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## Describing the Apprenticeship of Chemists through the Language of Faculty Scientists

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DESCRIBING THE APPRENTICESHIP OF CHEMISTS THROUGH THE  
LANGUAGE OF FACULTY SCIENTISTS

by

Brandy Ann Skjold

A Dissertation  
Submitted to the  
Faculty of the Graduate College  
in partial fulfillment of the  
requirements for the  
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Advisor: Renee' Schwartz, Ph.D.

Western Michigan University  
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## DESCRIBING THE APPRENTICESHIP OF CHEMISTS THROUGH THE LANGUAGE OF FACULTY SCIENTISTS

Brandy Ann Skjold, Ph.D

Western Michigan University, 2012

Attempts to bring authentic science into the K-16 classroom have led to the use of sociocultural theories of learning, particularly apprenticeship, to frame science education research. Science educators have brought apprenticeship to science classrooms and have brought students to research laboratories in order to gauge its benefits. The assumption is that these learning opportunities are representative of the actual apprenticeship of scientists. However, there have been no attempts in the literature to describe the apprenticeship of scientists using apprenticeship theory. Understanding what science apprenticeship looks like is a critical component of translating this experience into the classroom. This study sought to describe and analyze the apprenticeship of chemists through the talk of faculty scientists. It used Lave and Wenger's (1991) theory of Legitimate Peripheral Participation as its framework, concentrating on describing the roles of the participants, the environment and the tasks in the apprenticeship, as per Barab, Squire and Dueber (2000). A total of nine chemistry faculty and teaching assistants were observed across 11 settings representing a range of learning experiences from introductory chemistry lectures to research laboratories. All settings were videotaped, focusing on the instructor. About 89 hours of video was taken, along with observer field notes. All videos were transcribed and transcriptions and field notes were analyzed qualitatively as a broad level discourse analysis. Findings suggest that learners are expected to know basic chemistry content and how to use basic research equipment before entering the

research lab. These are taught extensively in classroom settings. However, students are also required to know how to use the literature base to inform their own research, though they were rarely exposed to this in the classrooms. In all settings, conflicts occurred when student under or over-estimated their role in the learning environment. While faculty moved effortlessly between settings, students had difficulty adjusting to new roles in different settings. The findings suggest that one beneficial way of bringing apprenticeship into the classroom, would be to expose students to scientific literature early, emphasizing the community of practice and the roles that learners, faculty and scientists play within it.

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## CHAPTER I

### THEORETICAL FRAMEWORK

#### Apprenticeship in Science and Science Education

##### A Basic Theory of Apprenticeship

There is a current trend in science education to promote an inquiry-based pedagogy. According to the National Research Council (National Research Council [NRC], 2000) a major benefit of inquiry teaching is that it supports a community-centered environment that parallels authentic scientific research. Further support comes from the cognitive apprenticeship model (Collins, Brown, & Newman, 1989), which suggests that to optimize student learning, authentic scientific activity should be integrated into traditional educational school settings. As such, educators continue to look for new ways to effectively incorporate research-based activities into the science classroom. Radinsky, Bouillion, Lento, and Gomez (2001) formally referred to these activities as simulation models of apprenticeship.

Simulation models of apprenticeship (Radinsk et. al., 2001) use the tools or data of science outside their normal environment of scientific labs, and incorporate them into the science classroom instead. A benefit of this approach is having a teacher to facilitate the cognitive development of students by making concepts visual, by situating tasks within authentic contexts and by aiding in transfer of learning to new contexts (Collins, Brown, & Holum, 1991). Teachers at all levels have therefore created many classroom activities meant to closely replicate what might be experienced in authentic research settings (Bouillion & Gomez, 2001; Etkina, Matilsky, & Lawrence, 2003; Luckie, Maleszeuski, Loznak, & Krha, 2004; Squire & Jan, 2007; Taasobshirazi, Zuiker, Svarosky, & Shaffer, 2007).

Because the teacher plays a critical role in cognitive apprenticeship, programs are being developed which provide opportunities for pre-service and in-service teachers to learn how to think and act like scientists (Brown & Melear, 2006; Brown & Melear, 2007; Luehmann & Markowitz, 2007). In addition, students, especially at high school and college levels are also offered opportunities to participate in programs that allow them first-hand experience in scientific research labs (Bell, Blair, Crawford, & Lederman, 2003; Charney et al., 2007; Hunter, Laursen, & Seymour, 2007; Markowitz, 2004). These participatory apprenticeships (Radinsky et al., 2001) allow learners to work at the elbows of scientists, conducting research as they might in authentic settings. The goal is for participants to transfer what they have learned to their own science classrooms (Bencze & Hodson, 1999). However, a recent review of the literature indicates that results from studies measuring the outcomes of these experiences are inconsistent at best (Sadler, Burgin, McKinney, & Ponjuan, 2009).

There are several possible reasons for this inconsistency in establishing outcomes of participatory apprenticeship programs. Sadler et al. (2009) suggests that because many of these studies rely on self-reported data, results are not overtly reliable. They also found that variables of studies are not always clearly defined and variations in apprenticeship format made generalizing across studies difficult. In addition, there is little evidence to suggest that simulation apprenticeships are effective in teaching and learning, in part because the authentic activities brought into the classroom are often not representative of actual scientific research (Chinn & Malhotra, 2002).

Part of the difficulty of measuring outcomes from these studies is the epistemological break between apprenticeship theories of learning and the constructivist learning pedagogies often employed in the classroom. The assumptions of the social apprenticeship model in



contrast to typical constructivist models is described next, along with an exploration of why the types of questions asked about the role of authentic science in learning may need adjustments.

## Social versus Constructivist Learning Theories

### Legitimate Peripheral Participation

Basic apprenticeship models, such as the cognitive apprenticeship model (Collins et al., 1989), are based on Vygotsky's social theories of learning, especially his theory of the Zone of Proximal Development (ZPD). A Russian psychologist working in the early 20<sup>th</sup> century, Vygotsky focused on learning through social interactions, and child development through cultural mediation and through play. His ZPD theory suggests that every individual has a range of learning they are capable of. Those who primarily work alone learn at the low end of their range, while those working in cooperative social relationships are able to learn at the higher parts of their range. These social interactions play an integral role in cognitive development and learning (Vygotsky, 1962).

One apprenticeship model based on Vygotsky's ZPD theory has since formed a basis for more specific models. Legitimate Peripheral Participation (LPP, Lave & Wenger, 1991) suggests that individuals develop expertise in an area by starting out as legitimate, but peripheral participants in the discipline. As they interact with others, most notably experts, but also peers as well as those outside the discipline, they negotiate their own, generally non-linear, path through the community. The community itself exists as it does, in part, because of the paths of movement undertaken by the individuals as they move through. As the novice is directly affected by the influence of the discipline, the discipline also evolves from the movements of its participants.

Learning through apprenticeship implies that an individual has the opportunity to interact with the ideas to be learned, usually through the guidance of an instructor. However, the entire learning environment also has to be taken into consideration, including the content being taught, the type of pedagogy employed, the way the lesson is sequenced *and* the sociological setting it is being taught within (Collins et al., 1989).

Lave and Wenger (1991) do not explicitly include education as an apprenticeship-like field. Wenger (1998) suggests that the most important aspect of education is not skills or information, but the sense of identity and belonging that comes with learning a trade. In apprenticeship theories, the primary requirement for learning is that the individual has a sense of legitimate participation in the community (Lave & Wenger, 1991). Successful implementation of apprenticeship in classrooms involves the teacher modeling the normative behaviors expected of students while interacting with them on a personal level. Students are then given opportunities to use those same behaviors with the teacher and their peers in new learning contexts (Collins et al., 1989).

### Conceptual Change Theory

Contrast this social learning environment with a typical constructivist learning model often employed by science educators today. Constructivist models are generally based on Piaget's psychological theories of cognition. One well-known example is conceptual change theory (Posner, Strike, Hewson, & Gertzog, 1982). This theory suggests that learners already have certain ideas about the material being learned. Meaningful learning takes place when students are made conscious of what they currently understand about a topic, and then are introduced to a viable alternative. On their own, learners need to integrate their new understanding into what they already know. The key interaction here is between the learner and the content. It is generally believed that hands-on, minds-on activities taught via inquiry are

important to developing cognition based on a constructivist approach to learning (NRC, 2005), but the social aspect is not taken into account. In essence, the learners construct their own understanding of new content through physical and mental interactions of that information, not necessarily through social interactions.

### Implications

Constructivist and social theories of learning are therefore not necessarily compatible. The former places the onus of learning on the individual, while the latter suggests that learning is dependent on the normative influences of society. Many studies that claim to be based on apprenticeship or social learning theory, however, attempt to use constructivist pedagogies, such as inquiry, or outcome measures, such as student-reported learning (Hsu & Roth, 2008; Hunter et al., 2006; Ritchie & Rigano, 1996; Roth & Bowen, 1995). Further, these same studies assume that a single act of teaching equates to an apprenticeship experience. This assumption fails to recognize the critical social component inherent in apprenticeship. Very few of the studies that employ a sociological theory of learning, but measure individual cognition, recognize or account for the conflict between the two. Those that do claim the research is justified because it relies on some hybrid of the two theories (Hunter et al., 2006; Ritchie & Rigano, 1996).

Therefore, the apprenticeship theory of learning is best applied to communities of practice or learning to become, in this case a scientist. Conversely, science education research generally employs constructivist theories of learning to determine appropriate pedagogies or cognitive outcomes. Attempts to combine the two force the researcher to compromise the fundamental tenets of one theory or the other. What is not currently found in the education literature is an empirical study that uses a sociological theory of learning to understand the role

of science education in learning to become a scientist, without trying to use a traditional constructivist theory to dictate methodology.

This study, therefore, has two intended goals. First it seeks to describe both classroom educational settings and science research settings under the same sociological theory of learning. Second, given that description, it attempts to identify areas in which the goals and social environment of the two settings might overlap, facilitating apprenticeship-like learning.

### Definitions and Assumptions

#### Learning Theory

This research is explicitly concerned with apprenticeship, which was soundly based in sociological learning theory. Specifically, this study uses Legitimate Peripheral Participation (LPP; Lave & Wenger, 1991) as its foundation. The LPP theory posits that learning takes place as individuals move through the social structures of communities as legitimate, but peripheral participants. Gatekeepers, usually disciplinary experts, determine legitimacy by dictating access to the community, and affecting movement through it. Individuals are considered peripheral participants because they often begin experiencing the community by participating in important, but non-integral tasks. As the individual spends more time interacting within the community they continue to move through it, although they always remain somewhat peripheral. This theory does not allow for individuals to become central within a community because the discipline itself is never static.

The research study described here, therefore, begins by making the assumption that learning to become a scientist does follow as an apprenticeship. Therefore, observations of settings associated with learning to become should provide information about how scientists become legitimate members of the community as well as the peripheral tasks, scaffolding, and

interactions they are exposed to as they move through. This study does not seek to evaluate or test LPP theory, but rather to use it in a consistent way to describe a community of practice.

The problem with studying a phenomenon via LPP is that there are many factors that contribute to the development of the community of practice, which can be used as units of analyses. Lave & Wenger (1991) cite six main aspects to consider:

1. How resources are structured in communities. This refers to how learning is arranged, including what knowledge is offered when and what access learners have to experts or other learners.
2. The place of knowledge in communities. This refers to how important certain types of knowledge are compared to other types, often dictating how each type of knowledge is conveyed.
3. Access to the community. Gatekeepers play a role in restricting learners from entering or advancing in a community or from obtaining information or resources. Although gatekeepers are often experts, they may also be peers, other learners or technology in general.
4. The language and discourse of the community. This refers to a range of language cues, and experts generally perpetuate the norms associated with discourse. Failure to negotiate the language of the discipline could result in problems of movement.
5. Motivation or identity toward the community. One of the prime goals of apprenticeship learning is that the learner identifies with the discipline, thereby increasing their intrinsic motivation to become expert.
6. Contradictions and change within the community. Communities of practice do not remain static. It is important to understand how they change and how those changes affect the individuals, both novice and expert, involved in them.

## Community of Practice

Because LPP focuses on communities of practice, it is important to identify which community is used for this study and why. Given the focus of this research it is possible to study three different communities of practice. One is of general education. Wenger (1998) has already described this community of practice. The second is the community of science education specifically. However, there are two barriers to studying this. One is the tradition of using constructivism in studying science education. The other is that Lemke (2001) has already described science education and the discourse in this field. Therefore, this research focuses on movement through the community of science as learners apprentice to become scientists. This apprenticeship generally begins in educational settings, college lecture and laboratory classrooms, and then develops into more intensive research laboratory work (Feldman, Divoll, & Rogan-Klyve, 2009).

