* and how this will impact successful collaborations. In their own words, the students in this case group "gave up", wrote naïve, unsubstantiated responses on their lab sheet, and turned their work in. As noted before, these were strong, motivated, engaged students and their discourse during the activity indicated a strong interest in knowing the right answer:

Perseverance can be defined as

> …having a consciousness of the need to use intellectual insights and truths in spite of difficulties, obstacles, frustrations; firm adherence to rational principles despite the irrational opposition of others; and a sense of the need to struggle with

> confusion and unsettled questions over an extended period of time to achieve deeper understanding or insight. (Elder & Paul, 1998).

Perseverance is cited in psychology as a component of intellectual maturity and should be fostered as a desired goal of education (Elder & Paul). It is also cited as a desirable trait in programs designed to enhance character education (Deitte, 2002). One characteristic that is identified as a student trait associated with a meaningful learning strategy for science is tenacity (Hogan, 1999), a synonym for perseverance.

In a humorous editorial addressing the question, "What is science?" Harold Jaus (2002) points out some fairly awful stumbling blocks he encountered while completing a research study on mice mating habits. The point of this editorial was to say that science is more than the usually identified components of process and product. Not insignificantly, perseverance in the face of obstacles (such as rounding up escaped mice) is a key component of success in science research.

Self-regulating, self-conscious learning is dependent, at least partially, on the disposition of the learner and one component of this disposition is the individual's perseverance (Schapiro & Livingston, 2000). From this, one could infer that perseverance is partially a component of an individual's personality—something they bring to the classroom. However, several studies indicate that perseverance can be strengthened. For example, in a yearlong study of the effects of a problem-solving curriculum, students in the class with the curriculum designed around problem solving worked on math challenge problems with little or no direction from the teacher. These students persevered for increasingly longer periods of time on their challenge problem-solving events over the course of the year. Students in a classroom that was not using the problem-solving curriculum typically quit trying to solve math problems if their work did not result in a

solution within twelve minutes. In contrast, students in the experimental classroom would spend hours to days on a solution. That perseverance increased was an unexpected finding of this study (Higgins, 1997).

Perseverance may also differ with the students' view of the activity with which they are engaged. For example, students enact different discourses when they work on school-required, classroom-based activities versus when they work on self-selected science activities such as participating on a robotics team (personal communication with H. Price Webb, Ph.D. candidate, 2008). This dovetails with a change in discourse patterns when students are "doing the lesson" versus "doing science" (Jimenez-Aleixandre et al., 2000), that is, when students are trying to accomplish an assigned task rather than trying to solve a problem. If one purpose of discourse is to establish one's identity (Gee, 2005) some activities may inspire students to take on an identity that more nearly approaches that of a scientist. This level of buy in will support the student's view of him/herself as a scientist and therefore, it will support the perseverance necessary to push through stumbling blocks.

Individuals experience learning contexts differently, and they may also differ in their views on learning as well as on their level of motivation to learn. These differences do not disappear when participating in collaborative work (Hogan, 1999). Vygotsky's *Zone of Proximal Development* says that:

> What the child can do in cooperation today he can do alone tomorrow. Therefore the only good kind of instruction is that which marches ahead of development and leads it…(p. 85).

But how far ahead should or can the instruction be without causing frustration? How far ahead will develop perseverance? In a study of eleven final year university students

completing culminating investigative projects, researchers found that a match between the epistemic demands of the project and each student's level of understanding of the relationship between data and knowledge was a factor in determining the successful completion of the project (Ryder & Leach, 1999).

Evans and Ravert (2007), studying the changes in student epistemology from undergraduate college students to graduate students, suggest that expecting students at lower epistemological levels to learn based on the principles of negotiation and shared construction of knowledge without consideration of their epistemological level is problematic. Frustration certainly has the potential for shutting down a learning process so consideration of the level of student distress needs to be factored into a learning sequence.

If perseverance is a desirable intellectual trait and its development can be affected within the classroom, research into this aspect of science education is needed. Again, the studies that have mentioned perseverance—and, mostly, perseverance was not the aim of the research—have focused on how it is changed, developed, or has an impact on the individual's student and his or her learning. As mentioned before, collaborative groups are different than individuals and the problem of perseverance within the context of collaboration merits study on its own, especially since reform documents call for more learning within social contexts.

A hint at the potential for this research into how perseverance affects/is affected by collaboration are studies that show that pairs of students spent more time working on solutions to the problems than did students working alone (Bearison, 1982). And, that students who exhibited a meaningful learning orientation exhibited tenacity in their

science problem solving. Further, this tenacity "came with" the student to contribute to a collaboration that was more successful than exhibited by groups that did not have a tenacious member (Hogan, 1999).

In this study, the students did not fruitfully persevere in the face of difficulties. The students' discourse indicates that laziness and lack of interest were not at issue. What factors were at play here? What was the group's potential? How does a group's practical epistemology dovetail with a group's perseverance in the face of adversity? Answers to such questions may provide teachers with valuable information about how to proceed within a curriculum and how to set up more successful collaborative problem-solving events. A collaborative group studied under natural conditions can yield a lot of information about how students learn, what constrains their learning, and what actions might be taken by educators to prompt more of the positive kinds of learning experiences.

The Effects of Normative Science on Conceptual Change

For these students, their classroom learning seemed to act as a misconception. Research into how classroom learning supports or constrains conceptual change would shed light on how to avoid the kind of frustration the students in this case group experienced.

How does the classroom culture contribute to the students' understanding of normative science? Much of classroom science is presented as a fact not unlike a historical date is presented in a history class. All things are made up of atoms would be a science example of this. Even the terminology used in science, Ohm's Law, implies a given, inviolable fact divorced from the work scientists did to determine these concepts.

What kinds of teaching would enable students to learn normative science without it becoming an obstruction to science process learning?

The Effects of a Science Teacher's Attitude about Lab Activities

When researchers asked teachers why discussions do not occur frequently in science classrooms one reason teachers cited for its absence is that discussions were considered an inefficient means of teaching (Driver, et al, 2000). This case group indicated that doing labs in their classroom was relatively rare. In fact, a talk with this teacher indicated she does about five labs per year because the curriculum is so packed. This statement seems to indicate that this teacher finds labs an inefficient means of teaching and/or learning. Since discourse is a natural product of lab activities and opportunities to see students' enacted epistemologies may be made apparent, lab activities have the potential to inform teaching and learning. Research into teachers' attitudes about the value of lab activities as learning events may lead to positive changes in science education practices.

Finally, the discourse and observations that were made based on this group were examined for evidence of conceptual change or development. The data could be analyzed as a response to other questions. For example, disposition of group members, the size of collaborating groups, the heterogeneity of the group, and the purpose for the collaboration, have been demonstrated to alter the success of a group's collaboration (Azmitia & Montgomery, 1993; Bearison, 1982; Dillenbourg et al, 1996; Hogan, 1999). These data could be applied to the relationships that exist within this group. This group was not totally unsuccessful but not completely successful either. What were the components within this group that supported or thwarted success? How could this

information be used to strengthen collaboration? For example, listening to these students it became clear that they had different learning dispositions. Puppet Master often seemed to be hurrying the group along, Larry and Mary Lou showed frustration more often than the other two group members, and Jimbo was more passive in his participation. How did these dispositions alter the outcome for this group? Another as yet not fully answered question with existing studies of collaboration is suggested by Scott et al (2000). Does changing communication patterns improve student learning?

Study Limitations

Only one case group was followed in this study. As with all of science, an instance of one event is not sufficient to make a universal statement. In other words, what happened with this group's collaboration cannot be generalized to all collaborative groups. For example, in a pilot study of a tenth grade chemistry class, conducted by myself, most of the groups, when given an assignment designed for collaboration, simply cooperated in generating their product. That is, the students in the pilot study very quickly subdivided the labor then simply did their part at home and emailed their contributions to a coordinator who cobbled it together for presentation. Very little discourse occurred and the discourse that did occur was procedural. Only one group truly collaborated and generated a cohesive product at the end. This subdivision of labor was probably a result of the type of activity the students were doing. There was no element of prediction in the activity and the students' physical presence was not required to get the assignment done. The results of the pilot study illustrated that not all groups in a science class with a science-based assignment will naturally collaborate and/or talk science.

In addition to this research being limited in its applicability to other cases, the analysis of the discourse depended on inferences drawn by myself. The conclusion that students hold naïve views of the nature of science is an inference that has been supported by many prior studies. The conclusion that the students lacked perseverance has not been supported by other studies in science education and so needs more support from additional research sources in order to become a valid conclusion. Thus, this case study needs to be considered within the body of many such studies in order to complete the picture of what collaboration can do for communication and conceptual change.

I was very invested in this study. I wanted to see "Aha" moments followed by conceptual change. I had very high expectations of what I might observe. To these albeit wonderful students, this was just another classroom assignment. Indeed, it was another assignment at the end of a long year of assignments. The students' own reflection expressed in the final interviews indicated they were quite satisfied with the way the labs had gone. The students' perspectives and my perspective were very different. Perhaps the students just did not care enough about these lab activities to pursue a more thoughtful resolution of their problem or maybe from their perspective they had done just fine and not having a reasonable resolution did not bother them. From my perspective, not having a reasonable resolution was unacceptable. Because these students were very mature, I assumed they had a high level of science ability and would be inquisitive. I thought that they would think like I think. This means that I assumed the students would respond to their anomalous data the way I would have responded. While not a working scientist, I would have immediately retried the lab. It was surprising to me that this never occurred to these students. I found it hard at the time not to say anything to the students.

A more relaxed student perspective is supported by changes that were made to this study. The plan for this study was that it be a usual class assignment and take place under usual classroom conditions. When the teacher and I laid out plans for this research she had indicated that these review activities would take place as preparation for the students' AP test. Due to personal issues, the teacher had to put off these activities. She rescheduled them as review activities for the general final exam. This meant that the teacher might not have placed the same kind of emphasis on these activities as she might have in the original plan. Changing the emphasis on these assignments would certainly change how the students viewed the work. Thus, this may have changed the dynamics of what rigor the students felt would be expected of them. However, the students always acted as though this work was important and several times their conversation clearly indicated they wanted to please their teacher and get the right answer. They never mentioned any pressure regarding grades that might result from this experience. This study may or may not have represented the normal and usual flow of activities for this class.

Personal Reflections

When I was interviewed for admittance to the doctoral program at Georgia State University, the questions addressed to me revolved around what research interests I held. Naively, I had decided to seek a PhD because I wanted to stretch myself. This concept, to me, meant looking for ways to improve my teaching as well as take some course work that would update my academic knowledge and skills. This is very different from what a PhD program is all about and that became very clear during this interview. However, as I was interviewed, many ideas about what aspects of science education needed research

popped into my head. By the time I was accepted into the program, my thinking had begun to make the transition to researcher.

From the beginning of my program of study, I have been interested in looking at students' talk and what that means to their learning in science. Initially, my interest focused on the dynamics of how questioning--both those questions posed by the teacher as well as those posed by the students--affected teaching and learning. This heightened my awareness in my own classroom, particularly how and when students spoke up or initiated questions. My program of study also made me aware of a set of research paradigms about which I knew nothing. Having been out of school for seventeen years, I was new to such important educational concepts as social constructivism and inquiry teaching. I was the equivalent of an educational Luddite! There are more of my type than one might imagine.

In becoming more aware of what was going on in my classroom, I found that my students made some of their biggest conceptual leaps when working together on difficult problem-based projects with more than one solution. In fact, this study stemmed from observations I made in my own classroom. When Chemistry students were given projects that required them to pull together material from several units, their talk indicated that what I thought I had taught and what the students had successfully reproduced on their tests was, in fact, no help to them in solving their problem. However, in the context of collaborative groups, I saw and heard students, through their discourse, work through the problem. Students, during their collaboration, pulled together the appropriate chemical concepts and formulated a coherent solution to the problem. I reasoned that this occurred because each student brought their personal history to the

table. Some of the students brought creative ideas about how to present their findings and some students remembered a key concept the others had forgotten. Each student made a contribution that was vital to the group's success. This reasoning about the value of collaboration was supported when former students would visit me in years following my class. These former students often recalled these difficult project events even remembering little details. The students recognized these activities as hard and were justifiably proud of their work. Hence, these kinds of activities had a lasting impact.