This area is worthwhile to explore for several reasons. First, the apprenticeship of scientists involves both classroom-based educational work, and authentic laboratory-based research, allowing consideration of both within the same community. However, just because classroom work and authentic research are part of the same community does not imply that they are compatible. The sociological perspective might suppose just the opposite. There probably are conflicts between education and research, but members of the community have difficulty seeing or understanding these differences (Lemke, 2001). This makes the college science setting useful because it allows identification of where the apprenticeship is most consistent between both settings and therefore most likely to succeed.

Another reason studying college science education is useful is because higher education in science goes beyond simply training future scientists. The pipeline of university science filters back to the K-12 system through teachers, administrators and parents (Siebert & McIntosh,

2001). These players in turn dictate the paths of students through the community of education and affect their future movements at the university level.

Finally, there has been a consistent call to reform college science education, which claim that despite requiring scientific vigor in their research laboratories, faculty scientists have essentially ignored best practice teaching evidence, relying on outdated transmission lectures and cook-book labs (Handelsman et al., 2004). However, these arguments do not take into consideration the fact that university science education arose as a component of the apprenticeship of scientists, *not* as a component of the community of education. By considering university science education as a piece of the community of science, it is possible to understand why it is implemented as it is, and how it contributes to the apprenticeship of scientists.

#### Variables to Consider

##### Aspects of Measurement

Studies grounded in sociological theory generally measure qualitative aspects of community structure such as how people talk or how the community affects our beliefs (Lemke, 2001). The six aspects of apprenticeship from Lave and Wenger (1991) describe a community of practice. This study focuses on the discourse within the community. Language use was chosen primarily because it is a consistent feature across all settings. While gatekeepers and resource availability may change from K-12 to university classroom, to university laboratory to research laboratory settings, discourse is consistently present in all settings. In addition, it is language that ultimately makes meaning for individuals about what science is and where they belong within the community, making it an important component of apprenticeship (Lemke, 1990).

However, discourse and language are both very complex and large areas of study. Discourse analysis, for example, consists of multiple levels ranging from investigating the

general structure of conversation to scrutinizing very specific word uses, pause tendencies or grammatical turns. Because of this wide scope in the study of discourse, it is imperative that researchers narrow their focus to address only what is most essential for their study (Fairclough, 2003). The essence of this study is the idea of investigating what authentic scientific development looks like. Authenticity of any one task, however, is actually relatively defined by the role of the task, the role of the student or apprentice, and the role of the environment, which combine to form a spectrum of authentic experiences (Barab, Squire, & Dueber, 2000). Therefore, the focus on this research was narrowed to concentrate on discourse that centers on the roles of the task, student and environment to develop a landscape of language use through an authentic community of learning.

#### Study Participants

It is also important to consider whose language would be the focus for this type of research. According to LPP two of the major players within community structures are the learner and the expert, or the apprentice and the teacher (Lave & Wenger, 1991). Discourse analysis in classroom settings often considers both of these players (Driver, Leach, Millar, & Scott, 1996; Lemke, 1990). But, as previously mentioned, successful attempts at simulation type-apprenticeships rely heavily on the teacher having the expertise to model authentic science (Collins et al., 1989). In addition, it is the experts that often act as gatekeepers to communities (Lave & Wenger, 1991). Therefore, this research focuses more specifically on discourse of faculty scientists in universities as opposed to students.



## Research Goals

Sociological theory regarding communities of practice generally allow for describing and analyzing what is happening within systems. This research focuses on two main objectives, both of which aim to better elucidate how apprenticeship models work in educational settings.

1. To describe faculty scientists' discourse across apprenticeship-like opportunities in a university chemistry department, specifically taking into consideration the role of the learner, the task and the environment.
2. To identify key components within discourse patterns that might indicate ways to successfully integrate authentic research opportunities and classroom science education.

This research considers a system that is already, historically considered a community of practice in which novices are trained to be experts through apprenticeship. It then seeks to use this understanding to determine if and how outcomes may be applied to educational settings or to fulfill the needs of educators.

## CHAPTER II

### LITERATURE REVIEW

#### Research Findings on Apprenticeships in Science Education

##### General Descriptions and Discussion

Apprenticeships were used historically as a way for experts in a field to teach novices a trade. Recently, the term “apprenticeship” was used in education as a way to describe teacher and learner relationships and as an equivalent to situated learning. Modifications of the apprenticeship model of learning took on various guises in order to explain the process of learning in social context (Collins et al., 1989; Lave & Wenger, 1991; Wenger, 1998). However, the general theory posited that individuals learned most effectively when they were allowed to interact socially within a community of practice, as legitimate players.

This social theory, coupled with a notion of inquiry, has led to reform that favored the use of authentic scientific activity at *all* levels of education (Siebert & McIntosh, 2001). There were two primary models for incorporating authentic science into science education to replicate an apprenticeship-like experience. The first was a simulation model of apprenticeship in which learners used the tools, methods or data from the field, under the environmental constraints of the classroom setting. The second was a participatory model of apprenticeship where learners were brought into a science research setting and allowed to work at the elbows of scientists (Radinsky et al., 2001).

Teachers and researchers used apprenticeship models because they believed they simulated authentic experiences. As such, they led learners to become experts in the discipline by teaching them the content knowledge and process skills inherent in the field as well as provided them an accurate understanding of the nature of science, and improved their attitudes

toward science. The research in this area therefore tended to focus on expertise, knowledge gains, both conceptual and process-based, nature of science, or affect.

This literature review explores how both simulation and participatory models have been used for the purposes of science education. It was intended to highlight the successes of lessons and programs that implemented apprenticeships, as well as their failures. There were, however, relatively few empirical studies that evaluated the use of apprenticeship learning models. The reasons for this along with a discussion of the use of apprenticeship for teaching and learning are included at the end of this section.

### Simulation Models of Apprenticeship Learning

#### Introduction

Because simulation models of apprenticeship were often conflated with inquiry teaching in general, the following definitions of both were used in this research. Inquiry was defined as a pedagogy in which students are given the opportunity to explore an idea via activity before simply being told the right answer (NRC, 2000). Inquiry does not imply authenticity in itself. Apprenticeship, however, is the very specific act of bringing in real research tools, ideas, methods or questions from currently functioning research laboratories and using them as part of learning in the classroom (Radinsky et al., 2001).

The key term “authentic” was often used in both apprenticeship research and research on inquiry as pedagogy. Therefore, two general criteria were used to ensure that the literature described here was not focused only on basic inquiry teaching. First, articles that used apprenticeship, or cognitive apprenticeship, as their theoretical framework were included. Second, articles that used the key word “authentic” were included only if they specifically involved participation in a program or lesson associated with an outside research group.

Beyond these two initial criteria for inclusion, only articles that outlined studies in the United States or Canada were reviewed here. As a sociological study, the community of practice was an important aspect of learning, and that community is highly influenced by the culture it is found within (Traweek, 1988). It was not assumed that the educational or scientific communities of practice in other countries were similar to those of the United States. In addition, only studies that involved empirical or experimental research on the apprenticeship opportunity were considered. There was a large body of literature that was found in trade journals that described various possible authentic, inquiry or apprenticeship programs, lessons or activities (Cavallo, 2007; Cavallo, 2008; Lundstrom, 2005; McCartney, Deroche, & Pontiff, 2008; Oates, 2002). These tended to neither extend the understanding of what scientific apprenticeships look like, nor did their publication imply sound instructional practice, constructivist or sociological. Any exceptions to these four criteria are explained further during review of the article.

#### Simulation Models at the Elementary (K-4) Level

There were no empirically designed research studies, meeting the criteria above, that explored how simulation apprenticeships worked at the elementary level. This in itself was significant because there is a consistent push in the theoretical literature to include authentic experiences in all levels of education. At the elementary level, at least, this appeared to translate into the use of inquiry as pedagogy rather than the use of apprenticeship learning. The elementary-based literature on authentic science activity tended to focus on either teacher training programs (Buxton, 2006; Carrier, 2009; Watters & Ginns, 2000) or on describing classroom lessons (Forbes & McClougham, 2010; Means, 1998; Ucar & Trundle, 2011). All of these studies focused on authentic science, but none did so from a strong socio-cultural perspective. The article discussed below focused on elementary teacher training and was based on the integration of constructivist and social learning models.

Glynn and Winter (2004) presented data from a US Department of Education research project, intended to design a Professional Development (PD) program for in-service elementary teachers based on Contextual Teaching and Learning (CTL) and the NRC's Science Education Standards (1996). Further, it sought to determine what factors in real classroom settings either hindered or facilitated teacher implementation of CTL techniques.

CTL is an informal integration of classic constructivist pedagogy along with an emphasis on social interaction and authentic settings. It is based on situated cognition models of learning, which suggest that critical thinking and inquiry were best situated in relevant social contexts. The particular CTL model used by Glynn and Winter (2004) emphasized five major teaching strategies that are often used independently, but in this case were closely integrated:

1. Inquiry Learning- In this research they assumed the definition given by the NRC (2000), which refers to inquiry as the processes and skills used by scientists when they investigate nature, and should be translated carefully to classroom learning.
2. Problem-based Learning- This is a common teaching tool whereby students were presented a real or reasonably possible problem and were asked to solve it using what they knew from a variety of disciplines.
3. Cooperative Learning- This referred to students working together in small groups to solve problems, and work through activities.
4. Project-Based Learning- Students were asked to work on generally large scale projects that had relevance to solving a problem or addressing a social concern of current import in the real world.
5. Authentic Assessment- These were assessments that were representative of what might actually be done in real-world settings, such as portfolios or research posters.

They were generally evaluated based on progress, achievement and effort as opposed to right and wrong responses.

This article was included in this literature review because the five CTL strategies incorporated into curriculum guides for the PD model included cooperative learning, authentic assessment and a definition of inquiry that specifically referred to students learning in the same way science is carried out. This was the closest representation of sociological learning theory for elementary education that could be found. Unfortunately, although it was empirical, it was only a program evaluation, versus an evaluation of the actual benefits or shortcomings of their model in K-4 classrooms.

The authors, both science educators, had expertise in designing and implementing (PD) for teachers. The grant that funded this project did so on the basis that the researchers would design a program that addressed current reform measures in the NRC Standards (1996), and use CTL strategies as a basis. To address reform measures and meet CTL strategies, Glynn and Winter collected a series of mini-lessons originally found on the Columbia Education Center (CEC) website (Delzeit, 1995) and a curriculum guide called *Project WET* (1995). Neither was described in the paper, nor was it explained why those two sources were chosen for creation of curricular examples of CTL teaching.

The CEC website (Delzeit, 1995) provided mini-lesson plans for a variety of disciplines at elementary, middle and high school levels. The elementary science section had 130 lessons. They were, as described, mini. For example, one lesson on Animal Life Cycles began with an appropriate grade level guide, in this case 3-8, followed by a short overview and a purpose statement. The overview suggested that students see living things in a variety of places in their everyday lives, each experience becoming a piece of a jigsaw, but they need help putting the pieces together to form a congruent whole. The purpose statement explained that the

information contained there constituted a unit on organismal Life Cycles, which included hands-on activities, art projects and cognitive experiences.

The purpose statement was followed by three objectives, which suggested that by the end of the unit students would be able to compare and contrast life cycles of different species, recognize the basic needs of living organisms, and evaluate their relationship with other life forms. There was then a list of possible activities used to fulfill the stated objectives. However, there was no explanation of how to implement these activities. The website provided some more specific examples such as setting up aquariums and getting fertilized frogs' eggs, but again there was no indication of how these activities fulfilled the objectives or how they related to the original purpose. There were also some additional suggestions for how to translate this activity into a language arts lesson, along with a basic explanation for how to tie everything together. The other mini-lessons in the set had similar characteristics to this one.

The *Project Wet* curriculum guide contained 91 lessons spanning K-12 education, focused primarily on teaching and learning about water systems (Project Wet, 1995). The Guide was developed via a US Department of the Interior, Bureau of Reclamation grant. The development of the guide began as a series of regional workshops with educators, resource managers and specialists. Participants came from all 50 states, the District of Columbia, other US territories and Canada. Using state curricula as their guides the experts initially created over 500 activities. The activities were collected, consolidated, tested and supplemented with additional information. Early drafts of activities were field tested in classrooms and other educational settings, and then were expertly reviewed by program evaluators from Western Michigan University. After field testing by teachers and other experts, the remaining lessons were revised and passed through a final review process.