Subsequently, in my PhD program, I began reading the literature, especially work by such researchers as Bearison, Hogan, Posner, Strike, Hewson, and Gertzog, Kelly, Kittleson and Southerland, and Kruger among others and found support for my growing idea that students need to be given the opportunity to collaborate—especially to talk to each other. This provides students with opportunities to come close to acting the role of a scientist, "forces" them to articulate what they know, and engages them actively in their own learning.

So, I set out to study students working together on activities in a natural classroom setting doing what students would actually be expected to do in school. And what I found is a cautionary tale. The conceptual understanding students build for themselves collaboratively may turn out to be dead wrong. This may be because of true misunderstanding or because students tire of puzzling. Whichever the case, the students settled for a quick, unreasoned answer. The students' expressions of confusion and frustration were both uplifting and disappointing. The fact that the students grappled with the inconsistencies between their understanding and the experimental realities represented positive opportunities for conceptual change and was wonderful to eavesdrop

on. The students' willingness to settle for simplistic answers to their dilemma was disappointing. What will students come away from learning experiences with if they are willing to settle for a nothing answer? On the other hand, they are, after all, just kids with limited stamina. How, then, might a teacher structure the curriculum to encourage students to take the next step? How and when might a teacher intervene to dissuade students form drawing unreasoned, unsupported answers?

In conclusion, the results of this research indicate that collaboration will generate student discourse that could be classified as science Discourse. However, even with appropriate discourse and engaged action, student conceptual change may not occur. This may be because the students bring naïve epistemology to bear on their problem or that perseverance in the face of difficulties is a stumbling block The results further indicate a need to teach students how to properly lay out and articulate a scientific argument. If further research substantiates these conclusions then research into strategies that can be developed to address students' practical epistemologies and increase their perseverance should follow.

On a positive note, the students I worked with were engaged, generally positive in their attitude, and good supports for each other. They brought a level of exuberance to the tasks that was fun to see and rewarding for a teacher to watch.

Summary

This case study closely examined student collaboration and its effects on conceptual change in high school physics students. A group of four students worked on three physics problem-solving activities. The students' discourse during these events was initially examined for instances of concept negotiation which would indicate times when

students were engaging in knowledge construction. It was determined that both concept and procedure negotiation events were important for fostering productive discourse. These negotiation events needed to be further examined for the kinds of argumentation elements and the scientific epistemology students used during their negotiations.

This study provided a description of how students approach and solve science problems and revealed conceptual changes that occurred. The findings of this study indicated that procedural negotiations were also hallmarks of knowledge construction for this group. Three major assertions are drawn from this work:

1. Activities that have an element of prediction as well as require physical engagement of all members generated extensive science Discourse. The science Discourse that occurred could be classified as knowledge construction.
2. When confronted with anomalous data, students retained a naïve understanding of science processes as a means of answering questions.
3. The student's reliance on their normative understanding of science as a set of undebatable facts acted as a misconception that prevented the students from moving from a novice science epistemology to a proficient position (Chinn, 1998).

A model for science classroom activities that generate science Discourse is proposed (see Figure 14). A discussion of the kinds of classroom changes that would positively support students' productive discourse and subsequent conceptual growth followed. Further research efforts into student reasoning regarding scientific experimentation, students' practical epistemologies, and the contributions of

perseverance to collaborative success are suggested as having the potential to improve science education. Finally, this is only one case study and the students involved were not average students, thus the applicability of this study is limited.

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APPENDIXES

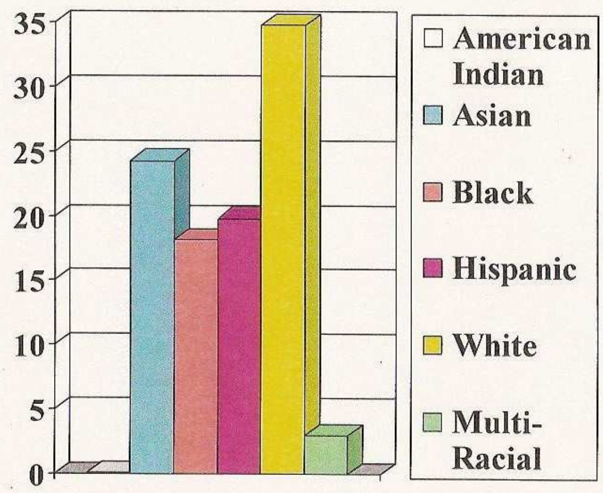
APPENDIX A

SCHOOL DEMOGRAPHICS

Student Ethnicity Report
as of November 1, 2006

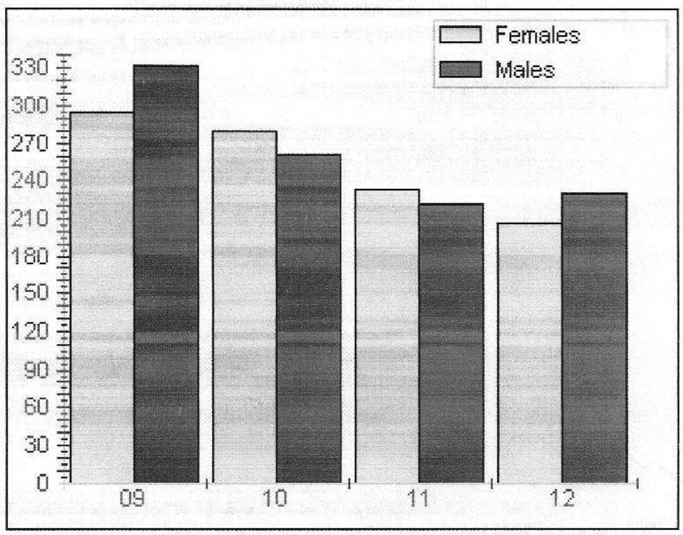
- Current Enrollment - 2060

- American Indian – 0.1%
- Asian – 24.3%
- Black – 18.1%
- Hispanic – 19.8%
- White – 34.8%
- Multi-Racial – 3.0%



Student Distribution - 11/17/06
Fri, Nov 17, 2006 07:43 AM Page: 1

Grade	Female	Male	Total
09	295	333	628
10	280	261	541
11	233	222	455
12	206	230	436
Total	1014	1046	2060



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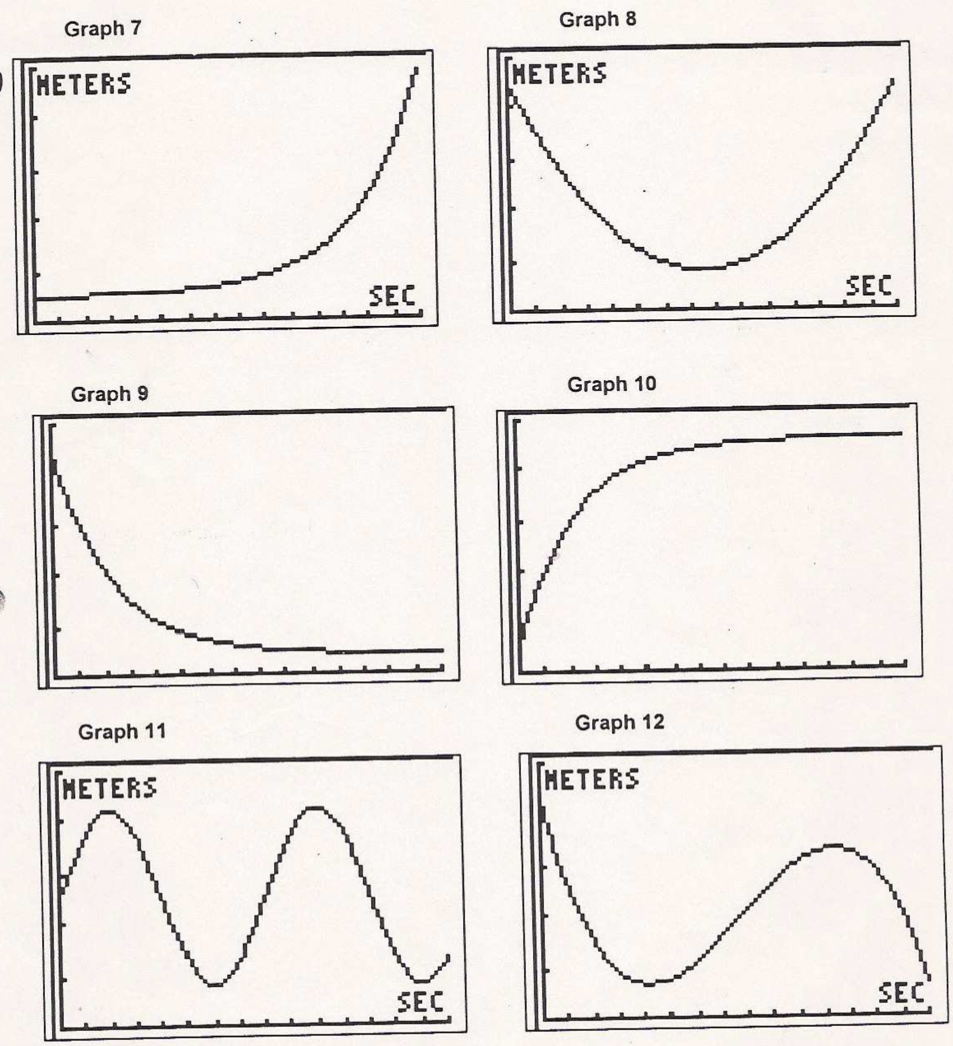
	Math				Critical Reading/Verbal				Math+ CR/Verbal	
White	556			White	540			White	1096	
Asian	616	60		Asian	523	-17		Asian	1139	43
Black	455	-101		Black	489	-51		Black	944	-152
Economically Disadvantaged	486	-70		Economically Disadvantaged	450	-90		Economically Disadvantaged	936	-160
Hispanic	480	-76		Hispanic	447	-93		Hispanic	927	-169
Limited English Proficiency	565	9		Limited English Proficiency	364	-176		Limited English Proficiency	929	-167
Students with Disabilities				Students with Disabilities				Students with Disabilities		

APPENDIX B

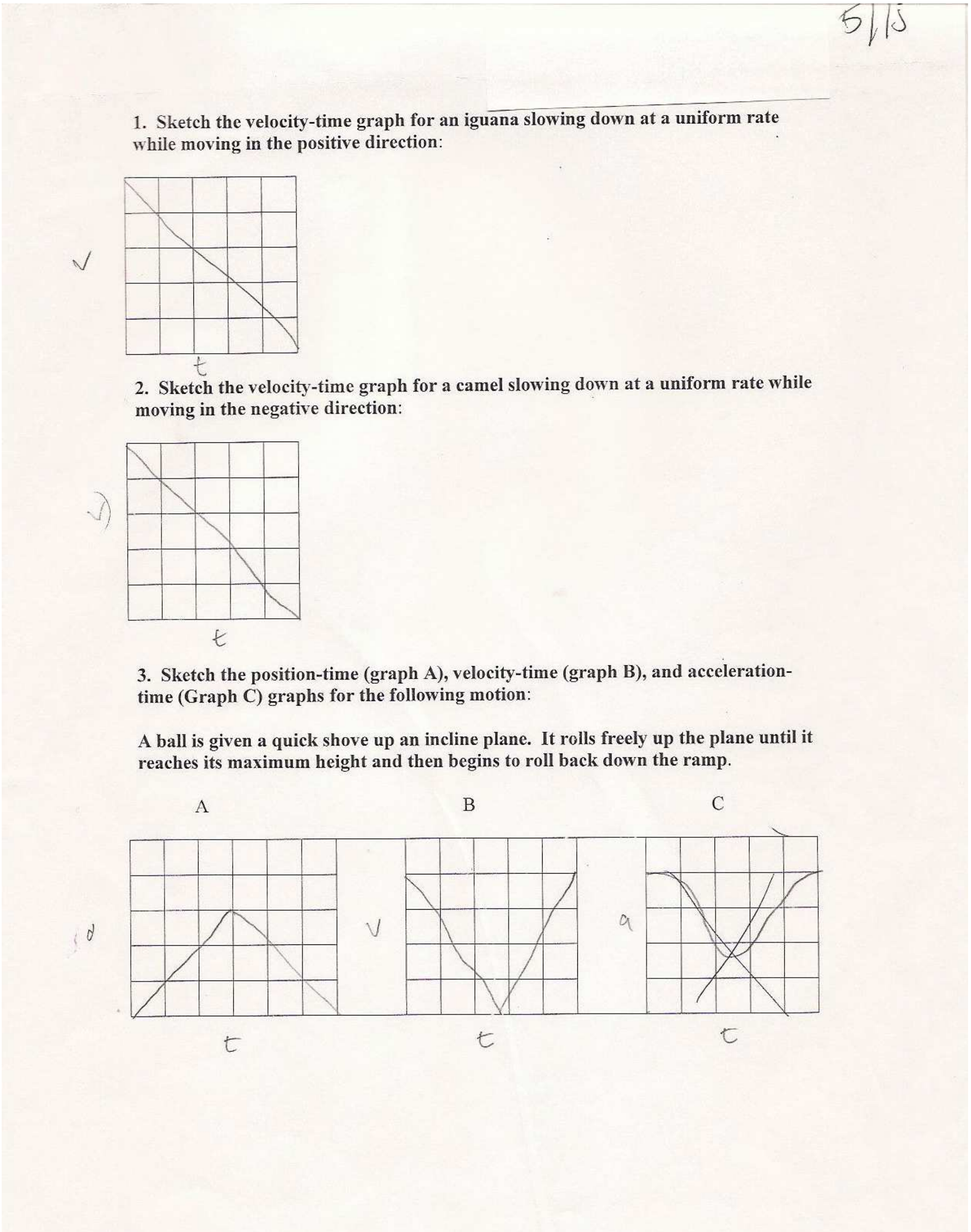
STUDENT ASSIGNMENTS AND ARTIFACTS

B.1 AP Physics B – Graph Matching Activity



Connecting Mathematics and Science 9 Texas Instruments ©2000

B.2 Student solutions to velocity and acceleration vs. time pre-activity problem, Student 1.



5/15

1. Sketch the velocity-time graph for an iguana slowing down at a uniform rate while moving in the positive direction:

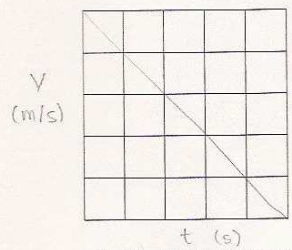
2. Sketch the velocity-time graph for a camel slowing down at a uniform rate while moving in the negative direction:

3. Sketch the position-time (graph A), velocity-time (graph B), and acceleration-time (Graph C) graphs for the following motion:

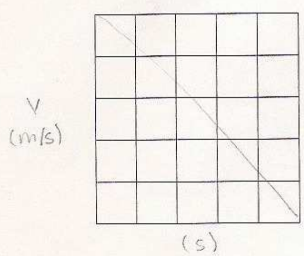
A ball is given a quick shove up an incline plane. It rolls freely up the plane until it reaches its maximum height and then begins to roll back down the ramp.

B.3 Student solutions to velocity and acceleration vs. time pre-activity problem, Student 2.

1. Sketch the velocity-time graph for an iguana slowing down at a uniform rate while moving in the positive direction:

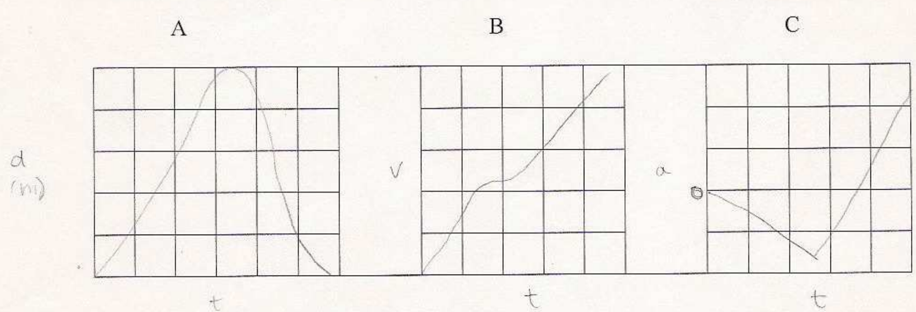


2. Sketch the velocity-time graph for a camel slowing down at a uniform rate while moving in the negative direction:

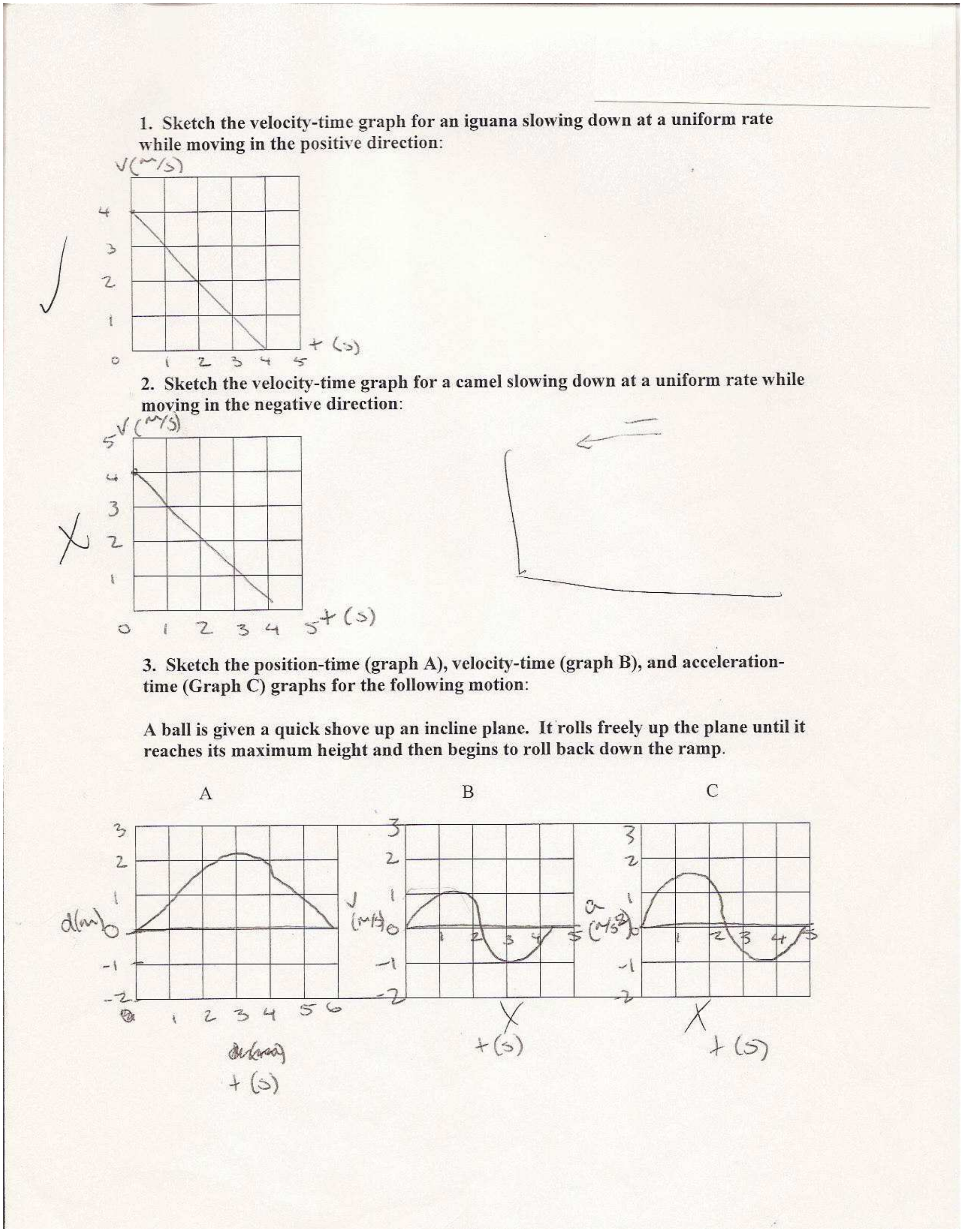


3. Sketch the position-time (graph A), velocity-time (graph B), and acceleration-time (Graph C) graphs for the following motion:

A ball is given a quick shove up an incline plane. It rolls freely up the plane until it reaches its maximum height and then begins to roll back down the ramp.



B.4 Student solutions to velocity and acceleration vs. time pre-activity problem, Student 3.



1. **Sketch the velocity-time graph for an iguana slowing down at a uniform rate while moving in the positive direction:**

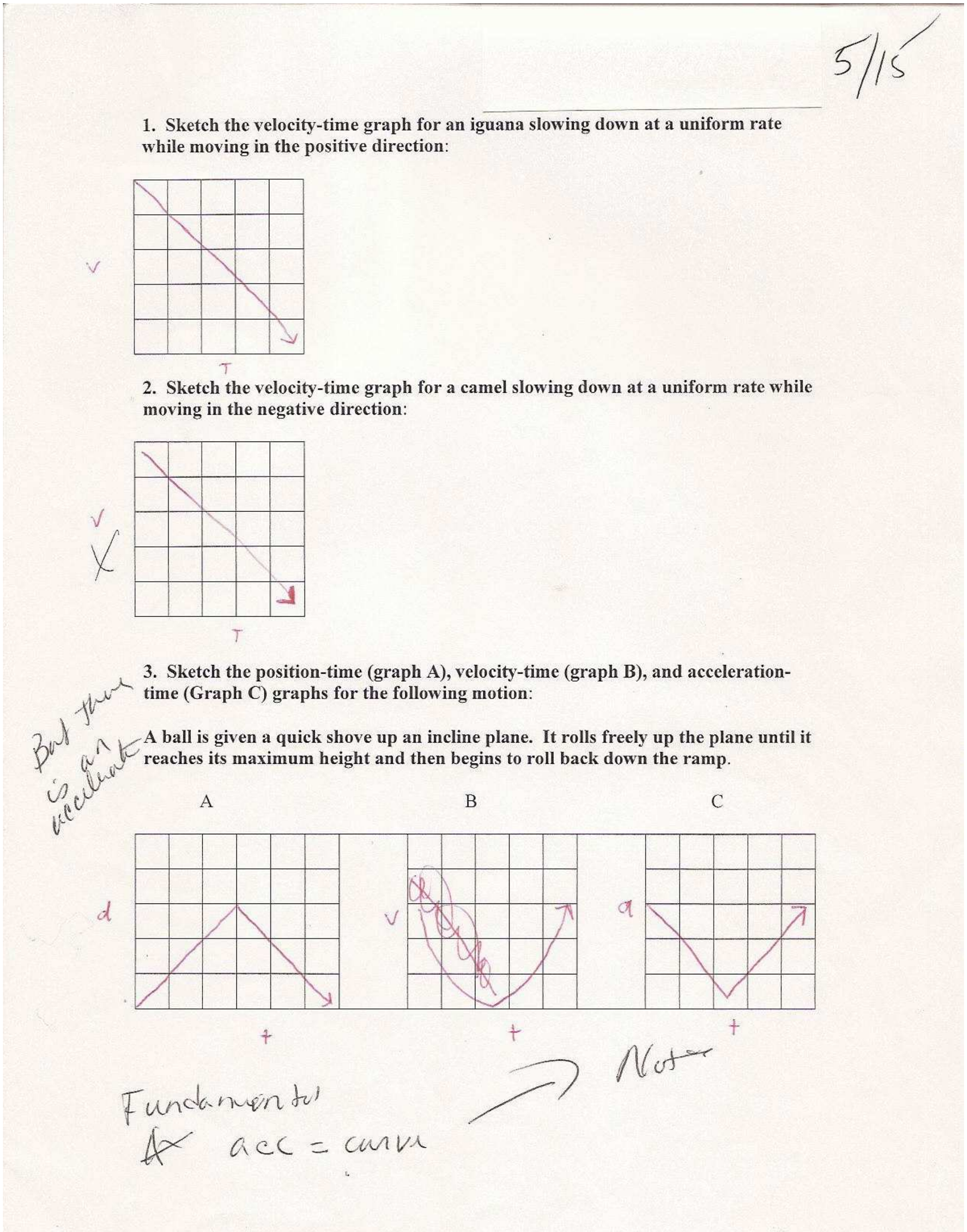
2. **Sketch the velocity-time graph for a camel slowing down at a uniform rate while moving in the negative direction:**

3. **Sketch the position-time (graph A), velocity-time (graph B), and acceleration-time (Graph C) graphs for the following motion:**

A ball is given a quick shove up an incline plane. It rolls freely up the plane until it reaches its maximum height and then begins to roll back down the ramp.

A B C

B.5 Student solutions to velocity and acceleration vs. time pre-activity problem, Student 4.