CTL was incorporated into the stock mini-lessons from the CED and *Project Wet* following Sears (2002). Sears' book *Contextual Teaching and Learning: A Primer for Effective Instruction* was the overall foundation for the Glynn and Winter (2004) paper. The book recommended the same CTL learning strategies as were employed by the authors. In addition, Glynn and Winter suggested that there were other important aspects of effective CTL, including self-regulated learning and learning in diverse context. These were also discussed in Sears' book.

Once the mini-lessons were developed with appropriate CTL they were demonstrated to 21 in-service teachers during a two-week graduate level PD workshop. Twenty of the teachers were female and 16 were Anglo-American. They ranged in age from 22-48 years old ( $M = 32$ ) and had between one and 27 years teaching experience ( $M = 8$ ). All teachers held at least a bachelor's degree, four held a master's and one had a Ph.D. After the initial demonstrations of the CTL appropriate lessons, each teacher presented three of their own, one-hour lessons in which they had incorporated CTL strategies. They were given formative feedback on how to improve their lessons.

After the two week workshop, the researchers followed all 21 teachers throughout the next school year, collecting the following data: semi-structured interviews, structured interviews, observations of lessons, teacher work products and student work products. There was no source given to find out what the PD demonstration lessons entailed, nor was there a description of the teacher designed lessons. There was no indication as to the length of interviews, the types of question asked in the interviews, the duration or number of observations per teacher, or how any of the data was analyzed. It was reported that this was a case study and therefore not generalizable.

Part of the data analysis included scoring of a rubric, which was based on teacher use of the five teaching strategies, along with other aspects of best practice such as "Continuously



assessing student understanding” and “Selecting and adapting the curriculum” (55). The rubric was based on a four-point likert scale rating, with four being equal to very good and one equaling unsatisfactory. According to Glynn and Winter the scores on the rubrics indicated that, “All 21 teachers used the CTL integrated strategies in their classrooms, with most using the strategies well and often...” (54). It was not clear what score, or combination of scores, on the rubric indicated that a teacher implemented something “well.” There was also no indication that the rubric was somehow validated, that the data was triangulated or that the rubric was scored consistently across participants.

The article continued with a case study analysis of three of the teachers’ lessons. These three teachers were considered representative of the majority of the 21 study participants. The case study descriptions were meant to explore aspects that facilitated or hindered implementation of CTL strategies. All three (female) teachers described had at least eight years of experience at the elementary level; this was at or over the mean for experience. All three had large rooms that were brightly decorated and arranged in learning-conducive ways, such as having desks turned in to form group-work tables. They all used good questioning strategies, including KWL, but nothing atypical in education.

The three case studies indicated that the teachers made use of several CTL strategies, including inquiry (exploring living creatures outside before discussing them), cooperative learning strategies (working together to learn vocabulary words), problem-based learning (designing a food web in small groups) and authentic assessments (turning in portfolios for formative assessment). However, it was not clear if teachers used any of these strategies prior to the PD workshop, as well.

All three teachers were also asked about their teaching philosophy. They each responded slightly differently. One emphasized constructive and meaningful learning, another

embraced science as a way of knowing and the third emphasized education as a democracy. However, none of this suggested that the PD was particularly successful. All three of these statements reflected back to each individual's suggested teaching philosophy.

Glynn and Winter suggested there were four conditions that facilitated CLT strategies across all 21 teachers:

1. CLT strategies worked well when the teachers viewed their students as collaborators in learning, respected their decisions, empowered them and shared decision-making responsibilities.
2. CLT strategies were facilitated when teachers used active, hands-on lessons and discouraged rote learning.
3. CTL strategies were supported when teachers made connections to real-world contexts. These contexts could be simple (looking at live plants) or more elaborate (visiting a butterfly garden outside), they only needed to be perceived as relevant.
4. CTL strategies were also more effective when science content was integrated with other disciplines (such as literature or math) or other skills (such as artistic skills).

This research indicated, however, that CTL strategies did not work well when teachers had limited classroom management skills. Asking students generally used to working alone, to work in cooperative groups led to poor student behavior and limited the effectiveness of the lesson. Punishments that countered CLT theory, such as taking points or giving times outs, also undermined the overall effect of these learning strategies. In contrast, punishments that corresponded with CLT theory, such as whole group accountability for student behavior, tended to support reform strategies.

There were several practical implications of this study including information on how research was conducted on these programs. First, teacher skills played an important role in

successful implementation of scientific activities. This suggests that having access to pedagogically sound activities does not automatically translate to successful teaching. Kelly and Staver (2005) had also reported elementary teacher difficulties in faithfully implementing pre-designed lessons. Significant to this research was that the instructor role in socially oriented activity was critical to student learning.

A second implication was the quality of the research design itself. There were no revised lessons provided and no indication for how the learning strategies were incorporated into the lessons for the workshop demonstrations. Descriptions of lessons implemented by teachers in their own classrooms were not explicit about what aspects were CTL and what were simply normal teaching behaviors. There was no comparison of teacher lessons before and after the PD workshop, so there was nothing to indicate that their teaching actually changed as a result. Although the researchers collected student work they did not discuss it, so there was no indication of student learning as a result of the CTL intervention.

The lack of detail made it difficult to draw conclusions about the effectiveness of the PD program or of the CTL lessons for student learning. This lack of detail is also what has led to conflation of inquiry with sociological learning. It is not always clear if lessons are enacted as authentic scientific research, or are just examples of basic inquiry pedagogy. Chinn and Malhotra (2002) have suggested that many of the activities meant to reflect authentic scientific practice in the classroom, simply do not.

The fact that this happened at the elementary level was critical. The NRC standards literature (1996, 2000) and the NSTA *Pathways* series (e.g. Siebert & McIntosh, 2001) emphasize the inclusion of *authentic* scientific activity at the early elementary level. However, this study indicated that even experienced elementary teachers still face difficulties in implementing scientifically authentic activities in the classroom, despite access to professional development. It

also indicated a need for researchers to find more effective ways of evaluating teaching and learning of these activities so that implications are clearly supported by evidence.

#### Simulation Models at the Middle School (5-8) Level

Middle school programs incorporating authentic science through either a cooperative with research labs or as part of theoretical work on apprenticeship were more common than elementary programs. However, there were few empirical studies on the effectiveness of these activities. There were some that provided program descriptions (Bodzin & Shive, 2004; Bryson, 2004). These were cooperatives through the Lehigh Earth Observatory and NASA respectively. Since neither presented data on aspects of program effectiveness, they were not discussed here. The following article review is of an empirical study on the effectiveness of a program designed under a theory of cognitive apprenticeship at a middle school level.

This study was done with eighth grade students as they encountered an open-inquiry science laboratory based on the theory of cognitive apprenticeship (Roth & Bowen, 1995). This study exemplified how apprenticeship learning opportunities were conflated with inquiry activity. The article began by suggesting that although schools claim they prepare students for everyday life, it was clear that *school culture was not equivalent to everyday culture* and success in one was not equivalent to success in another. Roth and Bowen then went on to describe current learning settings as being teacher centered, devoid of cooperative student learning, extrinsically motivated, and lacking inquiry.

In contrast to this current, unfavorable learning environment, Roth and Bowen described a preferred notion of learning called open-inquiry. In open-inquiry pedagogies students identify problems, develop solutions to those problems, test their solutions, formulate new questions, link their experience to prior knowledge, and socially share their solutions. All of this made learning intrinsically motivated compared to the external motivation found in

traditional teaching. They claimed that open-inquiry in classrooms reflected the socially constructed and highly circumstantial culture of scientists by having students:

1. Learn in contexts that consisted of ill-defined problems
2. Experience uncertainty and ambiguity along with a social nature of science
3. Learn by emphasizing their current knowledge
4. Be part of a community of practice
5. Draw on expertise of others within that community

Roth and Bowen took their idea of communities of practice from Lave and Wenger's (1991) LPP theory, which suggests that students should be exposed to knowledge through participation in authentic practice. According to the framework suggested by Roth and Bowen science apprenticeships generally begin at graduate school, but they *could* begin at any time, including elementary school. The claim that elementary school students could be considered apprentices in the community of science is based on a nuance of the LPP theory. LPP theory suggested that experts in the community of practice were not the only knowledge sources available to apprentices. Knowledge could also come from other apprentices or could be understood from the structure of the community itself. Roth and Bowen used this explanation of how knowledge is acquired to suggest that students can be apprentices to the community of science without having access to expert scientists. In this scenario, acceptance into the community is dependent only on whether or not there is access to a source of knowledge.

This claim was problematic because it ignored the requirement of legitimacy in apprenticeship. The question was *not* one of experts or novices passing along knowledge, but rather one of gatekeepers. Gatekeepers, not the holders of knowledge, grant legitimacy in LPP theory (Lave & Wenger, 1991). Gatekeepers do not need to be people, but if they are, then they must have some power in granting legitimacy. The culture of science could also be a gate-

keeper. This is known as cultural border crossing, but is in itself a complex concept (Cobern & Aikenhead, 1998; Costa, 1993). The question raised by Roth and Bowen's work was who or what was it that made elementary students legitimate participants in the community of science.

Elementary teachers themselves are generally not scientists, and there was no reason to assume they were familiar with the cultural norms of apprenticing to become one. Roth and Bowen mentioned peers acting as sources of learning, but those peers were no more apprentices than the student himself. It is possible that the culture was open to students, and allowed them to border cross, as was suggested in the article, but the authors had already admitted early on in the paper that the culture of school (science) was nothing like the culture of everyday (science) and success in one was not indicative of success in the other, indicating that border-crossing is difficult for students to accomplish. In Roth and Bowen's paper there was no obvious gatekeeper that was able to make elementary education students legitimate participants in the community of science.

This is not to suggest that apprenticeship like activities cannot be brought into elementary classrooms, as described by Collins et al. (1989). However, Roth and Bowen suggested that students at any level were able to be legitimate apprentices learning to become scientists, as long as there was a source of knowledge available. This takes a liberal view of LPP theory and undermines the concept of legitimacy. For example, the Yucatec Midwives Lave and Wenger (1991) described as an example of apprenticeship had very specific requirements for legitimacy. The *legitimacy* of a midwife came directly from her mother or grandmother, as midwifery ran along family lines. Throughout her training an apprentice midwife witnessed many women giving birth, *learning* from each along the way. The perspective Roth and Bowen take suggests that because the women giving birth were *teaching* a novice about labor and delivery they were the gatekeepers that provided the novice with legitimate access to the

community of practice. If this was the case, many women *and* men would be legitimate participants in the community of midwives. The critical role of midwifery running along family lines disappears.

After Roth and Bowen claimed that elementary children could begin apprenticeship toward science, they explained that learning in school science should be understood in terms of changes in practices and resources. They sought to understand this kind of learning, focused on social structures, at the individual, group and classroom level. Their work was centered on cooperative learning through peer collaboration and authentic practice as defined by cognitive apprenticeship models, which they interpreted as an open-inquiry setting. They metaphorically equated science students and science teachers to science graduate students and graduate student advisors, and suggested that their open-inquiry labs were representative of how graduate students learn to become scientists.

There were two problems with comparing an open-inquiry pedagogy with apprenticing to become a scientist. First, there have been no studies done on the apprenticeship of graduate students into scientists, making it impossible to know whether the process might reflect an open-inquiry pedagogy or not. Second, open-inquiry in general is not representative of apprenticeship theory. LPP requires that apprentices begin as peripheral members of the community of practice. The open-inquiry system described by Roth and Bowen suggested that students should be able to identify problems and design solutions to them all while effectively linking their experiences together to generate new knowledge. Although this is probably a fair representation of what scientists do, it may or may not be a fair representation of what science apprentices do.

Lave and Wenger's (1991) LPP model suggests that new-comers to a community of practice begin apprenticeship by completing important, but peripheral tasks. None of the

apprenticeship structures Lave and Wenger observed in developing their model started with novices doing the work of experts. Tailor apprentices spent long hours ironing, becoming familiar with the textiles and stitching patterns in the process. Midwives were trained through observing many births, but not participating in any, usually until after they had their own child. Butchers first completed some schooling, learning many things that were not particularly relevant, and even once they began formal apprenticeships, they were first taught things like how to sharpen knives. New-comers to the community of practice arrive as peripheral members, learning important but not necessarily integral tasks to the community. Once they mastered those tasks, new tasks were added on as they slowly moved through the community. To assume that apprenticeship implies immersion does not coincide with the LPP model of learning Roth and Bowen used.

Perhaps because Roth and Bowen recognized that to apprentice a learner must be both legitimate and peripheral, they did state that the students were prepared for this new unit on two levels. First, they progressively changed the format of the class by first having students conduct pre-determined experiments based on teacher developed questions, followed by students designing their own experiments to questions. This served as peripheral movement through the community. The teacher then spoke to students about being biologists and as such, they must learn how to act appropriately. This talk was meant to grant legitimacy. Neither attempt at fulfilling the LPP model appeared to be sufficient, and the problems with assumptions about student legitimacy and peripherality remained.

After their theoretical framework was presented, Roth and Bowen described their research design as being conducted from a constructivist perspective, using discourse analysis. The authors did not attempt to reconcile using a sociological theory of learning as well as a constructivist perspective. The two are not synonymous. They also reported this study as action



research though they did not document changes they made after initial iterations of the project or the effects of those changes. In this sense, it was action, only in that the researchers desired to learn how they could make beneficial changes to the implemented program.

The study took place in a private school in Canada, which was described as being monetarily driven and generally disinterested in best practice educational approaches. However, Roth and Bowen were brought into the school to change the teacher-centered approach currently employed by most science faculty. Over a period of several years, the science program was restructured, and teachers began using more student-centered approaches to teaching, which though successful from an educational perspective, caused tensions with parents who believed their children should be taught more traditionally. Roth and Bowen, were also the teachers involved in this study. Both had higher degrees in the sciences, as did their teaching assistant and student teacher. A total of sixty-five students, mostly boys, were involved in the study, and equally represented all abilities, other than the lowest quartile of a general school population. Most were middle to upper class. All of these aspects indicated that this was an atypical situation in middle school educational experiences.

The open-inquiry event was structured around an ecology unit. Pairs of students were provided a plot of land and asked to investigate the biotic and abiotic factors associated with their *ecozone*. Students met three times a week, twice outside with their plots and once in the classroom. They had field notebooks where they kept information about questions, data, weather and other important notes. In-class times were used for discussion and background research. Equipment, such as meter sticks and soil thermometers, was made available to groups, along with several written resources. Typically students would spend five to ten minutes preparing and consulting with advisors, 40 to 50 minutes on their research and another five to

ten minutes in closing. The teacher made sure to visit each group at least once during research time, although students generally worked unsupervised.

The data collected for this study included videotapes of every lesson in one section of the course, along with a few videos in a second section. They also collected "... all of the laboratory reports, field notebooks, word problems designed to test *in situ* emerging hypotheses about student learning, and examination results..." (85). Students handed in four formal field reports during the research, although there was no indication of how teacher feedback on these reports looked. In addition, researchers interviewed students about their views of the open-ended format and administered the Constructivist Learning Environment Scale (CLES) The CLES measures how closely the learning environment corresponds to constructivism as perceived by the students. Roth and Bowen reported the reliabilities of each CLES subscale to be between 0.69 and 0.85. Though not high, these reliabilities are not unreasonably low.

The data collected in this study, especially the use of the CLES, also reflected a problem with the research. Roth and Bowen were using a sociological theory of learning and they had created a learning experience which they believed mimicked the apprenticeship of scientists. However, they then attempted to measure the quality of the experience using data based on constructivism. It is unreasonable to assume that the learning environment designed in the study would reflect constructivism, as measured by the CLES, when it was designed to reflect a sociological perspective. In addition, sociological research focuses on how participants identify with and interact within a community of practice. The data collected in this study focused on student learning gains in various areas. There was conflation between the theoretical framework and the measured outcomes of the research.

The results of this study focused on student gains in three areas: mathematical representations, problem solving and attitudes and achievement. Students continually used more mathematical representations as time went on, including maps, graphs and taking averages. The authors suggested this increase was a direct result of peer group discussion and teacher questioning. In general, students moved from using qualitative language to describe things like plant density (e.g. more or less) to using quantitative measurements, such as per m<sup>2</sup>. In addition to an increased number and type of mathematical representations used, students also increased the amount of information portrayed in any one chart or graph.

However, on the exam, students were less inclined to use mathematical representations than when they wrote their lab reports. The authors attributed this to the difference between the decontextualized exam questions and the contextualized open inquiry lab. Also students worked individually on the exam, but cooperatively in the field. Mathematical quantification skills may have been a product of the social group, rather than a gain in individual cognition. This is an example of Vygotsky's ZPD (1962), but it also exemplifies why social theories of learning do not emphasize individual gains of knowledge and instead focus on the characteristics of the community as a whole. A third reason Roth and Bowen gave for students' failure to use mathematical representations on the exam was that students had not moved far enough along in their apprenticeship, and therefore were not able to think like scientists. This statement was difficult to evaluate because the open-inquiry experience itself was not apprenticeship-like, so movement through the community should not be expected. However, it is also not clear that the ability to transfer knowledge from one context to another is only achievable for scientists. Finally, Roth and Bowen suggested that students just used different problem-solving techniques when out in the field compared to taking the exam.

Students encountered three different types of problems during the ten week study: research questions, “local troubles,” and problems given explicitly by the teacher. The first two problem types were referred to as student-framed problems and the third as teacher-framed problems. Students dealt with each type differently. Students developed more complex and interesting research questions as time progressed, but this was highly influenced by their interactions with the teacher. They also investigated new questions as they arose from their research, which were called local troubles. Some students initially needed help framing questions, but as time went on, they were able to work more independently. In addition, they were able to cooperatively solve problems that arose as they tried to collect data to answer their main research questions. Therefore, students were able to effectively deal with student-framed problems given the appropriate scaffolding in the form of teacher or peer guidance.

Teacher-framed problems were difficult for students to deal with, and the problems would often take on unintended meanings. There were three different types of teacher-framed problems that students dealt with. Open-ended problems were handled by students in a similar fashion as student-framed problems. However, when students perceived a correct answer to a problem existed, they would reconstruct it in their own terms, which resulted in responses that were unexpected, or not desired by the teacher. For decontextualized problems, students would input their own context to attempt solving them. One expectation of the research students conducted was that they would work mostly independently on open-ended, self-created research questions. It therefore made sense that they would become accustomed to and proficient at solving these types of problems. Problems that were closed ended or decontextualized would be more difficult to deal with because students did not have practice solving them.

Roth and Bowen also measured student attitudes and achievement, which they explored both quantitatively and qualitatively. Actual student achievement was measured via a unit test and questions on a final exam. Results from the CLES scale indicated that student achievement was significantly correlated to the classroom measures of Prior Knowledge, Autonomy and Teacher Expectations. However, when considering only the final exam questions student performance only correlated with the Autonomy scale of the CLES. Only 29% of performance could be attributed to the environmental factors from the CLES This dropped to 21% when considering only the final exam. There was no significant effect of Negotiation on student performance.

Case studies of five students were constructed using qualitative data collected throughout the unit. These case studies supported the CLES data suggesting that autonomy was an important factor in achievement. The five students chosen for case studies represented all four quartiles of achievement in terms of grade point average, and had a range of attitudes towards science. One student, Mick, was troubled and had difficulty staying on task. He did not like the open-ended lab format and generally performed poorly on assessments. He did not feel the unit allowed him enough autonomy, or let him adequately pursue his own interests. He claimed he would have preferred more attention from the teacher. In contrast, Miles was a high performer, and enjoyed the open-ended format. He understood that the inquiry lab required more of his time than other class formats. He appreciated it when tasks were clearly defined by the teacher and when teacher support was available.

Sean was a low performing student who benefitted greatly from the open-ended setting. He was generally positive, but would have liked more autonomy on choosing projects. Ellen was one of the highest performing students of the group. She did not participate well in her group, choosing instead to work parallel to her partner, and she cooperated only on field

reports. She did well incorporating her previous knowledge into the current project and enjoyed her self-imposed autonomy. Finally, Jamie benefited greatly from the open-ended format by engaging in sense-making in the small group settings. He did not, however, feel he had enough opportunity to work with peers or to use his prior knowledge.

These vignettes provided a basic understanding of how the open-ended approach influenced student learning. Lower performing students who had troubles working independently had a difficult time acclimating to the openness of the lessons and also did not like them, while higher achieving students were able to work independently and achieve high scores. Some students enjoyed the student centeredness and autonomy of the course, while others would have preferred more teacher involvement. Therefore, success in this open-ended environment was student dependent.

The authors finally attempted to draw insights into how the social structure of the classroom contributed to student learning. To do this they considered what happened at each of three levels: individual, group, and class. They found that learning focused on either the *practice* of science or the *resources* of science. At the individual level, students were concerned about making sense of what was happening. This is different from what happens in a traditional lab, where students follow along a set of directions without considering what they are doing or why they are doing it. By focusing on the process students gained an understanding of how to measure and collect data, and they learned concepts. It also resulted in them making future decisions on course of action, assessing their claims and interpreting patterns they found. In addition, as students worked in this environment they changed their understanding of how their ecozone functioned and what factors affected those functions.

Sense making was not always cogent and it did not necessarily follow the actual biological or chemical principals at work. For example, one student group spent time trying to

understand the pH of their soils at three different plots, developing a variety of reasons for its change. They focused their attention on causal factors with variables they either measured or accounted for such as plant density or nearness to a lake. They did not consider the one variable that most affected soil pH: soil type. Although students sought to make sense of their observations, their scientific *content* understanding was still poorly developed and they may have gained inappropriate conceptions of biology. While the open-inquiry approach developed student's abilities to make sense of scientific processes, it failed to significantly develop content knowledge. A similar result was found in a study by Haukoos and Penick (1983). Though this study took place with community college students, they also found an open-lab approach had no effect on learning content, but significantly impacted process skills.

Students working in small groups sought to make sense of what they saw by collaboratively taking turns to add to the development of an idea. The process of developing ideas went beyond the final conclusions brought out by these students, however. Students expressed more knowledge and understanding about an idea during group discussion than what they recorded as their final product for the purposes of grading. In addition to making meaning as collaborative groups, students negotiated with others about what to do for their experiments. The authors described these negotiations. Four characteristics of group negotiating were described, though they were not supported by examples:

1. Students worked toward a common goal, and had to negotiate differences, but only as they arose in context. Students did not purposefully seek out and explore differences in ideas.
2. Outcomes of negotiations were not predictable. Academic achievement of students did not determine the outcome of a negotiation.

3. Because students were being assessed as a group, an individual winning or losing at a negotiation was moot.
4. Arguments used in negotiations were not formal, logical arguments used to support and defend scientific research in written publications. They were natural, everyday arguments more often encountered in research lab settings.

Roth and Bowen attempted to relate their descriptions of group negotiations in this classroom setting with an authentic research setting. They suggest that student behavior in the group does not mimic scientist behavior in research labs. However, the argument can be made that the open-inquiry experienced by students also did not mimic the authentic research conditions experienced by scientists. Another problem, though, was that Roth and Bowen did not provide any evidence to suggest that their interpretation of how scientists negotiated in research settings was accurate.

Students were also able to gain extra knowledge about their systems through peer group discussions, even when the knowledge was not used for assessments. These informal clarification discussions between group members reflected Vygotsky's ZPD (1962). Students in peer groups were able to interact to combine their understandings to form a more complete whole.

The problem with this was the example used to exemplify it. In the example provided by Roth and Bowen two students were trying to determine why the soil was wetter at the base of a slope versus the top of the slope, and quite dry further out into a field. A female, Ellen, was described earlier as being a very strong student who would rather work independently than in a group. Ellen first pointed out the pattern of soil moisture, and suggested it was weird. Her partner Damian, was a male who was not as academically strong as Ellen. He used the term "softer" to describe the soil, which Ellen immediately restated with the words "wetter" and



“moister” rather than “softer.” Damian suggested that the leaves in the canopy prevented evaporation, a comment Ellen ignored. Instead, she suggested that the water had all run downhill. Damian passively agreed with her and she ended with, “Well, I got it figured out.” There was no indication that Ellen had used her conversation with Damian to expand her understanding of what was happening in this situation, or that Damian accepted Ellen’s explanation for soil moisture. It was likely that both factors were important in soil moisture, but Ellen appeared to patently ignore Damian’s suggestion, preferring her own interpretation. It was not clear from the presentation of data if either Ellen or Damian actually incorporated both types of reasoning into their collective understanding of soil moisture.