1. Sketch the velocity-time graph for an iguana slowing down at a uniform rate while moving in the positive direction:

2. Sketch the velocity-time graph for a camel slowing down at a uniform rate while moving in the negative direction:

3. Sketch the position-time (graph A), velocity-time (graph B), and acceleration-time (Graph C) graphs for the following motion:

A ball is given a quick shove up an incline plane. It rolls freely up the plane until it reaches its maximum height and then begins to roll back down the ramp.

B.6 Projectile motion student handout

B.4 AP Physics B – Projectile Motion Student Handout

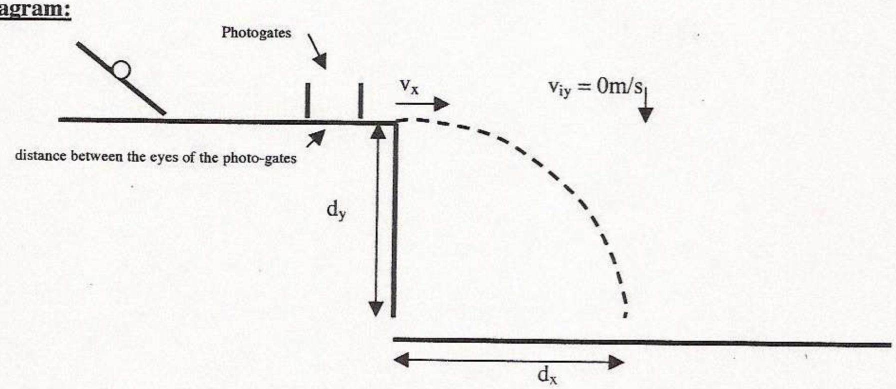
<u>Dual-Photogate Projectile Motion Lab *Set-up* Directions</u>

READ ALL OF THIS BELOW BEFORE DOING ANYTHING!

The purpose of this lab is to determine *exactly* where on the ground a marble will land if it rolls off the edge of the lab table with a *known* horizontal velocity. This lab is *just* like the physics problems we have been doing in class. In order to determine where it will hit on the floor (d_x), you will need to know the horizontal velocity (v_x) it rolls off the lab counter with and the time it takes to hit the ground. To find the *time it takes to hit the ground*, you will need to know the height of the lab counter (d_y), the initial vertical velocity (v_{iy} , which is zero) and the acceleration due to gravity (9.8m/s/s, down).

The only thing you will actually need to *experimentally* determine (rather than just measure with a meter stick or calculate with a physics equation) is the horizontal *velocity* (v_x) that the marble is moving across the lab counter with *the moment it falls off the lab counter*. You will be using the CBL Photogates to help you determine this. In order to find the *horizontal velocity*, you will need to set your *two* Photogates a certain, precise *distance* apart and then measure the *time* it takes your marble to roll through the distance between them (the CBL will determine the *time* for you). Using the "distance traveled" and the "time it took the marble to travel that distance", you can use the constant velocity equation ($v = d/t$) to determine the horizontal velocity (v_x) of the marble as it rolls off the counter. Once you have obtained the horizontal velocity, you simply need to treat the whole thing like a physics problem to determine where on the ground it will hit at the moment it hits the ground. If you are confused about this, consult your physics notes (and the problems that deal with this type of motion). **The diagram below is a diagram of what your set-up will look like.**

<u>Diagram:</u>



BEFORE BEGINNING WITH THE CBL SET-UP, make a ramp with a couple of books and a ruler (with a center groove down the center of it) on the lab table. The ramp should be arranged in such a way so that the *bottom* of the ramp (where the marble will actually leave the ramp and begin rolling on the lab table) is *about* 10-15 cm from the edge of the lab table where the marble will roll off. ONCE YOU HAVE SET YOUR RAMP UP, DON'T MOVE IT FOR THE REST OF THE LAB OR IT WILL THROW YOUR CALCULATIONS OFF!!! You might want to tape it so it doesn't shift during the lab.

TO SET UP YOUR CBL AND PHOTOGATES FOR DATA COLLECTION, FOLLOW THE FOLLOW DIRECTIONS:

1. Turn on the calculator (the CBL unit should automatically turn on at this time). Start the PHYSICS application (under APPS), and hit ENTER to proceed to the MAIN MENU.

2. Plug the *white plug* of one Photogate into the **DIG/SONIC** port of the CBL. Plug the *white plug* of the *other* Photogate into the "*white plug hole*" on the first Photogate (so they are chained together). **This may have already been done for you.**

3. To set up the calculator *and* the CBL to detect the Photogates, follow the following directions:
   - Select SET UP PROBES from the MAIN MENU on the calculator screen.
   - Select ONE as the number of probes. (Even though you are using two Photogates, they use a single channel of the CBL. As a result, the PHYSICS application considers it only *one* probe.)
   - Select PHOTOGATE from the SELECT PROBE menu (you'll need to scroll through 2 screens to get there).
   - Press [ENTER] to proceed to the TIMING MODES menu.

Continued on back.....

4. To *test* to see if the Photogates are working, follow the following directions:
   - Select **CHECK GATE**.
   - While looking at the calculator screen, block each Photogate (one at a time) with your hand and note that the Photogate is shown as *blocked* on the calculator screen. When you remove your hand, the display should change to *unblocked.*
   - Press the [+] key on the calculator to return to the **TIMING MODES** menu.

5. Now set up your Photogates so their openings are *parallel to each other* and place them *about* 5 cm apart and so one of them is close to the edge of the lab table where your marble will roll off (see diagram on previous page). Measure the *exact distance* between the two ***beams*** of the Photogates and record this on your ***Data Sheet*** in the ***Data Table***. This is the *distance* the marble will move during the *time* it takes to get through the Photogates. Once you have recorded this distance, do not move your Photogates as you need the *exact* distance to record the *exact* horizontal velocity. You might want to tape them in place so they don't move for the rest of the lab.

6. The calculator and Photogates you will be using will measure the *time* it takes for your marble to move through the certain, precise distance between the Photogates. To set the calculator up to collect this data, follow the following directions:
   - Select **PULSE** from the **TIMING MODES** menu.
   - Press [ENTER] to arm the gates.
   - Release the marble from the ramp and allow it to roll through the Photogates. DO NOT LET YOUR MARBLE HIT THE GROUND OR YOU WILL NOT BE ELIGIBLE FOR ANY EXTRA CREDIT!!!!!
   - Record this time in your Data Table under Time #1.
   - To collect more time trials, press [ENTER] (at the screen with the time interval showing)
   - Select **YES** to perform another time measurement.

7. Repeat 3 more times (for a total of four time trials). Take care not to bump the Photogates or your horizontal velocity data will not be precise! After your *last* trial, choose NO to leave the PULSE MODE Menu, and select RETURN TO MAIN. Select QUIT to return to the home screen.

8. After you have collected four time trials, take the average of the four times to find the average time and follow the directions on the Data Sheet.

9. **IMPORTANT---DO NOT TAKE YOUR RAMP DOWN AS YOU WILL BE USING IT WHEN I COME AROUND TO CHECK WHERE IT LANDS!!!!!!**

B.7 Group lab work, projectile motion lab

Range of a Projectile 5/17

Name:__________________________

Purpose: To predict the horizontal displacement of a *horizontally* projected object.

Materials: Ramp (ruler with a groove in it and two books), steel ball, meter stick, Photogates, **CBL-2** unit

DATA TABLE:

Horizontal Distance (m) Between the two *beams* of the Photogates	Time 1 (sec)	Time 2 (sec)	Time 3 (sec)	Time 4 (sec)	Avg. Time (sec)	*Horizontal* Velocity(m/s)
	0.08967	0.09039	0.08931	0.08948	0.0897125	v = d/t v = 1.115 m/s

$d_y = 0.75$ m

Procedure:

Finish the lab by reading and doing the Calculations and Analysis below.

Calculations and Analysis: (Show All Work!)

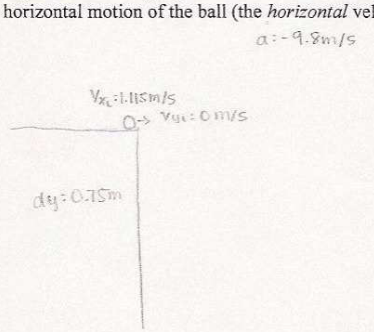
1) Calculate the *constant horizontal velocity*, v_x, the marble had while it was moving on the lab counter by using the distance the marble moved through the Photogates and the average time it took to move through *that* distance using $\bar{v}_x = \frac{d_x}{t}$. **Record this velocity in the Data Table above.**

$\frac{.1}{0.0897125}$ =

2) Measure the *vertical* distance from the edge of the table *straight down* to the floor (this is your d_y). Record this in the space below.

$d_y = 0.75$m

3) Draw a properly labeled physics diagram of the marble's motion once it's in free-fall (if you need help, look on the *front* of the CBL *direction sheet*). List all your "knowns" regarding *both* the *vertical* motion of the ball when it goes over the edge (the initial *vertical* velocity, the *vertical* acceleration, the *vertical* displacement) and the horizontal motion of the ball (the *horizontal* velocity and the *horizontal* displacement).



4) Using one of the 4 funky equations, solve for the *total time the ball is in the air* (t). If you are confused about this, please look at your notes for the section on these types of problems).

$d_y = v_{iy}t + \frac{1}{2}at^2$

$d_y = \frac{1}{2}at^2$

$t = \sqrt{2d/a}$

$t = 0.3912s$

5) Using the total time the ball is in the air (from Step 4) and the *horizontal velocity* of the ball (v_x) that you found in Step 1, calculate how far the ball will travel *horizontally* (the horizontal displacement, d_x). If you are confused about this, please look at your notes for the section on these types of problems).

$v = d/t$

$t = 0.3912s$

$v = 1.115 m/s$

$d = vt$

$d = 0.436m$

6) **WHEN YOU THINK YOU KNOW WHERE YOUR BALL WILL HIT THE GROUND, CALL ME OVER. IF IT HITS WHERE YOU THINK IT WILL, YOU'LL GET A LITTLE EXTRA CREDIT. HOWEVER, IF YOU LET YOU BALL HIT THE GROUND *AT ALL* DURING THIS LAB (BEFORE I COME OVER TO CHECK), YOU ARE OUT OF THE RUNNING FOR THE EXTRA CREDIT……**

7) Compare the *horizontal distance* your marble actually moved to the *calculated* value it should have moved. Are the values close? Should they be? What might make them slightly different?

Friction & air resistance

B.8 Student solutions to projectile motion pre and post activity problem, Student 1.

5/17

Projectile motion problem:

Please TELL me how you would solve this problem, however, you may write things down and/or draw pictures as you explain your solution:

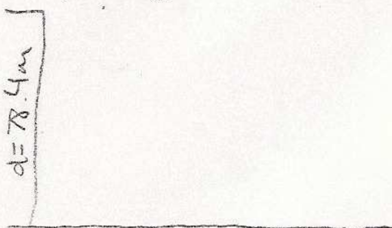
1. A stone is thrown horizontally at a speed of 5.0 m/s off the top of a cliff 78.4m high.

a. How long does it take the stone to reach the bottom of the cliff? **(4 s)**

b. How far from the base of the cliff does the stone strike the ground? **(20 m)**

c. What are the horizontal and vertical components of the velocity of the stone just before it hits the ground? **(vyf = -39.2 m/s, vx = 5 m/s as there is no acceleration acting on the projectile in the horizontal dxn)**

$v_i = 0$ m/s $a = -9.8$ m/s² $t = ?$



$v_x = 5$ m/s

$v_f^2 = v_i^2 + 2ad$

a. $d = v_i t + \frac{1}{2}at^2$

$t^2 = \frac{2d}{a}$

$t = \sqrt{2d/a}$

$t = \boxed{4\ s}$

b. $d_x = ?$

$v = d/t$

$d = vt$

$\boxed{d = 20\ m}$

c. $v_x = \boxed{5\ m/s}$

$v_{fy} = ?$

$v_{fy} = v_i + at$

$v_{fy} = \boxed{-39.2\ m/s}$

B.9 Student solutions to projectile motion pre and post activity problem, Student 2.