Roth and Bowen included a section on off-task behavior in their discussion of small group dynamics. However, some of the behaviors described were individual tasks such as day-dreaming or making intense observation of irrelevant objects. Roth and Bowen suggested that while these behaviors seemed off task, students actually drew conclusions from them. They justified this with two anecdotal examples of students developing ideas despite off-task behavior. The individual pace of students influenced how much they accomplished, but a slower pace was not necessarily indicative of wasted time. Also some students had difficulty trying to formulate questions. Students who were the most teacher-centered tended to have the most difficult time. Day-dreaming, attention to irrelevant objects and difficulty formulating questions were all characteristics of individuals rather than groups. It was not clear why they were described in a section intended to relay information about the social construction of knowledge. The only off-task behavior that did stem from social interaction with small groups was the tendency for students to engage in off-topic conversation while walking to and from their study plots.

The community of the classroom, and how knowledge was passed between groups within the community was also explored. In this case, knowledge diffused through the classroom in a way analogous to a network. Knowledge traveled through lines of interested individuals. This happened when two groups independently decided to use graphs to display some of their data, after which the use of graphs spread through the other groups. The same happened when one group started to use a balance to provide evidence that sugar did not disappear when dissolved, and when another group used their own soil testing kit to collect data. This trickling down of information only occurred when there was ample talk between groups. When isolated, ideas did not travel. Also, communication between groups was no guarantee that an idea from one would be transferred to another. In order for the idea to transfer, students in the second group had to recognize that task as being relevant and useful to solve their own problem.

Roth and Bowen drew several conclusions from their research. One was how much students learned that stretched beyond what was generally assessed. This learning included knowing what resources were available, where to find them, and how to use them. As students interacted with their ecozone, they also increased their biologically appropriate concept knowledge. However, this claim was not clearly supported by the data presented in the paper. Although students were given a content test, there was no discussion about whether students made appropriate gains on the exam. In fact, the instructor of the class was frustrated by the outcome of the exam results. So, even if students were gaining knowledge, they did not do so in a way that reflected learning of the assessed content goals, assuming the exams used in the study were reflective of the primary learning goals of the unit. This was unknown as the assessment was not described or reported as validated.

A second claim was that the research supported social learning theory, with students collaborating to extend their understanding of a topic, as well as using tools from other groups to solve problems. In addition, student performance in group work was not necessarily linked to their academic or social standing. In other words, lower performing students could and did significantly contribute to the group. However, the student population was extremely homogenous compared to a normal public school setting, and this may not be consistent in more diverse classrooms.

Finally, Roth and Bowen pointed out the difficulty of getting small groups to interact, as well as finding ways to ensure that information got passed accurately, from one group to the next. For example, in one problem solving episode, one group interacted with two other groups who were using a graph to display their data. Despite these two interactions, the group did not choose to make a graph, which would have been the most appropriate course of action for the activity. In addition, another group did not interact with other groups at all, and did not come up with using a graph on their own. A third group decided to make a graph only because the other groups were doing it. The problem was ensuring that all groups communicated with each other and that the exchanges were such that they influenced the conceptions of group members.

This paper provided two insights into research based on apprenticeship theory. First, any research based on Lave and Wenger's LPP theory should consistently define the ideas of both legitimacy and peripherality. The Roth and Bowen paper suggested that anyone can be dropped into the community at any point, including at the level of an expert scientist. Neither idea is an accurate representation of LPP theory.

Second, apprenticeship theory should be used to answer questions relevant to sociological learning, versus constructivist learning. Constructivism focuses on the individual, while sociological learning focuses on communities. Roth and Bowen attempted to do both in

this paper, but by including both, the research became confounded. There is no way to explain one in terms of the other because they are related, but mutually exclusive approaches to learning.

The Roth and Bowen paper was the only one that was found that used a strong apprenticeship framework and employed an empirical versus descriptive approach. Selover, Dorn, Brazel, and Dorn (2003) focused on an activity for 8<sup>th</sup> grade students, pre-service elementary education teachers and 8<sup>th</sup> grade in-service teachers, coordinated with Motorola, Inc. However, they did not use a formal theoretical framework for their study. It was also more descriptive than empirical though it did present some data on motivation gathered through informal interviews. Other articles that could be found for middle schools were either purely theoretical or descriptive (Bencze & Hodson, 1999; Griffis, Thadani, & Wise, 2008) and/or approached the research from a non-sociocultural perspective (Gobert & Pallant, 2004; Svarovsky & Shaffer, 2007; van't Hooft, 2005).

#### Simulation Models at the High School (9-12) Level

It was difficult to find studies discussing simulation models of apprenticeship in high school science classrooms, because there was an emphasis on participatory programs at this level. Research on authentic teaching in the 9-12 classroom focused primarily on program or theoretical descriptions (Baumgartner & Zabin, 2008; Hapkiewicz, 1999; Richmond, 1998). The study discussed below is empirical in nature, and it adopts a sociological perspective but it did not partner with scientific laboratories to provide an in-class experience for students (Nicaise, Gibney, & Crane, 2000).

Nicaise et al. suggests that schools in the United States are teacher centered and lack the integration of multiple disciplines. As such, students were not provided opportunities to explore science as a product of their own curiosity. Student learning focused on what was

known rather than discovering what was unknown. To ameliorate this problem, education began to pursue the idea of authentic learning, or the solving of real-world problems within a field of study that maintained realistic levels of complexity. The key was that students had to work cooperatively with their peers, and teachers had to become guiders rather than tellers. Several source citations were provided, in which authentic tasks were used in school settings. The problem was that none of the studies listed empirically researched these experiences. They were all descriptive studies. The paper by Nicaise et al. was meant to act as an evaluation of a sociologically based authentic experience.

The framework for this paper suggested that science classrooms should be like the authentic scientific research setting. The authors claimed that by using authentic tasks teachers can help “students to implement knowledge in genuine ways, ways that practicing professionals implement knowledge and skill” (80). This idea is not new. Educational reforms in the mid 1900’s encouraged an applied approach to science teaching. Scientists and science teachers taught students how to do science as it was done in research and industry. The downside to this approach was that it resulted in students gaining very contextualized knowledge about science without having a strong grasp of generalizable theory and law (Rudolph, 2002).

It is not clear that authentic science lessons do help students implement knowledge in the same way as practicing professionals because there have been no studies on this. Nicaise et al. did not seek to address whether or not this authentic approach to science teaching led to appropriate gains in process or content skills. Rather, their research question focused on student attitudes towards an authentically-based pedagogy. This study provided insight into student perceptions of authentic, socially-structured, classroom activities.

This study focused on three high school classes, all of which aimed to teach students about aerospace. The instructor of the course taught about aerospace through the use of an

authentic task, specifically a week long simulation of a space shuttle mission. Students in each class learned about their topic by physically participating in the preparation of the mock mission, which was carried out at the end of the school year. There were anywhere from 17-27 students working on the mission at any one time during the week long simulation. Each student participated through role playing a specific position based on an authentic shuttle launch, such as shuttle pilot or part of mission control. Students were forced to deal with mock emergency situations as they arose and were able to provide educational lessons to elementary school children via a broadcast of the events on local television. The simulation took place in a warehouse behind the school, and some students stayed for several days as part of the project.

The simulation was managed by two teachers, one of which was a language arts teacher whose role was to integrate writing and public speaking into the project. The other was a science instructor who used an apprenticeship model to organize his class. The teaching approach appeared to reflect the appropriate steps of teacher modeling followed by student involvement, though it was not fully described. In addition to the teachers, three community members were involved in the projects. Each helped with different areas of expertise: biological research, computer networking and heating/cooling systems.

Some students did not participate in the simulation because they did not turn in enough of their homework or because they chose not. The qualifications students were required to meet in order to participate in the simulation were not described. Limitations in student participation and resources presented a problem with these types of authentic activities. It was unrealistic to implement so that all students equally benefited or for the activity to be easily transferred to new settings. Having a large shed behind a school that had no current function and could be used to build a mock mission control shuttle system was limiting. Having three field experts willing to volunteer significant time on the project added to the difficulty of

implementing such a lesson elsewhere. Also of concern was that some students could not participate. Science education has demanded a Science for All curriculum (AAAS, 1989), which was not attained in this setting. A total of 59 students participated in the three aerospace classes, but only 27 took part in the simulation. Over half of enrolled students did not contribute to the actual authentic task, which was what their entire year of coursework was built around.

Data collected in this study included classroom observations, interviews and document analysis to respond to two questions: 1.) What does the environment look like? 2.) What do students think about it? A grounded theory approach was used to analyze the data. A total of 59 students (90% male) were involved in the project. At the end of the year a sample of 20 students were interviewed. Students were chosen for interviews based on nonprobability sampling methods, which were meant to provide a diverse group of interviewees.

Nicaise et al. found that successful students enjoyed the structure of the course, while unsuccessful students did not. Some students enjoyed and thrived in an environment where tasks were student initiated, while others floundered. One female student said the class required a certain amount of prior expertise in technological areas, something that she did not have, but would have been willing to learn. However, because others in her group did have this knowledge, they took over technical tasks, while she typed up the outcomes of her group work, a task she excelled at. As a result, she never gained knowledge on how to do the more technical or scientific tasks.

For some students the course work seemed to reflect real-world activities, while others believed they were fully scripted by the teacher and not realistic. For example, one student believed that they would not, as part of mission control, be doing tedious tasks such as wiring intercom systems. Other students simply did not take the tasks seriously, saying that they just were not interested in it enough to spend all their extra time outside of school on it. In general,

the majority of students enjoyed the experience, but many found themselves unmotivated to learn in a non-structured, unguided classroom.

In addition, there was no indication that content learning of science took place. When asked about how this activity related to science or math, many students said that it did, but few were able to articulate how. Students viewed the actual simulation as more theatrical than scientific or real-world, and most preferred to talk about the smaller group work activities leading to the simulation. Even though the classroom work was completed toward the goal of the simulated shuttle mission, students generally did not connect the two in their talk with the researchers.

The authors of the article provided several generalizations about their findings. They pointed out that because Caucasian males were dominant in the class, extending their findings to general classrooms would be inappropriate. Also, the simulation did not contribute to students' overall sense of learning science and many students appeared ambivalent about it. Student discussions about the course centered more around friendships and group work, than around content or process skills. Part of this might be influenced by the previously mentioned situation in which not all students participated in the simulation, and the fact that students felt the simulation was teacher, rather than student, oriented.

Students enjoyed and took pride in their individual small group work projects. These were not traditional in the sense that there were specific learning goals for all students, but the teacher was not concerned that each group was learning different types of material depending on their tasks. These smaller projects boosted student pride and they showed enthusiasm for their work. However, there were differences in how students perceived these small projects. Some believed they were ultimately dictated by the teacher and rarely reflected real life aerospace-centered tasks. Others thought they were student directed and highly applicable.



There were some general problems with the learning environment, including lack of resources, and lack of knowledge on how to use those that were available. Students had a difficult time self-monitoring, and without structured training or extra support, some floundered. Because the teacher was stretched with so many students doing many different projects, one-on-one time was rare and students cited that the instructor often forgot conversations or changed his mind on things without realizing it. In other words, the authentic environment benefited a small number of highly motivated students, but caused problems for those without interest or prior expertise in the project.

This paper highlighted two problems with large scale contextual tasks in the classroom. One was the same problem encountered in the Roth and Bowen (1995) paper. Students were inserted into a scientific project without having peripheral experience. The result was that those students who did not have enough background knowledge or expertise, became marginalized. For example, the student forced to type up the group work because she was unable to adequately participate in the projects. The second problem was the high allocation of time and resources, resulting in limitations on student involvement. Current reform emphasizes a curriculum that includes science for all Americans (AAAS, 1989). Programs or lessons that leave some students out from participation undermine the Science for All initiative.

#### Simulation Models at the College Level (Undergraduate)

The only empirical article that could be located with a strong emphasis on sociological learning theory at the college level used cognitive apprenticeship as its framework (Etkina et al., 2010). This paper sought to determine whether students gained scientific abilities when exposed to an apprenticeship-like activity in the classroom. Scientific abilities were defined as the important procedures, processes or methods used by scientists to solve problems, including things like collecting data, validating hypotheses or communicating ideas. In this respect it was

similar to the Roth and Bowen (1995) paper discussed earlier, but it took a more holistic view and presented a more consistent framework.

Rather than basing the support for introducing apprenticeship learning to students at an early age on the assumption that students at any age can apprentice, Etkina et al. focused on the understanding that sociological apprenticeship provides a type of knowledge called interpretive knowing, which was not generally accentuated in typical school settings. Therefore, the task was appropriate because their learning objectives were for students to gain the type of knowledge that would most likely be gained through apprenticeship activities.

This study did not insert students into the middle of an authentic experience and expect them to make gains in their understanding of science. Rather, the student experience was directly aligned with the recommendations of cognitive apprenticeship. A program called The Investigative Science Learning Environment (*ISLE*) was designed to have students “think of relevant physics principles, assumptions in the mathematical procedure, uncertainties in the experimental results, the need to confirm the results with an independent method and so on, when faced with an experimental problem” (60). Teachers modeled behavior through teacher demonstrations, coached through careful organization and structuring of tasks, and scaffolding took place through student use of course materials and instructor input. In addition, throughout all of the activities students worked in cooperative groups, another main feature of cognitive apprenticeship.

The *ISLE* system was designed specifically for traditional introductory level lecture-based physics courses. The goal of the program was for students to learn both typical physics concepts and how to approach problems as a scientist might. Students were faced with many small problems during the course of a typical lecture or lab, which they solved using a standard pattern. First, students observed and collected data on a specific problem solving event,

modeled by the instructor. Then they used available tools to find patterns in the data, developing possible explanations for those patterns. They then tested their ideas and applied what they had learned to new situations. This approach was reiterated in all of their coursework, no matter the setting.

Etkina et al. wanted to know how important design and reflection were to student learning. Two formats of the *ISLE* program were designed. One was standard, in which students were required to design their own experiments to solve problems, referred to as the “design program.” A second version allowed students to follow the same format as the design program, but left out the student design component. However, students did have to develop their own mathematical procedures for data analysis. This was referred to as the “non-design program.” Each format was implemented with students taking different sections of the same course.

Another difference between the two *ISLE* formats was the use of a self-assessment rubric. These rubrics were given to students using the design program as way to organize and revise their work. There were several types of rubrics students were given each of which were pertinent to the activities being conducted. One example was a rubric for the scientific ability of being able to “...evaluate the results by means of an independent method” (63). Students in the design group were given this rubric, which told them that it was important to devise an independent method of evaluating results, and that adequate independent methods were those that not only provided an evaluation of original results, but were also used to explain discrepancies between methods. Non-design students did not get this information. The reason for this was as a way to control for reflection, the second goal of the research. Students in the non-design program were not provided explicit opportunities to reflect on their work, while students in the design group were.

The study involved 186 college students enrolled in a physics course. The eight lab sections associated with the physics lecture were divided such that four of them used the design program and four of them used the non-design program. Students in the design labs were scaffolded through previous experience in lectures and problem-solving sessions of the course. Course instructors did not help students with experimental design. At the end of each design lab students responded to questions forcing them to reflect on what they had done, its overall purpose and its place in science. They also had to do some reading and reflection questions dealing with real-world activity. Students in the non-design labs were given the experimental procedure, though the labs and equipment were the same as in the design classes. Rather than reflecting on science processes on the end of lab homework, these students solved traditional physics problems.

After experience with their respective lab programs, students in both groups were tasked with two lab sessions in which they were required to design their own experiments to solve a problem. Data revolving around both types of laboratory experiences were gathered. First, time on task of the design versus the non-design group was compared. Students in the design program spent more time in the lab than students in the non-design group. The extra time spent in the design labs was focused around sense making activities such as discussing physics concepts, design issues, mathematical models, assumptions, uncertainties, revisions and laboratory questions. Students in the design program spent an average of 23 minutes longer on sense-making than those in the non-design labs. Part of sense making activities was discussing experimental design, which students in the non-design section were given, so they would not be expected to spend time discussing it. Also, time spent talking about uncertainty, assumptions and mathematical models would be limited in the non-design group because these would be non-issues if the experimental design was given. Rather than suggesting that designing

experiments contributed significantly to a gain in process skill, this data introduced a confounding variable of time on task into the research. It might have been a more appropriate test if students in the non-design groups were forced to spend the same amount of time in discussing the protocol, even though it was already given to them.

After 10 weeks of experience with their respective lab experiences, students in both groups were required to complete two lab sessions in which they had to design their own experiments. Student groups in each setting were evaluated on design performance based on teacher scoring of the assessment rubrics described earlier. The task of designing two labs, which were scored using reflective rubrics, allowed Etkina et al. to assess both the effects of design experience and reflection on group performance. The students in the design group scored significantly better on the rubrics than students in the non-design groups.

However, the methodological approach used in the study confounds these findings. First, students in the standard labs had 10 weeks of experience with both designing labs and using the assessment rubrics. The students in the non-design settings had no experience with either. Second, there was a time on task factor that was not accounted for. The only legitimate conclusion from this study was that students exposed to scientific abilities will learn them, and those not exposed will not learn them. This is the difference between implicit and explicit teaching, which has been studied heavily in the area of nature of science, but has also been explored in learning scientific content. This literature base suggests that students are only able to learn skills that are taught to them explicitly. Information assumed to be implicit in the delivery generally remains unlearned (Bell, Matkins, & Gansneder, 2011; Jaakkola, Nurmi, & Veemans, 2011; Khishfe & Abd el Khalick, 2002).

There were some instances in which students in the non-design group had explicit instruction on certain scientific abilities, such as identifying sources of uncertainty, but failed to

use this ability in the open-ended labs. However, the level of training received by the two groups was too different to expect equal outcomes. Scores on a traditional concept exam containing both forced answer and open-ended questions, resulted in no difference in content understanding between the two groups. Students learned material that was explicitly taught to them, no matter the approach, apprenticeship or not, and this study did little to contribute to an understanding of how well apprenticeship activities taught students scientific skills compared to other techniques.

The problem here was a methodological one, not a theoretical one. The framework used to set up the study was sound and the *ISLE* program closely mimicked that of a cognitive apprenticeship approach. The studied outcome itself, gains in scientific ability, was also legitimate. Learning how to design and control experiments is considered an important part of learning to become a scientist. This was a problem of attempting to support the use of a pedagogy in the school system by designing a study that was inherently biased toward that pedagogy. When two groups are compared but only one is actually taught how to use or is forced to use scientific abilities, there is a danger in presenting an unfair test. It was possible that Etkina et al. believed these skills could be implicitly relayed to students via their lab work, but literature about implicit learning does not support this assumption.

Another article studying cognitive apprenticeship at the college level focused on teaching scientific reading and writing (Kolikant, Gatchell, Hirsch, & Linsenmeier, 2006). In this case the reading and writing of science is defined as a problem-solving event. As such, novices and experts are assumed to each use different strategies to read and write in science. The goal was to use a cognitive apprenticeship model to develop students' abilities to read and write scientific papers. This study was conducted at the college level because in this setting novices could be automatically paired with experts who were able to model and scaffold appropriately.

This study involved designing a course around a cognitive apprenticeship model, which included the basic steps of instructor modeling and scaffolding, along with student articulation, reflection and exploration. The assignment consisted of students being required to investigate an animal adaptation that humans did not share with them, such as hibernation. They had to collect two to four scientific research papers on the topic and then compare the animal's system to analogous systems in other organisms, including humans. Students were required to write a proposal discussing their topic, which was submitted to both the teacher and two of their peers for review. The peer review was used to force students to reflect on their work, which is one of the components of cognitive apprenticeship.

Students were given three weeks to write their paper, which was divided into several specific tasks, as a way to scaffold. Three documents were provided to students, along with two discussion sessions and an evaluation form. The documents defined the assignment, gave the proposal and paper structure, and provided strategies for writing and suggestions on how to reason through the process. The discussion sessions were optional. The first was used to help students find relevant literature for their research. The second involved the instructor discussing with students his techniques for surveying literature. He then engaged students in an activity where they analyzed several papers as a group to find common structural components, such as headings and information. During the second discussion session the instructor explained to students how he chose relevant literature, following a strategy of reading certain sections in more or less detail.

Student papers were graded according to a rubric, which corresponded with the typical expectations of reviewers of a scientific paper. The instructor, though, did not act as a reviewer might, because he eased the evaluation of certain requirements. For example, students had to write a typical discussion section. In scientific papers authors put their work in the context of a

broader field. Since students were not necessarily familiar with the broader literature, this section was not evaluated based on content, but points were taken if it was missing or unreasonable.

The study itself consisted of 24 students out of 42 enrolled in the class who agreed to participate. The authors asked all students to fill out a survey to see how the different parts of the experience affected their ability to read and write scientific papers, using a four point likert scale. Only 17 of the 24 filled out the survey. In addition, 22 papers from the 24 participants were used to explore further how they performed and what difficulties they had. There was no explanation as to why the other two papers were not used. All data was analyzed quantitatively. Student scores on their paper rubrics along with their self-reported scores on the likert survey were averaged, and standard deviations were determined. No statistical measurements were reported.

Most students had never had a scientific writing assignment before (63%) and did not know where to find citations (86%). Others said they did not know where to find recent work on a topic (40%) or did not know how to get papers not carried in their library (~33%). Most students found all parts of the support assignments helpful both for this assignment and because they thought it would be beneficial to their careers. Grades on the task itself were satisfactory, according the author, but there was no explanation of what satisfactory meant considering most students (82%) did not meet expectations for the literature review. In addition, several had problems with the discussion, but were not necessarily docked points for it. Although students seemed to understand the papers they read they were not able to translate that to what they wrote, indicating that the scaffolding did not go into fine enough detail to meet this goal.



This paper was different from those discussed previously, primarily in that it was purely quantitative. The results indicated a problem with bringing apprenticeship experiences into classrooms, which was that not all aspects of learning can easily be covered in a reasonable amount of time. So, whereas students did quite well on some aspects of the papers after the extra modeling experiences, they simply did not have enough experience to be able to adequately understand all of the intricacies of reading and writing scientific work. Also, the task, in itself, was not purely authentic in that the discussion could not be written in terms of the broader literature. It was not a research paper but a review of a few articles. Trade-offs between learning objectives and actual apprenticeship were forced because of time constraints that were not applicable in authentic apprenticeship.

#### General Discussion of Simulated Apprenticeship Activities

The literature discussed above brings out several important points about conducting research on apprenticeship in science classrooms. First, there is a need to keep consistency within the theoretical framework. Apprenticeship theories, such as LPP or cognitive apprenticeship, are defined explicitly. A consistent interpretation of the theory is important. Some studies (Roth & Bowen, 1995; Nicaise et al., 2000) used an apprenticeship approach, but ignored the idea of peripheral participation or scaffolding. They conflated open inquiry with authentic apprenticeship, though the two are not synonymous.

This led to the second problem, inconsistency in outcomes. Using a sociological framework presumes that researchers ask questions related to sociological interests. While constructivist theories of learning are concerned with the individual and how they learn, sociological theories of learning are interested in describing and explaining constructs of the community of practice as a whole. Seeking constructivist outcomes using sociological learning

theory becomes problematic. The theory does not imply constructivist outcomes are possible and the measured outcomes do not reflect a deeper understanding of the theory.

Finally, assumptions about what science apprenticeship looks like are prevalent. However, there are no studies that describe the apprenticeship of scientists, so there is no way to know if those assumptions are accurate. What is needed in the literature base are descriptions of learning to become, which could then be used to guide classroom reform. In sociological theory learning is based on interactions within a normative community of practice. In order to implement apprenticeship in a classroom setting, it would be first necessary to understand the normal community that apprenticeship is based on. This is not the case with constructivist learning theory, which because it applies to the individual, can be implemented in any setting where learning takes place.

## Participatory Models of Apprenticeship Learning

### Introduction

Rather than attempt to introduce students to authentic scientific study in the classroom, several programs have been designed which bring students directly into the research laboratory. These experiences are called participatory models of apprenticeship, where individuals are encouraged to act like scientists in authentic scientific settings. Unlike the simulation model literature, there was nothing about participatory models below the high school setting. Although strong empirical studies on simulation models of apprenticeship were difficult to locate for early education, it was not impossible to find studies that at least reflected the idea. Participatory studies at the K-8 level, however, simply did not exist. Though there was no explicit reason that was found for this, the assumption was because it was difficult to bring young students into research labs with high end technical equipment and costly supplies.