Projectile motion problem:

Please TELL me how you would solve this problem, however, you may write things down and/or draw pictures as you explain your solution:

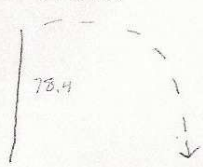
1. A stone is thrown horizontally at a speed of 5.0 m/s off the top of a cliff 78.4m high.

a. How long does it take the stone to reach the bottom of the cliff? **(4 s)**

b. How far from the base of the cliff does the stone strike the ground? **(20 m)**

c. What are the horizontal and vertical components of the velocity of the stone just before it hits the ground? **(vyf = -39.2 m/s, vx = 5 m/s as there is no acceleration acting on the projectile in the horizontal dxn)**

$a = -9.8\ m/s^2$



t ?

$d = v_i t + \frac{1}{2} a t^2$ ✓

$0 = \frac{1}{2} a t^2 + v_i t - d$

$4.9t^2 + 5t - 78.4$

$t = 4\ s$

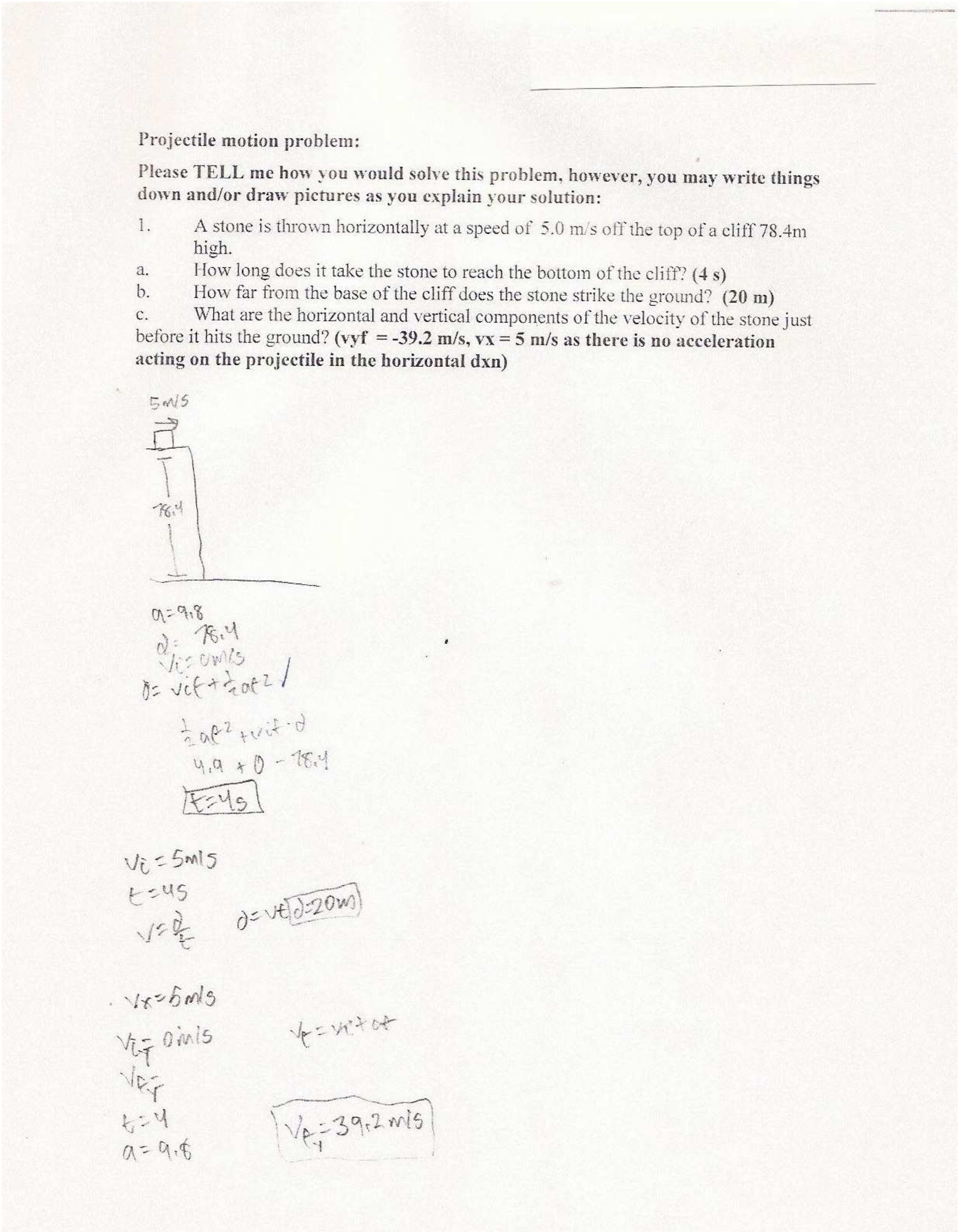
$v = \frac{d}{t}$

$= 20\ m$

$v_f = v_i + at$

$= -40\ m/s$

B.10 Student solutions to projectile motion pre and post activity problem, Student 3.



Projectile motion problem:

Please TELL me how you would solve this problem, however, you may write things down and/or draw pictures as you explain your solution:

1. A stone is thrown horizontally at a speed of 5.0 m/s off the top of a cliff 78.4m high.

a. How long does it take the stone to reach the bottom of the cliff? **(4 s)**

b. How far from the base of the cliff does the stone strike the ground? **(20 m)**

c. What are the horizontal and vertical components of the velocity of the stone just before it hits the ground? **(vyf = -39.2 m/s, vx = 5 m/s as there is no acceleration acting on the projectile in the horizontal dxn)**

5 m/s

78.4

a = 9.8
d = 78.4
vi = 0 m/s
d = vit + ½at²

½at² + vit - d
4.9 + 0 - 78.4
t = 4s

vi = 5 m/s
t = 4s
v = d/t
d = vt d = 20m

vx = 5 m/s
viy = 0 m/s
vfy
t = 4
a = 9.8
vf = vi + at
vfy = 39.2 m/s

B.11 Student solutions to projectile motion pre and post activity problem, Student 4.

Projectile motion problem:

Please TELL me how you would solve this problem, however, you may write things down and/or draw pictures as you explain your solution:

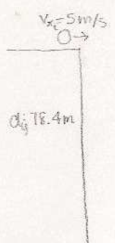
1. A stone is thrown horizontally at a speed of 5.0 m/s off the top of a cliff 78.4m high.

a. How long does it take the stone to reach the bottom of the cliff? **(4 s)**

b. How far from the base of the cliff does the stone strike the ground? **(20 m)**

c. What are the horizontal and vertical components of the velocity of the stone just before it hits the ground? **(vyf = -39.2 m/s, vx = 5 m/s as there is no acceleration acting on the projectile in the horizontal dxn)**

t: ? d: ? V_x: ? V_y: ?



a) V_{y_i}: 0m/s
a: 9.8m/s²
d: 78.4m

d: $v_i t + \frac{1}{2}at^2$
d: $\frac{1}{2}at^2$
t: $\sqrt{2d/a}$
[t: 4s]

b) d: ? v: 5m/s
v: d/t
d: vt [d: 20m]

c) V_f^2: v_i^2 + 2ad
V_f : $\sqrt{2ad}$
[V_{f_y}: -39.2 m/s]
[V_x : 5m/s]

d: 78.4m
a: -9.8 m/s
V_i: 0m/s

B.12 Group solution to projectile motion lab

5/17 group @ end

Projectile motion problem:

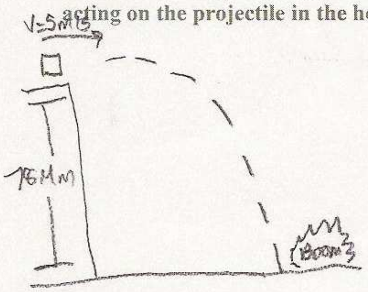
Please TELL me how you would solve this problem, however, you may write things down and/or draw pictures as you explain your solution:

1. A stone is thrown horizontally at a speed of 5.0 m/s off the top of a cliff 78.4m high.

a. How long does it take the stone to reach the bottom of the cliff? **(4 s)**

b. How far from the base of the cliff does the stone strike the ground? **(20 m)**

c. What are the horizontal and vertical components of the velocity of the stone just before it hits the ground? **(vyf = -39.2 m/s, vx = 5 m/s as there is no acceleration acting on the projectile in the horizontal dxn)**



$d = v_i t + \frac{1}{2} a t^2$

$v_{iy} = 0$ m/s

$d = -78.4$

$a = 9.8$

$t = 4$ sec

$d = \frac{1}{2} a t^2$

$-78.4 = 4.9 t^2$

$v = \frac{d}{t}$

$d = vt$

$t = 4$ sec

$d = 20$ m

$v = 5$ m/s

$v_x = 5$ m/s

$v_{iy} = 0$ m/s

$v_{fy} = ?$

$a = 9.8$

$t = 4$

$v_f = v_i + at$

$v_f = at$

$v_f = -39.2$ m/s

B.13 AP Physics B, Individual student series circuit labs, Student 1.

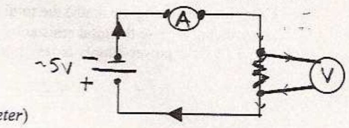
Lab: Series Circuits

Purpose:

To construct a series circuit to determine how current, voltage, and resistance relate to each other when you add more devices in series.

Materials:

- Power supply, set to ~5V
- 2 bulbs
- connecting wires and 2 probes
- 2 **Digital Multi-Meters (DMM**; one set as an *ammeter* and one set as a *voltmeter*)



Procedure:

Part ONE: Setting the Power Supply to Deliver ~5V

1. Place the banana-plugs of your two *probes* into the two RIGHT ports (the COM and the one with the lightning bolt on it) of one of your DMMs. The voltmeter / DMM dial should be turned to DC Volts (**V**). Temporarily connect the voltmeter to your power supply by doing the following: Place the pointy-end of "the probe that is attached to the "COM" port on the DMM" *inside* the negative port of the *power supply* (so the metal end of the probe is physically touching the metal *inside* the negative port of the power supply). Place the other probe exiting the "Volt-port" (the right-hole) on the DMM into the positive port on the power supply (so metal touches metal). Turn on the power supply *and* the DMM, and *while looking at the voltmeter,* slowly turn the *voltage adjust knob* on the *power supply* until ~5V registers on the *voltmeter*. Once 5V registers on the voltmeter, **record the voltage below** and **don't touch the voltage adjust knob on the power supply again the rest of the lab**. You now have the power supply set to deliver ~5V (5 Joules of potential energy for every Coulomb of electrons flowing out of it). **Turn off the power supply and voltmeter (but don't remove the probes from the voltmeter, you'll be using it in PART TWO, below).**

V (of the power supply) = 4.99V

Part TWO: Measuring and Calculating the Individual Resistances of the Individual Light Bulbs

1. Before you can do the actual lab (coming up in **Part 4**), you will need to find out the individual resistance of *each* of your 2 bulbs (they both most likely have slightly different resistances) by: **(1)** finding the current each *individual* bulb draws from the power supply and **(2)** finding the *actual* voltage drop across (voltage used by) the bulb and then **(3)** using Ohm's Law.

-TO DO THIS: Hook up the power supply (which is set to ~5V), the ammeter (a DMM set on **A**), and ONE of the bulbs in *series* with each other (you'll need to do this with *each* bulb separately both times, so just pick either bulb to start with and do the following *to one bulb at a time*). **Exactly follow the directions below when hooking everything up.**

1. A cord (not probe) leading away from the (-) terminal of the *power supply* should be plugged into the COM port of the *ammeter* (set to DC Amps, **A**). Another cord (not probe) will come OUT of the *ammeter* from the "10A" port (the hole on the left). This cord coming *out* of the *ammeter* should lead *and attach to* one side of your bulb. Attach another (3^{rd}) cord to the other side of the bulb and plug the other end *into* the (+) terminal of the *power supply.*
2. Turn on the power supply (but don't touch the voltage adjust knob!), the ammeter, *and* your voltmeter.
3. Look at the reading on the *ammeter* (records current, I) and record it in the appropriate space below (for Bulb #1).
4. Temporarily touch the probes of the *voltmeter* on either side of the metal clips on the bulb (one probe on each side of the bulb). You don't have to permanently "clip" the probes on the bulb, just simply hold them in place (with metal touching metal) until you get a reading on the *voltmeter*. When you get a voltmeter reading, record it in the appropriate space below (disregard the negative sign if you get one).
5. Once you have the current *through* Bulb #1 and the voltage drop *across* it, use Ohm's law to *calculate* the resistance of the bulb. Take Bulb #1 out of the circuit, replace it with Bulb #2 and repeat. Turn everything off until PART FOUR

Skinny.
Bulb #1-I= .216A
V= 4.52V
R= 20.13Ω

Fatty
Bulb#2- I= 0.141A
V= 4.67V
R= 33.12Ω

Part THREE*:* This part does NOT require you to hook anything up in a circuit yet!!!!!