However, there is a large collection of literature that involves students at both the high school and the college level taking place in participatory apprenticeships. This section of the literature review focuses on these papers with the goal of understanding how or why participatory programs affect students' learning of science. Studies that only described programs open for student participation were not included here. In addition, preference was given to research that was based on a framework involving apprenticeship. Studies were chosen for inclusion if based in the United States or Canada as a reflection of the cultural impact on communities of practice. Exceptions to any of these criteria are explained during their discussion. Even though the research here only covered grades 9-16, the literature base was much broader than that in the previous section.

#### Participatory Models at the High School (9-12) Level

*Gaining expertise.* The first study involved a research opportunity for high school students built around a cognitive apprenticeship model (Ritchie & Rigano, 1996). It points out benefits associated with participatory programs, but it also introduces conflicts of theory use, similar to those seen in simulation models of apprenticeship. This study was one of two discussed here that considered how students move toward expert understanding of scientific processes and concepts when exposed to authentic research experiences. It did take place outside the US or Canada, in Australia. An exception was made in this case because aspects of this study paralleled the simulation model literature discussed previously.

Ritchie and Rigano used a constructivist epistemology, emphasizing the need for students to both build and test their new knowledge as they learn. The role of teachers was to create environments that allowed students to use various "warrants (i.e., authority, coherence, empirical evidence) to demonstrate the viability of their knowledge claims" (800). However, they also appealed to an apprenticeship model of learning based on sociological epistemologies,

rather than constructivist ones. The attempt was made to reconcile the differences or support the use of an integrated model, which was similar to that of Roth and Bowen (1995).

Apprenticeship-based pedagogy was introduced as a way to build and then assess an individual student's content knowledge. This was the only paper that explicitly pointed out the conflict between the two theories and attempted to reconcile them. There is no reason to assume that an individual is not changing in a measurable way as they interact socially within a community of practice, even if a sociocultural perspective would not find it as useful to study that aspect.

However, the claims that the authors made about the compatibility of sociocultural and constructivist perspectives became confused once the project was explained in detail. The study involved two students, one in 11<sup>th</sup> and one in 12<sup>th</sup> grade that left school once a week to work in a chemical engineering lab at a local university. The lab leader, Geoff, explained that his approach to mentoring was very hands off, suggesting he preferred to allow students to work on their own, only meeting with them periodically for basic guidance. However, this view of mentoring does not fit the pedagogy of cognitive apprenticeship, which Ritchie and Rigano use as their framework.

In the simulation apprenticeship literature, one of the problems was the use of an apprenticeship theory, while implementing constructivist pedagogies. The Ritchie and Rigano study has the opposite problem. It sets ahead of time a pedagogical theory of cognitive apprenticeship, but attempted to apply it to an authentic research setting. Cognitive apprenticeship, however, was not meant to be a description of an authentic setting, but rather a way to teach that mimicked a theoretical apprenticeship. The specific experience of students in this study did not reflect a cognitive apprenticeship experience. It was not clear why the authors chose to apply a pedagogical approach to an authentic lab setting that did not mimic the intended approach.

There was a second point of confusion that was related to applying the cognitive apprenticeship approach to a research lab. One of the authors, a scientist, claimed that her own education did not, but should have, resembled her apprenticeship to becoming a scientist. Again, there was inconsistency between the theory and the researchers' interpretations of that theory. Apprenticeship theory does not divide learning experiences into episodes and suggest each should look equivalent to a generic model of apprenticeship. Rather, apprenticeship theory suggests that all learning experiences contribute to the overall apprenticeship of members of the community. It appeared that the theoretical framework was not fully understood before it was used to guide the research.

The data collected in this study consisted of field notes from observations of all of the laboratory experiences of the two high school students, as well as interviews with each student. The students worked in the research lab one afternoon a week for up to six months. Interviews focused on showing the students video tapes of laboratory behavior and asking them to recall what they were thinking during the episode. Data was analyzed using a qualitative, hermeneutic approach, which included giving participants the interpretations of the data as a means of authenticating conclusions.

Three major themes were developed from data analysis. First, students had to learn their laboratory skills before they could make gains in conceptual understanding. In a traditional apprenticeship the expectation would be that students would have many experiences that would prepare them for expertise in the field. These high school students took several weeks to learn the appropriate lab procedures and how to implement them correctly. After learning the lab procedures the students felt they could understand the concepts behind those procedures. The lab leader, Geoff, admitted that he did not scaffold or model lab techniques for the students, as might have happened in cognitive apprenticeship. It was not clear if the time for

students to learn would have been shorter had he done so, or if both conceptual learning and skill acquisition could have happened simultaneously with more modeling.

Another finding was that the two high school students often spent time going down “blind alleys” which both provided them opportunities to improve their skills, but also caused frustration. When students’ results were inconsistent with expectations it reminded them of times in school when they would change their data to match what the teacher wanted, rather than use mistakes to learn. In the authentic laboratory setting the students did not manipulate their data to match expectations. This was because they believed accuracy was important in this project, and because they had time to correct problems or mistakes.

These student observations reflected a difference between authentic science and what was found in science classrooms. Class-based laboratories focused on standard exercises, usually with a single correct outcome, something that did not generally exist in scientific research. This created a conflict because these “blind alleys” caused the students to become frustrated. Considering these were high performing students who were interested in science, it is not clear what the effect of a frustrating laboratory experience would be on low motivation students. The question was whether presenting this authentic science with logistical, tedious problems would actually turn off more students than the rote school labs, as they currently exist.

A final finding was that over the course of the experience the two students became more independent. At the beginning of the project the students were closely supervised by both Geoff and the lab technician. The students relied on Geoff and the lab tech for learning how to do general lab work and for developing the questions and tasks needed to progress. Over time, however, the students phased out their need to rely on supervisors and took more control over the project. This independence led to confidence in their ability to plan and implement the

research. This finding, though, was problematic because the claim at the beginning of the research was that Geoff was a hands-off supervisor, preferring to allow students to work independently. This discrepancy was neither pointed out nor explained.

The two students worked together well, but did little talking about concepts or context, while working. Neither took a leadership role, despite the fact that one was in a higher grade and had more practical experience than the other. The students had a shared understanding of what was needed and expected in the lab, but they did not discuss these things. The authors suggest that this quiet cooperation was different from what is often found in typical work situations where discussions focus on developing an understanding of who is responsible for tasks and how these tasks contribute to the overall project.

This article provided an example of how the use of sociocultural theory in education can cause complexities in research. Ritchie and Rigano acknowledged the students did not have the background they needed to enter into a research laboratory. The implications of this for the study were inconsistent, however. Sometimes this lack of background was described as unproblematic, other times the authors suggested it negatively affected the students. There was also inconsistency in how the conditions of this study reflected accepted theory. For example, first they described Geoff as a hands-off advisor and later suggested that students had high levels of scaffolding early in their project. Interpretation of the data was inconsistent because the theory used to frame the research was inconsistently applied.

A second article was located that focused on student gains in expertise through apprenticeship programs (Hsu and Roth, 2008). Hsu and Roth claimed that authentic science opportunities were important for learning and they described both the simulation and participation models as defined by Radinsky et al. (2001). They also added a third model called a “partnership” model where students and scientists work cooperatively to gather and analyze

data as part of a program. Students were placed in a participatory setting to study the “transactions” between the major players in the experience.

Legitimate Peripheral Participation (Lave & Wenger, 1991) was used as the main theory of learning in this study. The roles of modeling and scaffolding were emphasized, as was student independence inherent in cognitive apprenticeship teaching models. Vygotsky’s ZPD (1962) was also used to highlight the importance of cooperative learning. High school students were assumed to be legitimate participants to the discipline of science, and were placed in a research laboratory to engage in activities at the “center” of the community. The question was how students and lab technicians interact with each other in a participatory apprenticeship setting.

Thirteen high school students from a public Canadian high school, enrolled in an 11<sup>th</sup> grade honors biology class, participated in a program where they were placed in research labs. Their internships lasted two months and students were supervised by two scientists. Students interacted with those scientists twice during the internship. Once was at the beginning of the experience, and again at a final presentation of research results. Otherwise students interacted only with the five laboratory technicians. It was the technicians’ responsibility to devise a research plan for the high school students. Four projects were selected, all of which emphasized the role of science in everyday life. It was not clear why the lab technicians had to devise the research projects, or why students were not part of the decision making. Students spent a total of 10-16 total hours completing their projects.

To describe the interactions between students and lab technicians, data was collected in the form of video recordings of the lab settings, along with researchers taking field notes. Conversation analysis was used to analyze the data. Conversation analysis does not focus on trying to explain verbal interactions as mental constructs of individuals, but rather attempts to describe how the conversation is constructed and the role these conversations play in the



overall context. Hsu and Roth claimed they were informed in their analysis by several months of “prolonged engagement” in both the students’ classrooms and in the research labs prior to the actual internship. They also said that their findings were validated by discussing them with peers who had no vested interest in the study, which led to adjustments to their claims.

Because the lab technicians had no teaching experience, data was analyzed around looking at how experts in science, but not education, might teach novices. Five discursive strategies were found that showed the technicians not only affected the students’ understanding of the experience, but the students also affected the technicians’ ability to teach. The following themes in the discourse between the two groups were found: (a) clarifying presuppositions, (b) reformulating retrospective instructions, (c) further explanation, (d) connecting previous and upcoming practices, and (e) reflecting science practices.

Only one of these, reflecting on science practices, is discussed in detail here and only as a way to exemplify two fundamental problems with the research. First, the key finding was that the students learned from the technicians but also that the technicians learned from the students. The problem was that this should have actually been a starting assumption, as LPP theory explains that in apprenticeship the community is in constant flux, with all parties affecting each other’s ultimate behaviors. This is why there is no “central” location in a community of practice. As old-timers continue to interact with new-comers in various ways their position within the community continues to change.

Second, the examples Hsu and Roth used to exemplify changes in knowledge or behavior were forced. For example, the last claim was that discourse provided opportunity for reflecting on science practice. It was suggested that the line between expert and novice was not clear and that novices also had their own level of expertise they contributed to the community. The evidence for this claim was a discursive episode between Nora, the technician, and several

students (Cindy, Joe and Kelly). Nora asked if someone would like to try to filter a small water sample, as per her previous demonstration. Cindy volunteered, but had problems with getting the filter paper out, finally ripping it. Nora offered support and suggestions and Cindy clarified out loud how it might be best to remove the filter. Finally, Kelly suggested that Cindy just hold the filter when trying to pull, which Nora supported by affirming this suggestion and then added that it should be held loosely.

Hsu and Roth suggested that this demonstrates that Kelly had some expertise to contribute to the group, even though she had no more experience than Cindy. They also suggested that since Nora supported her idea, Nora had learned a new way of explaining how to do this task, expanding her own expertise. Therefore it was not possible to tell the difference between experts and novices and so it was not necessary to draw boundaries between them. However, there was nothing to suggest that Nora had never thought of this before, but just did not say it, that she ever described it the same way again, or that she even actually thought this was a good idea as opposed to simply agreeing with it knowing it would do no harm and would make Kelly feel good. In addition, Kelly's statement, "hold just the filter," says little about the technique when compared to Nora's qualification of holding it loosely and then pulling. The entire episode was 33 lines long, with Kelly's statement only two of those. The suggestion that this single statement was equal on all levels to Nora's expertise was an overstatement.

The terminology of expert and novice were not used in Lave & Wenger's work. They preferred to use the less definitive "old-timers" and "new-comers." Wenger (1998) described the relationships between these individuals. He suggested that newcomers were apt to contribute new ideas to a community of practice, not because they were looking to change it, but because they were trying to form their own identity within it. The previous trajectory of new-comers had given them different experiences than old-timers. New-comers were trying to

reconcile their own differences with the accepted traditions so as not to cause discontinuity. At the same time, old-timers tended to outwardly accept new notions of doing things because they were looking for ways of giving old practices “new wings.” The theory that Hsu and Roth used as their research foundation suggests that experts and novices will interact in just the way they have described. If the goal of the research had been to test this aspect of LPP theory, then the findings would be legitimate, but that was not the stated goal.

Throughout the findings of the paper, Hsu and Roth referred back to the idea that their data suggested distinctions could not be made between experts and novices. Two years previously, Roth co-authored another paper which drew the same conclusion (Roth & Middleton, 2006). It was not clearly explained if Hsu and Roth attempted to exemplify the original study in a new setting, or if they had different research goals and the idea of defining expert and novice came out of the data. Either way, based on the weakness of the presented evidence, it appeared the authors knew what they were looking for ahead of time and interpreted the data to support their preformed ideas.