This section will have you *theoretically* calculate (using Ohm's Law) what the "Total Resistance (R_t)", "Total Current (I_t)", and "Voltage drop across each bulb (V_1 and V_2)" *should be* IF both of your bulbs were hooked up *together* in a series circuit across the voltage you set in PART ONE of this lab (the ~5V). *Draw* a circuit diagram in the space below showing your *2 bulbs* hooked in series with a power supply (clearly showing the voltage you set in PART ONE) and an ammeter. Include in your diagram a voltmeter to measure the voltage drop across bulb #1 and electron flow direction.

THIS IS STILL THE "THEORETICAL" PORTION OF THE LAB (PART THREE)---DO NOT HOOK ANYTHING UP YET!

1. **Calculate** (by doing the math) the total resistance your circuit *should have* **IF** both of your bulbs are hooked up in **series** *together* (use the resistance values you measured/calculated in Part 2). **Show the equation to calculate the total resistance and show your work below (with units!).** [R_T : 54.05 Ω]

2. **Calculate** (by doing the math) the total current (I_t) your circuit *should have* **IF** your 2 bulbs are hooked in series together with your power supply. Use the total resistance you JUST calculated in the previous question and the voltage across your circuit you set in Part 1 (the ~5V the power-supply is set up to deliver). **Show the equation and all of your work in 5 steps (with units!).**

   V: IR
   I: V/R   [I_T : 0.01 A]

3. Record the total current in the *Theoretical* section in the Data Table Below.

4. **Calculate** (by doing the math) what the voltage drop across EACH bulb *should be* if your two bulbs were hooked in series with each other by using Ohm's law, the *theoretical* total current from the previous question, and the values of your two resistors that you calculated in PART 2 of this lab. **Show your work in 5 steps (with units!). Remember: The two individual voltage drops of the individual bulbs should add-up to the total voltage of your circuit (the ~5V you set in Part One)**

   V_1- $I_T R_i$ [V_1: 1.88v]

   V_2- IR   [V_2 : 2.98v]

5. Record the above values in the *Theoretical* section of the Data Table.

PART FOUR: This part will have you *physically* hook your two bulbs *together* in a series circuit and make actual *measurements* (with the ammeter and voltmeter) of the total current in the circuit and the voltage drop across each resistor. You will then compare them with your *theoretical* values from Part Three (above).

1. *Physically* hook your two bulbs up in a series circuit with the ammeter AND the power supply. The power supply should still be set to deliver the voltage you set in Part 1. Your circuit should be hooked up just like your diagram shows in Part 3, #1. **Please double check to make sure all the connections are correct. Does the cord coming from the negative port on the power supply *enter* the COM on the ammeter and does the cord coming *out* of the ammeter come out of the *left hole* (the 10A)? Is your ammeter set on A?**

2. Turn on the Power Supply, the ammeter, and the voltmeter. Record the ammeter reading in the Data Table under the *Measured* section. This reading represents the TOTAL current flowing through the two-resistor series circuit.

3. **Measure** the voltage drop across EACH bulb (one at a time) with the voltmeter (just like you measured the voltage drop across the bulb when you were initially trying to figure out their resistances in PART 2). Make sure you watch the direction the current will be moving into and out of the voltmeter so you have the leads attaching the voltmeter to the bulb oriented correctly.

4. Record the *measured* individual voltage drops of the two resistors in the Data Table.

	Theoretical	Measured (with the meters)
I (total)	0.09A	.102
V_1	1.88V	1.55
V_2	2.98v	3.01

5. How does the *measured* total current compare to what you thought the current should be (your *calculated value*, from Part 3)? **If it differs, WHY?**

   The measured value is greater than the theoretical value.
   V: IR   I: V/R   we are confused!   maybe resistors have been worn out

6. How do the *measured* individual voltage drops from above compare to the values you *calculated* the voltage drops should be (from PART 3)? **If it differs, WHY?**

   V_1 lower   V: IR
   V_2 greater   Ammeter takes voltage

B.14 AP Physics B, Individual student series circuit labs, Student 2.

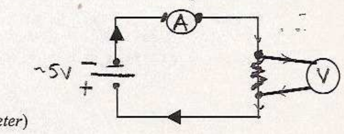
Lab: Series Circuits

Purpose:

To construct a series circuit to determine how current, voltage, and resistance relate to each other when you add more devices in series.

Materials:

- Power supply, set to ~5V
- 2 bulbs
- connecting wires and 2 probes
- 2 **D**igital **M**ulti-**M**eters (**DMM**; one set as an *ammeter* and one set as a *voltmeter*)



Procedure:

Part ONE: Setting the Power Supply to Deliver ~5V

1. Place the banana-plugs of your two *probes* into the two RIGHT ports (the COM and the one with the lightning bolt on it) of one of your DMMs. The voltmeter / DMM dial should be turned to DC Volts (V). Temporarily connect the voltmeter to your power supply by doing the following: Place the pointy-end of "the probe that is attached to the "COM" port on the DMM" *inside* the negative port of the *power supply* (so the metal end of the probe is physically touching the metal *inside* the negative port of the power supply). Place the other probe exiting the "Volt-port" (the right-hole) on the DMM into the positive port on the power supply (so metal touches metal). Turn on the power supply *and* the DMM, and *while looking at the voltmeter,* slowly turn the *voltage adjust knob* on the *power supply* until ~5V registers on the *voltmeter*. Once 5V registers on the voltmeter, **record the voltage below** and **don't touch the voltage adjust knob on the power supply again the rest of the lab**. You now have the power supply set to deliver ~5V (5 Joules of potential energy for every Coulomb of electrons flowing out of it). **Turn off the power supply and voltmeter (but don't remove the probes from the voltmeter, you'll be using it in PART TWO, below).**

V (of the power supply) = 4.99

Part TWO: Measuring and Calculating the Individual Resistances of the Individual Light Bulbs

1. Before you can do the actual lab (coming up in **Part 4**), you will need to find out the individual resistance of *each* of your 2 bulbs (they both most likely have slightly different resistances) by: (**1**) finding the current each *individual* bulb draws from the power supply and (**2**) finding the *actual* voltage drop across (voltage used by) the bulb and then (**3**) using Ohm's Law.

   -TO DO THIS: Hook up the power supply (which is set to ~5V), the ammeter (a DMM set on **A**), and ONE of the bulbs in *series* with each other (you'll need to do this with *each* bulb separately both times, so just pick either bulb to start with and do the following *to one bulb at a time*). **Exactly follow the directions below when hooking everything up.**

   1. A cord (not probe) leading away from the (-) terminal of the *power supply* should be plugged into the COM port of the *ammeter* (set to DC Amps, **A**). Another cord (not probe) will come OUT of the *ammeter* from the "10A" port (the hole on the left). This cord coming *out* of the *ammeter* should lead *and attach to* one side of your bulb. Attach another (3rd) cord to the other side of the bulb and plug the other end *into* the (+) terminal of the *power supply.*
   2. Turn on the power supply (but don't touch the voltage adjust knob!), the ammeter, *and* your voltmeter.
   3. Look at the reading on the *ammeter* (records current, **I**) and record it in the appropriate space below (for Bulb #1).
   4. Temporarily touch the probes of the *voltmeter* on either side of the metal clips on the bulb (one probe on each side of the bulb). You don't have to permanently "clip" the probes on the bulb, just simply hold them in place (with metal touching metal) until you get a reading on the *voltmeter*. When you get a voltmeter reading, record it in the appropriate space below (disregard the negative sign if you get one).
   5. Once you have the current *through* Bulb #1 and the voltage drop *across* it, use Ohm's law to *calculate* the resistance of the bulb. Take Bulb #1 out of the circuit, replace it with Bulb #2 and repeat. Turn everything off until PART FOUR

Skinny
Bulb #1- I= .216 A
V= 4.52
R= 20.93Ω

fat man
Bulb#2- I= .141
V= 4.67
R= 33.12Ω

$I = \frac{V}{R}$

$R = \frac{V}{I}$

Part THREE: This part does NOT require you to hook anything up in a circuit yet!!!!!

This section will have you *theoretically* calculate (using Ohm's Law) what the "Total Resistance (R_t) ", "Total Current (I_t) ", and "Voltage drop across each bulb (V_1 and V_2)" *should be* IF both of your bulbs were hooked up *together* in a series circuit across the voltage you set in PART ONE of this lab (the ~5V). *Draw* a circuit diagram in the space below showing your *2 bulbs* hooked in series with a power supply (clearly showing the voltage you set in PART ONE) and an ammeter. Include in your diagram a voltmeter to measure the voltage drop across bulb #1 and electron flow direction.

Series Circuit Lab

1

THIS IS STILL THE "THEORETICAL" PORTION OF THE LAB (PART THREE)---DO NOT HOOK ANYTHING UP YET!

1. **Calculate** (by doing the math) the total resistance your circuit *should have* **IF** both of your bulbs are hooked up in **series** *together* (use the resistance values you measured/calculated in Part 2). **Show the equation to calculate the total resistance and show your work below (with units!).** $R_T = R_1 + R_2$

   $= 54.05\Omega$

2. **Calculate** (by doing the math) the total current (I_t) your circuit *should have* **IF** your 2 bulbs are hooked in series together with your power supply. Use the total resistance you JUST calculated in the previous question and the voltage across your circuit you set in Part 1 (the ~5V the power-supply is set up to deliver). **Show the equation and all of your work in 5 steps (with units!).**

   $I = \frac{V}{R}$

   $I = .09A$

3. Record the total current in the *Theoretical* section in the Data Table Below.

4. **Calculate** (by doing the math) what the voltage drop across EACH bulb *should be* if your two bulbs were hooked in series with each other by using Ohm's law, the *theoretical* total current from the previous question, and the values of your two resistors that you calculated in PART 2 of this lab. **Show your work in 5 steps (with units!). Remember: The two individual voltage drops of the individual bulbs should add-up to the total voltage of your circuit (the ~5V you set in Part One)**

   V_1- $V = IR$ $V = 1.88$

   V_2- $V = IR$ $V = 2.98$

5. Record the above values in the *Theoretical* section of the Data Table.

PART FOUR: This part will have you *physically* hook your two bulbs *together* in a series circuit and make actual *measurements* (with the ammeter and voltmeter) of the total current in the circuit and the voltage drop across each resistor. You will then compare them with your *theoretical* values from Part Three (above).

1. *Physically* hook your two bulbs up in a series circuit with the ammeter AND the power supply. The power supply should still be set to deliver the voltage you set in Part 1. Your circuit should be hooked up just like your diagram shows in Part 3, #1. **Please double check to make sure all the connections are correct. Does the cord coming from the negative port on the power supply *enter* the COM on the ammeter and does the cord coming *out* of the ammeter come out of the *left hole* (the 10A)? Is your ammeter set on A?**

2. Turn on the Power Supply, the ammeter, and the voltmeter. Record the ammeter reading in the Data Table under the *Measured* section. This reading represents the TOTAL current flowing through the two-resistor series circuit.

3. **Measure** the voltage drop across EACH bulb (one at a time) with the voltmeter (just like you measured the voltage drop across the bulb when you were initially trying to figure out their resistances in PART 2). Make sure you watch the direction the current will be moving into and out of the voltmeter so you have the leads attaching the voltmeter to the bulb oriented correctly.

4. Record the *measured* individual voltage drops of the two resistors in the Data Table.

	Theoretical	Measured (with the meters)
I (total)	.09A	.108
V_1	1.88V	1.55
V_2	2.98V	3.01

5. How does the *measured* total current compare to what you thought the current should be (your *calculated value*, from Part 3)? **If it differs, WHY?** Measured was greater because there is some ~~[illegible]~~ Resistance in the wires that we couldn't measure

6. How do the *measured* individual voltage drops from above compare to the values you *calculated* the voltage drops should be (from PART 3)? **If it differs, WHY?** V_1 is greater than measured and V_2 is less than measured. human error
   $V = IR$

Series Circuit Lab

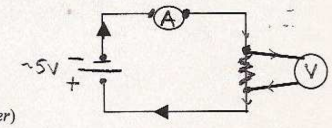
B.15 AP Physics B, Individual student series circuit labs, Student 3.

Lab: Series Circuits

Purpose:

To construct a series circuit to determine how current, voltage, and resistance relate to each other when you add more devices in series.

Materials:



- Power supply, set to ~5V
- 2 bulbs
- connecting wires and 2 probes
- 2 **D**igital **M**ulti-**M**eters (**DMM**; one set as an *ammeter* and one set as a *voltmeter*)

Procedure:

Part ONE: Setting the Power Supply to Deliver ~5V

1. Place the banana-plugs of your two *probes* into the two RIGHT ports (the COM and the one with the lightning bolt on it) of one of your DMMs. The voltmeter / DMM dial should be turned to DC Volts (**V**). Temporarily connect the voltmeter to your power supply by doing the following: Place the pointy-end of "the probe that is attached to the "COM" port on the DMM" *inside* the negative port of the *power supply* (so the metal end of the probe is physically touching the metal *inside* the negative port of the power supply). Place the other probe exiting the "Volt-port" (the right-hole) on the DMM into the positive port on the power supply (so metal touches metal). Turn on the power supply *and* the DMM, and *while looking at the voltmeter,* slowly turn the *voltage adjust knob* on the *power supply* until ~5V registers on the *voltmeter*. Once 5V registers on the voltmeter, **record the voltage below** and **don't touch the voltage adjust knob on the power supply again the rest of the lab**. You now have the power supply set to deliver ~5V (5 Joules of potential energy for every Coulomb of electrons flowing out of it). **Turn off the power supply and voltmeter (but don't remove the probes from the voltmeter, you'll be using it in PART TWO, below).**

V (of the power supply) = 4.99 V

Part TWO: Measuring and Calculating the Individual Resistances of the Individual Light Bulbs

1. Before you can do the actual lab (coming up in **Part 4**), you will need to find out the individual resistance of *each* of your 2 bulbs (they both most likely have slightly different resistances) by: (**1**) finding the current each *individual* bulb draws from the power supply and (**2**) finding the *actual* voltage drop across (voltage used by) the bulb and then (**3**) using Ohm's Law.

-TO DO THIS: Hook up the power supply (which is set to ~5V), the ammeter (a DMM set on **A**), and ONE of the bulbs in *series* with each other (you'll need to do this with *each* bulb separately both times, so just pick either bulb to start with and do the following *to one bulb at a time*). **Exactly follow the directions below when hooking everything up.**

1. A cord (not probe) leading away from the (-) terminal of the *power supply* should be plugged into the COM port of the *ammeter* (set to DC Amps, **A**). Another cord (not probe) will come OUT of the *ammeter* from the "10A" port (the hole on the left). This cord coming *out* of the *ammeter* should lead *and attach to* one side of your bulb. Attach another (3rd) cord to the other side of the bulb and plug the other end *into* the (+) terminal of the *power supply*.
2. Turn on the power supply (but don't touch the voltage adjust knob!), the ammeter, *and* your voltmeter.
3. Look at the reading on the *ammeter* (records current, **I**) and record it in the appropriate space below (for Bulb #1).
4. Temporarily touch the probes of the *voltmeter* on either side of the metal clips on the bulb (one probe on each side of the bulb). You don't have to permanently "clip" the probes on the bulb, just simply hold them in place (with metal touching metal) until you get a reading on the *voltmeter*. When you get a voltmeter reading, record it in the appropriate space below (disregard the negative sign if you get one).
5. Once you have the current *through* Bulb #1 and the voltage drop *across* it, use Ohm's law to *calculate* the resistance of the bulb. Take Bulb #1 out of the circuit, replace it with Bulb #2 and repeat. Turn everything off until PART FOUR

Bulb #1-I= .216 amps
Skinny V= 4.52 V
R= 20.93 Ω

Bulb#2- I= .141 amp
Fatty V= 4.67 V
R= 33.12 Ω

I = V/R
R = V/I

Part THREE: This part does NOT require you to hook anything up in a circuit yet!!!!!

This section will have you *theoretically* calculate (using Ohm's Law) what the "Total Resistance (R_t)", "Total Current (I_t)", and "Voltage drop across each bulb (V_1 and V_2)" *should be* IF both of your bulbs were hooked up *together* in a series circuit across the voltage you set in PART ONE of this lab (the ~5V). *Draw* a circuit diagram in the space below showing your *2 bulbs* hooked in series with a power supply (clearly showing the voltage you set in PART ONE) and an ammeter. Include in your diagram a voltmeter to measure the voltage drop across bulb #1 and electron flow direction.

THIS IS STILL THE "THEORETICAL" PORTION OF THE LAB (PART THREE)---DO NOT HOOK ANYTHING UP YET!

1. **Calculate** (by doing the math) the total resistance your circuit *should have* **IF** both of your bulbs are hooked up in **series** *together* (use the resistance values you measured/calculated in Part 2). **Show the equation to calculate the total resistance and show your work below (with units!).** $R_1 = 20.93\,\Omega$ $R_2 = 33.12\,\Omega$ $R_T = R_1 + R_2 = 54.05\,\Omega$

2. **Calculate** (by doing the math) the total current (I_t) your circuit *should have* **IF** your 2 bulbs are hooked in series together with your power supply. Use the total resistance you JUST calculated in the previous question and the voltage across your circuit you set in Part 1 (the ~5V the power-supply is set up to deliver). **Show the equation and all of your work in 5 steps (with units!).**
   $R_T = 54.05\,\Omega$ $V = 4.99$ V $V = IR$ $I = V/R$ $I = 0.09$ amps

3. Record the total current in the *Theoretical* section in the Data Table Below.

4. **Calculate** (by doing the math) what the voltage drop across EACH bulb *should be* if your two bulbs were hooked in series with each other by using Ohm's law, the *theoretical* total current from the previous question, and the values of your two resistors that you calculated in PART 2 of this lab. **Show your work in 5 steps (with units!). Remember: The two individual voltage drops of the individual bulbs should add-up to the total voltage of your circuit (the ~5V you set in Part One)**
   V_1- 1.88 v V_2- 2.98 v
   $I = .09$ amps $V = IR$

5. Record the above values in the *Theoretical* section of the Data Table.

PART FOUR: This part will have you *physically* hook your two bulbs *together* in a series circuit and make actual *measurements* (with the ammeter and voltmeter) of the total current in the circuit and the voltage drop across each resistor. You will then compare them with your *theoretical* values from Part Three (above).

1. *Physically* hook your two bulbs up in a series circuit with the ammeter AND the power supply. The power supply should still be set to deliver the voltage you set in Part 1. Your circuit should be hooked up just like your diagram shows in Part 3, #1. **Please double check to make sure all the connections are correct. Does the cord coming from the negative port on the power supply *enter* the COM on the ammeter and does the cord coming *out* of the ammeter come out of the *left hole* (the 10A)? Is your ammeter set on <u>A</u>?**

2. Turn on the Power Supply, the ammeter, and the voltmeter. Record the ammeter reading in the Data Table under the *Measured* section. This reading represents the TOTAL current flowing through the two-resistor series circuit.

3. **Measure** the voltage drop across EACH bulb (one at a time) with the voltmeter (just like you measured the voltage drop across the bulb when you were initially trying to figure out their resistances in PART 2). Make sure you watch the direction the current will be moving into and out of the voltmeter so you have the leads attaching the voltmeter to the bulb oriented correctly.

4. Record the *measured* individual voltage drops of the two resistors in the Data Table.

	Theoretical	Measured (with the meters)
I (total)	.09 amps	.108 Amps
V_1	1.88 v	1.55 v
V_2	2.98 v	3.01 v

↑ $I = V/R$ ↓ ↓
↓ $V = IR$ ↓

5. How does the *measured* total current compare to what you thought the current should be (your *calculated value*, from Part 3)? **If it differs, WHY?**
   The actual is greater than the theoretical value we are confused it should be lower b/c resistance ~~stated~~ ~~the~~ could have worn out

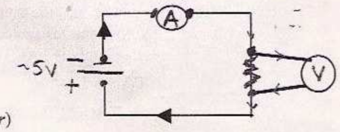
6. How do the *measured* individual voltage drops from above compare to the values you *calculated* the voltage drops should be (from PART 3)? **If it differs, WHY?**
   One lower One higher
   are going to be flaws
   - ammeters
   - wires

B.16 AP Physics B, Individual student series circuit labs, Student 4.

Lab: Series Circuits

Purpose:

To construct a series circuit to determine how current, voltage, and resistance relate to each other when you add more devices in series.



Materials:

- Power supply, set to ~5V
- 2 bulbs
- connecting wires and 2 probes
- 2 **D**igital **M**ulti-**M**eters (**DMM**; one set as an *ammeter* and one set as a *voltmeter*)

Procedure:

Part ONE: Setting the Power Supply to Deliver ~5V

1. Place the banana-plugs of your two *probes* into the two RIGHT ports (the COM and the one with the lightning bolt on it) of one of your DMMs. The voltmeter / DMM dial should be turned to DC Volts (**V**). Temporarily connect the voltmeter to your power supply by doing the following: Place the pointy-end of "the probe that is attached to the "COM" port on the DMM" *inside* the negative port of the *power supply* (so the metal end of the probe is physically touching the metal *inside* the negative port of the power supply). Place the other probe exiting the "Volt-port" (the right-hole) on the DMM into the positive port on the power supply (so metal touches metal). Turn on the power supply *and* the DMM, and *while looking at the voltmeter,* slowly turn the *voltage adjust knob* on the *power supply* until ~5V registers on the *voltmeter*. Once 5V registers on the voltmeter, **record the voltage below** and **don't touch the voltage adjust knob on the power supply again the rest of the lab**. You now have the power supply set to deliver ~5V (5 Joules of potential energy for every Coulomb of electrons flowing out of it). **Turn off the power supply and voltmeter (but don't remove the probes from the voltmeter, you'll be using it in PART TWO, below).**

V (of the power supply) = 4.99V

Part TWO: Measuring and Calculating the Individual Resistances of the Individual Light Bulbs

1. Before you can do the actual lab (coming up in **Part 4**), you will need to find out the individual resistance of *each* of your 2 bulbs (they both most likely have slightly different resistances) by: (**1**) finding the current each *individual* bulb draws from the power supply and (**2**) finding the *actual* voltage drop across (voltage used by) the bulb and then (**3**) using Ohm's Law.

-TO DO THIS: Hook up the power supply (which is set to ~5V), the ammeter (a DMM set on **A**), and ONE of the bulbs in *series* with each other (you'll need to do this with *each* bulb separately both times, so just pick either bulb to start with and do the following *to one bulb at a time*). **Exactly follow the directions below when hooking everything up.**

1. A cord (not probe) leading away from the (-) terminal of the *power supply* should be plugged into the COM port of the *ammeter* (set to DC Amps, **A**). Another cord (not probe) will come OUT of the *ammeter* from the "10A" port (the hole on the left). This cord coming *out* of the *ammeter* should lead *and attach to* one side of your bulb. Attach another (3^{rd}) cord to the other side of the bulb and plug the other end *into* the (+) terminal of the *power supply*.
2. Turn on the power supply (but don't touch the voltage adjust knob!), the ammeter, *and* your voltmeter.
3. Look at the reading on the *ammeter* (records current, **I**) and record it in the appropriate space below (for Bulb #1).
4. Temporarily touch the probes of the *voltmeter* on either side of the metal clips on the bulb (one probe on each side of the bulb). You don't have to permanently "clip" the probes on the bulb, just simply hold them in place (with metal touching metal) until you get a reading on the *voltmeter*. When you get a voltmeter reading, record it in the appropriate space below (disregard the negative sign if you get one).
5. Once you have the current *through* Bulb #1 and the voltage drop *across* it, use Ohm's law to *calculate* the resistance of the bulb. Take Bulb #1 out of the circuit, replace it with Bulb #2 and repeat. Turn everything off until PART FOUR

Skinny Bulb
Bulb #1-I= .216 A
V= 4.52 V
R= 20.93 Ω

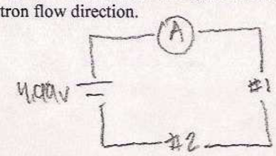
Fat Bulb
Bulb#2- I= .141 A
V= 4.67 V
R= 33.12 Ω

Part THREE: This part does NOT require you to hook anything up in a circuit yet!!!!!

This section will have you *theoretically* calculate (using Ohm's Law) what the "Total Resistance (R_t) ", "Total Current (I_t) ", and "Voltage drop across each bulb (V_1 and V_2)" *should be* IF both of your bulbs were hooked up *together* in a series circuit across the voltage you set in PART ONE of this lab (the ~5V). *Draw* a circuit diagram in the space below showing your *2 bulbs* hooked in series with a power supply (clearly showing the voltage you set in PART ONE) and an ammeter. Include in your diagram a voltmeter to measure the voltage drop across bulb #1 and electron flow direction.

R_T = 54.05 Ω

I = .09A



THIS IS STILL THE "THEORETICAL" PORTION OF THE LAB (PART THREE)---DO NOT HOOK ANYTHING UP YET!

1. **Calculate** (by doing the math) the total resistance your circuit *should have* **IF** both of your bulbs are hooked up in **series** *together* (use the resistance values you measured/calculated in Part 2). **Show the equation to calculate the total resistance and show your work below (with units!).**

   $R_T = R_1 + R_2$ $R_T = 54.05\Omega$

2. **Calculate** (by doing the math) the total current (I_t) your circuit *should have* **IF** your 2 bulbs are hooked in series together with your power supply. Use the total resistance you JUST calculated in the previous question and the voltage across your circuit you set in Part 1 (the ~5V the power-supply is set up to deliver). **Show the equation and all of your work in 5 steps (with units!).**

   $R_T = 54.05\Omega$ $I = .09A$
   $V = 4.99V$

3. Record the total current in the *Theoretical* section in the Data Table Below.

4. **Calculate** (by doing the math) what the voltage drop across EACH bulb *should be* if your two bulbs were hooked in series with each other by using Ohm's law, the *theoretical* total current from the previous question, and the values of your two resistors that you calculated in PART 2 of this lab. **Show your work in 5 steps (with units!). Remember: The two individual voltage drops of the individual bulbs should add-up to the total voltage of your circuit (the ~5V you set in Part One)**

   V_1- 1.88V V_2- 2.98V

5. Record the above values in the *Theoretical* section of the Data Table.

PART FOUR: This part will have you *physically* hook your two bulbs *together* in a series circuit and make actual *measurements* (with the ammeter and voltmeter) of the total current in the circuit and the voltage drop across each resistor. You will then compare them with your *theoretical* values from Part Three (above).

1. *Physically* hook your two bulbs up in a series circuit with the ammeter AND the power supply. The power supply should still be set to deliver the voltage you set in Part 1. Your circuit should be hooked up just like your diagram shows in Part 3, #1. **Please double check to make sure all the connections are correct. Does the cord coming from the negative port on the power supply *enter* the COM on the ammeter and does the cord coming *out* of the ammeter come out of the *left hole* (the 10A)? Is your ammeter set on A?**

2. Turn on the Power Supply, the ammeter, and the voltmeter. Record the ammeter reading in the Data Table under the *Measured* section. This reading represents the TOTAL current flowing through the two-resistor series circuit.

3. **Measure** the voltage drop across EACH bulb (one at a time) with the voltmeter (just like you measured the voltage drop across the bulb when you were initially trying to figure out their resistances in PART 2). Make sure you watch the direction the current will be moving into and out of the voltmeter so you have the leads attaching the voltmeter to the bulb oriented correctly.

4. Record the *measured* individual voltage drops of the two resistors in the Data Table.

	Theoretical	**Measured (with the meters)**
I (total)	.09A	.108A
V_1	1.88V	1.54
V_2	2.98V	3.01

5. How does the *measured* total current compare to what you thought the current should be (your *calculated value*, from Part 3)? **If it differs, WHY?**

   The measured value is greater than the theoretical. There is no explanation?

6. How do the *measured* individual voltage drops from above compare to the values you *calculated* the voltage drops should be (from PART 3)? **If it differs, WHY?**

   V_1 measured is lower than the theoretical but the V_2 measured is greater than the theoretical. Ammeter takes some of the voltage.

B.17 Student solutions to series circuit pre and post activity problem, Student 1.

Jimbo
Problem #3

Please TELL me how you would solve the following problems:

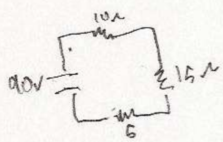
1. A 10 resistor, a 15 resistor, and a 5 resistor are connected in series across a 90V battery.

a. What is the equivalent resistance of the circuit? 30Ω

b. What is the current in the circuit? 3 A

c. What is the voltage drop across each resistor? 30, 45, 15

d. What is the power of each resistor? 90W, 135 W, 45



$I = V/R$

$V = 90V$ $I = 3A$

$R = 30$

$P = I^2R$

9

B.18 Student solutions to series circuit pre and post activity problem, Student 2.

Mary Lou
Problem #3

Please TELL me how you would solve the following problems:

1. A 10 resistor, a 15 resistor, and a 5 resistor are connected in series across a 90V battery.
   a. What is the equivalent resistance of the circuit?
   b. What is the current in the circuit?
   c. What is the voltage drop across each resistor?
   d. What is the power of each resistor?

a. $R_T = R_{10} + R_{15} + R_5$

$R_T = 30\ \Omega$

1
45
3
135

b. $V = 90\ V$

$R = 30\ \Omega$

$I = V/R = 3$ amps.

c. $V = IR \quad I = 3$

$V_{10} = 30$ volts

$V_{15} = 45$ volts

$V_5 = 15$ volts

d. $P = IV$

$P_{10} = 90$ J/s (W)

$P_{15} = 135$ J/s (W)

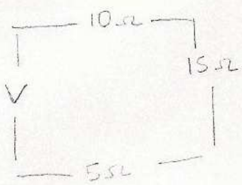
$P_{15} = 45$ J/s (W)

B.19 Student solutions to series circuit pre and post activity problem, Student 3.

Larry
Problem #3

Please TELL me how you would solve the following problems:

1. A 10 resistor, a 15 resistor, and a 5 resistor are connected in series across a 90V battery.
a. What is the equivalent resistance of the circuit?
b. What is the current in the circuit?
c. What is the voltage drop across each resistor?
d. What is the power of each resistor?



a) $R_T = R_{LT}$

$R_T = 30\Omega$

b) $I_T = \frac{V_T}{R_T}$ $I_T = 3A$

c) $I_T = 3A = I_i$

$V_{10} =$ IR $V = 30V$

$V_{15} = IR_{15}$ $V = 45V$

$V_5 = IR_5 =$ $15V \cdot V$

d) $P = IV$

$P_{10} = 90W$

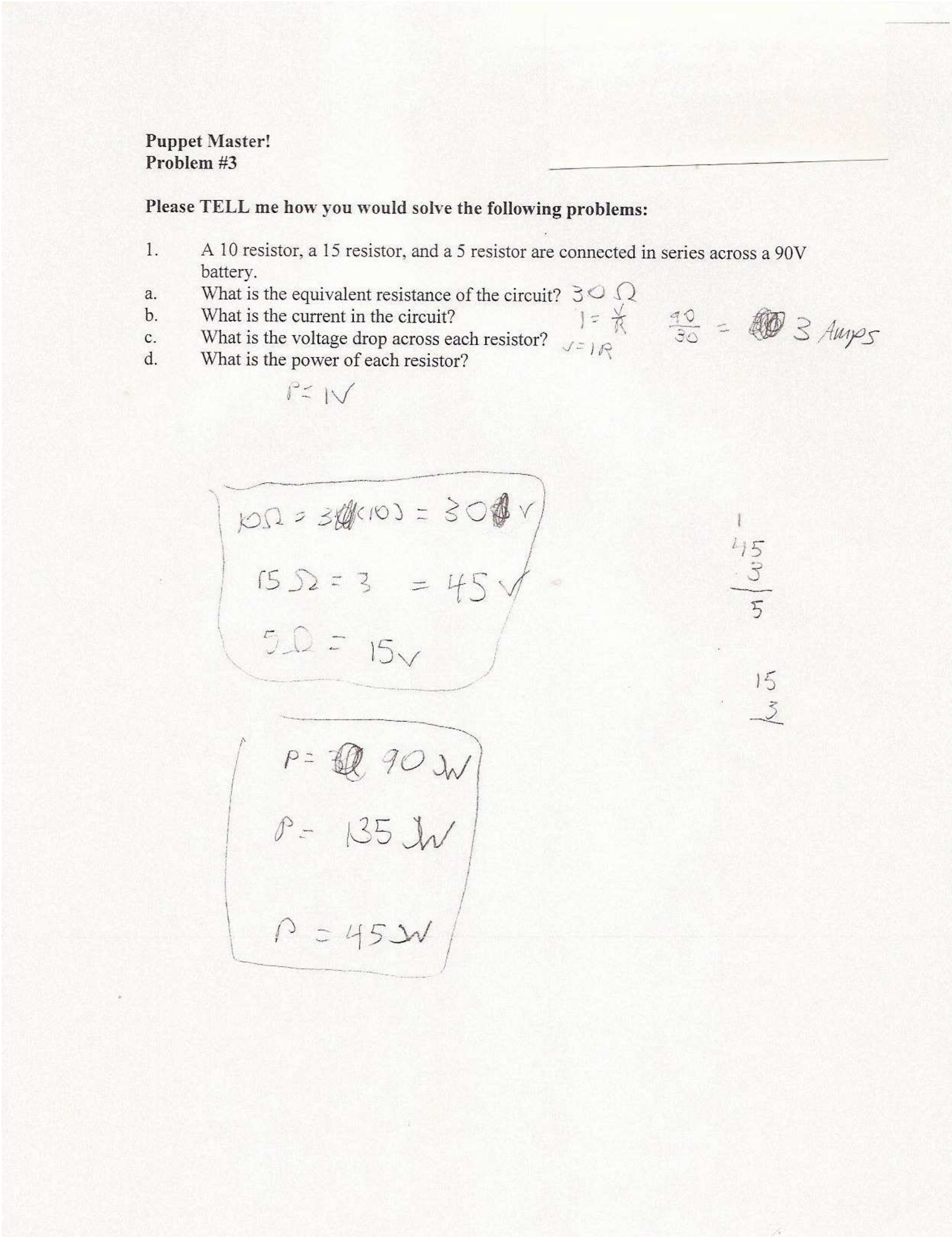
$P_{15} = 135W$

45 × 3 = 135

$P_5 = IV$

$P_5 = 15W$

B.20 Student solutions to series circuit pre and post activity problem, Student 4.



Puppet Master!
Problem #3

Please TELL me how you would solve the following problems:

1. A 10 resistor, a 15 resistor, and a 5 resistor are connected in series across a 90V battery.
a. What is the equivalent resistance of the circuit? 30 Ω
b. What is the current in the circuit? I = V/R   90/30 = 3 Amps
c. What is the voltage drop across each resistor? V = IR
d. What is the power of each resistor?

P = IV

10Ω = 3(10) = 30 V
15Ω = 3 = 45 V
5Ω = 15V

P = 90 W
P = 135 W
P = 45 W

45
3
5

15
3

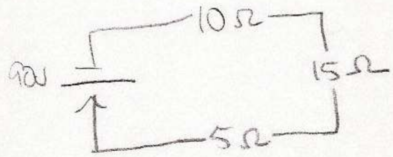
B.21 Group solution to series circuit pre-activity problem

The gang of four
Problem #3

Please TELL me how you would solve the following problems:

1. A 10 resistor, a 15 resistor, and a 5 resistor are connected in series across a 90V battery.

a. What is the equivalent resistance of the circuit?
b. What is the current in the circuit?
c. What is the voltage drop across each resistor?
d. What is the power of each resistor?



a. $R_T = \Sigma R_i$

$R_T = 30\Omega$

b $I = V/R$

$I = 3$ amps

c $V = IR$

$V_{10} = 30$ v

$V_{15} = 45$ v

$V_5 = 15$ v

d. $P = IV$

$P_{10} = 90$ W

$P_{15} = 135$ W

$P_5 = 45$ W

Group 7

B.22 Blank contact summary sheet

Contact summary Sheet
Date:________________________________Location

1. What people, events, or situations are involved?

2. What is the main theme or issue in the contact/

3. Was there discourse that typified concept negotiation? What was said, who said it- key phrases used?

4. Speculations/suggestions for subsequent contact?

Observations