*Gaining content knowledge or process skills.* One article was found that studied how participatory apprenticeships contributed to learners’ understanding of either content or process skills (Lewis et al., 2001). This article took a different stance on apprenticeships compared to previous articles described here. It was not purely participatory apprenticeship because high school students were given both classroom and laboratory experiences, but they did so during the summer at a local university, not during the course of the normal school year. In addition, it was not at all founded on any kind of apprenticeship theory. The article did not, in fact, mention any kind of learning theory, claiming only that teaching students about the topic of biotechnology is important and teaching them earlier, rather than later, is beneficial. This article also served a dual purpose, both presenting the results of the research the students

conducted as well as trying to convey what was learned from assessing faculty and students on the experience. For the sake of space and relevance the findings from the student research projects were not described here, as they were purely scientific.

For the study a total of seven high school students, and one eighth grader, were involved in a five week summer course on biotechnology at a large mid-western university. The program consisted of both lecture-based learning as well as laboratory-based practicums. The difference between this and a typical lab class was that the research conducted here was original and novel. At the end of the experience students and instructors were asked to fill out evaluations about the program and what was learned. In addition, any comments or challenges that came up during the program were also used as a data source.

The instructors (N = 5) and students (N = 7) were given different likert scale assessments that covered several areas such as program design, personal experiences and personal commitments to the experience. The goal was to gauge learning and student perceptions of the activity. No specific study questions were given. Data was analyzed quantitatively, but rationale for responses was also provided, based on interviews. There were two key findings from this research. One was that the instructors believed students made gains in both their content understanding of the material and in their process skills. In addition, students believed they had the competency to be successful in reaching the research goals of the program.

The innate problem with both of these claims was that they were based primarily off of personal belief statements, and the supporting quotes from the interviews lacked conviction. For example, to support the claim that “students successfully exhibited cell culture techniques, including accurate pipetting, sterile technique and cell splitting” (35) a quote given by a student in a public media interview was given. The student said they learned to culture cells in a petri dish, grow them and keep them alive. Culturing, growing, and keeping cells alive is not the same

as pipetting, using sterile technique, or splitting cells. This article did suggest, however, that students learned process skills while in the laboratory setting, even if they did not have those skills before. However, they did not provide reliable evidence that students were able to learn content.

*Gaining understanding of Nature of Science.* The study discussed here was conducted as a way to consider how authentic experiences in research laboratories led to changes in high school students' conceptions of the nature of science (NOS) and the nature of scientific inquiry. (NOSI; Bell et al., 2003). Unlike some of the other articles in this literature review, this paper did not use a sociological theory of learning as their basis for research. The focus was on the use of authentic experiences as a way to familiarize students with NOS and NOSI. This study was conducted using a scientific apprenticeship program to see if students changed their conceptions of NOS or NOSI, and if so, what elicited those changes. An apprenticeship model was used because it provided opportunities for both implicit and explicit experience with NOS.

There was no attempt to combine sociological and constructivist approaches in this paper. Changes in cognition were studied in response to a specific learning experience. That learning experience was chosen because the approach best addressed concerns that typical authentic experiences assumed students learned NOS and NOSI even when they were implicit in the activity, versus part of explicit instruction. There was no conflation here between attempting to use a sociological theory of learning to answer constructivist questions. This study provided a good example of how research could be framed to avoid conflation of the data.

The apprenticeship experience was an eight week summer science program for students entering into 12<sup>th</sup> grade. Students had to apply to get into the program and were chosen based on rigorous standards. Once accepted, students were asked first to read the scientific literature concerning their topic of research, and then participate in authentic laboratory-based research.

The program insisted that students be exposed to all aspects of the laboratory. The laboratory leaders could not just give the students “grunt work” to do. The experience was intended to cover a range of science skills, such as data collection and communication of results. Some students were also allowed to pursue their own research questions.

There were two points that came out of this research design. First, like in several apprenticeship programs, students were chosen after an application process, suggesting they were high academic achievers. For the purposes of designing a research program, this was probably an important requirement. However, one reason for educational reform in the United States is because it is believed that science remains inaccessible to the population as a whole (AAAS, 1989). The intent of apprenticeship programs was to introduce the inquiry skills needed for developing scientific literacy. When these programs have strict acceptance criteria, they remain inaccessible to the majority of students. Also, laboratory mentors were explicitly told to allow “...the apprentices in all aspects of research, and not merely the grunt work often assigned to temporary laboratory employees” (490). This made student experiences inauthentic, giving a false impression of what scientific research actually entails.

It appeared that there was a conflict between what the general literature suggested ought to be done and what doing that actually means. Bell et al. (2003) cited AAAS (1989) and the NRC (1996) to emphasize the need to increase students’ involvement in authentic programs. To do this, though, only the best students were allowed to participate, leaving many out. When students were integrated into the community, the authentic experience was undermined by changing the interactions students had within the lab.

The study itself involved ten students (six females and four males) chosen from the applicants for the program. All ten were given the Views of Nature of Science, Form B (VNOS-B) both prior to their experience and after. The VNOS is an open-ended assessment consisting of

six generally context-free questions. The limitations of the VNOS-B were adequately discussed in the paper. Two questions were added at the end of the assessment, which were meant to measure students' conceptions of scientific inquiry. Students were interviewed about their responses to the VNOS-B questionnaire, and they were asked to provide additional information about the apprenticeship experience. In addition, the research mentors were also interviewed about their thoughts on the program and their impressions of how NOS and NOSI were used during the experience. This information was used to produce individual profiles of understanding of NOS and NOSI for all student participants before and after the experience.

Student experiences in the program were not videotaped, though they were observed, with field notes taken. Mentors were not given the VNOS-B to assess their understanding of NOS and NOSI. Not assessing the mentors' conceptions of NOS or NOSI was problematic because it was then difficult to know what they might teach students about NOS. If the mentors had naïve views of NOS themselves, there was no reason to assume they would pass on appropriate views to their students and therefore it would be difficult to discover if students' views changed or remained the same based on the innate experience or because of explicit talk from their mentors. The results discussion did not ameliorate this because although the researchers did speak with mentors about their views of nature of science in interviews, only a few described them.

Initially students tended to overemphasize the empirical nature of science and failed to consider the idea that changes in perspective might affect changes in theory, versus simply the accumulation of new data. They believed that laws were static and factual and that theories eventually turned into laws. Although all students believed science involved creativity, they focused it on the initial development of a scientific project, rather than distributing it

throughout a study. Many believed that science was subjective, but believed the goal of science was to minimize this subjectivity.

After the apprenticeship experience there was very little change in student views. When probed, few mentioned the program as a source of or as affecting their ideas of NOS. One student did experience a change in her views of the nature of theories, realizing that there could be multiple theories to explain the same phenomenon. This change in perspective was a result of an experience she had during her field work with a scientist. She was also led to a more complete view of the role of creativity, understanding that it was important during data analysis as well as in developing a methodology. Only one other student changed his views of NOS. He understood that the structure of an atom was not directly visible, but was known based on inferences from patterns in data. He did not attribute this change to the apprenticeship experience.

Many of the students made gains in their abilities to perform the basic processes of science required for their own study. These included things like improved understanding of laboratory safety, more expert use of specialized data collection equipment, and using their data to draw conclusions. Students were not able to participate in the aspect of formulating initial questions, though several were able to design their own methodologies to answer those questions. However, few of them showed an increased understanding of the nature of scientific inquiry as demonstrated by the questions on the VNOS-B.

Students continued to believe that there was a single scientific method, despite all apprentices using a variety of methodologies to accomplish their research. Several students conducted studies that used very controlled methodologies, so their apprenticeship experience may have reinforced the notion of there being a single scientific method. Three students did say that there was no single scientific method, but they did not attribute this understanding to their



own research. The second NOSI aspect the authors looked at was that of the importance of testing ideas. Students came into the study with an understanding that ideas needed to be tested, and there were no changes after the experience. However, none of the students suggested that it would be important to have prior knowledge about a topic before testing it, or that the results of those tests might lead to further questions.

Students did not change their ideas about NOS or scientific inquiry substantially during the experience. Next, Bell et al. considered the role the mentors played in the research experience. This was where the problem of not assessing mentors' views of NOS and NOSI became important. Mentors believed students learned a great deal from their experiences, especially process skills associated with scientific research. They also believed students had many opportunities to learn about and engage in scientific activities such as testing ideas and using various methods. Only two said anything about what their students may have learned about NOS, one of whom emphasized the tentative nature of. Some mentioned their own views, again focusing on tentativity. There was no way to tell if mentors reinforced student thinking about science because they had the same basic views and therefore conducted their labs as such. Since students generally did not change their views, there was no way to compare to mentors of students who did change.

Bell et al. made the claim based on the data presented here that students will not learn the nature of science simply by doing science. Most of the mentors suggested explicit teaching of NOS was unnecessary because students would learn it intuitively. The authors alluded to a second potential outcome of this research. Learning to become a scientist, which included an understanding of its nature and inquiry, was a process that took years, not weeks. Time was a factor mentioned by the mentors, suggesting the experience was too limited to expose students to other important activities like library research or publishing. Given a normal path of

apprenticeship, it was possible that learning about NOS and NOSI took time to develop and learners could only really understand it after having many experiences in the community of science.

*Conclusions.* Asking high school students to participate in apprenticeship like research programs did not appear to significantly advance their expertise or change their conceptions of either scientific concepts or nature of science. The reason for this might have been because students were not cognitively ready for the experience, since it was out of step with a normal apprenticeship experience. It might also be that their experience was not appropriately scaffolded by mentors. Students did, however, gain process skills directly related to the research they were personally conducting.

In addition, access was an issue. If the goal was for population-wide gains in scientific literacy, then these programs were unrealistic. In most cases, only a limited number of highly motivated students were able to participate, which excluded those for whom science was uninteresting or difficult to grasp. Limited access was compounded with limited exposure time, and a false representation of what science does look like, especially when there was no development of questions, if methodologies were predetermined, or if experiences purposefully lacked any mundane or repetitive work. This was not to say that these experiences were not valuable, as they appeared to generate interest in students, and taught them valuable lessons about scientific endeavors, however, they did not suggest that providing high school students with an opportunity to work in a research lab would lead them any further down the path of becoming a scientist.

#### Participatory Models at the College Level

The question was whether it might be the case that students at higher levels of education might have better, more productive experiences in apprenticeship activities than did

high school students. Empirical literature on participatory models of apprenticeship at the college level was difficult to find, perhaps because it might be assumed that by this time students were already a part of the community and therefore the experience was not special. The exception to this was papers about Research Experiences for Undergraduates (REU) programs. REUs are NSF funded programs, which encouraged organizations to implement research opportunities for undergraduate students. There were several articles about REU programs, one of which was included here. However, many of these tend to focus on program descriptions, rather than on empirical evaluations of outcomes from the program (Ellington, Wachira, & Nkwanta, 2010; Gentile, 1988; Russomanno et al., 2010; Yarnal & Neff, 2007).

*Gaining expertise.* This study investigated the role mentoring played in graduate students' learning to become expert scientists (Dolan & Johnson, 2009). It was the only article that focused attention on the graduate student and was therefore an important contribution to this review. Involving undergraduate students in research had become typical across the United States, and these experiences led to increased confidence or improved process skills. However, as these experiences became more popular, it was impractical to have one faculty member mentoring their own students and the undergraduates involved in research. Therefore, experienced Master's and Doctoral level students or post-docs took on the role of mentoring undergraduates. Dolan and Johnson were interested in this unique situation where an individual was both expert and student, and how graduate students interacted with both the undergraduate students they mentored and the faculty they were mentored by. They were also interested in what role age played in these relationships.

Undergraduates might have benefited more from being mentored by graduate students because it created the appearance of a safer environment. Graduate students might have benefited from being mentors by improving their self-awareness and from the basic enjoyment

of collaborating. However, there were also problems with these relationships. Some students in undergraduate research experiences felt that they did not get enough guidance, a problem that might be increased if their mentor was another student. These relationships may also have inadvertently bred competition as both the graduate student and the undergraduate student fight for their mentors' time. The risk was that negative experiences were a better predictor of future performance than were positive experiences, indicating that if the experience did not go well it could severely impact the students' decisions to continue.

The theoretical framework used in this paper was one of mentoring theory, which "...explores the outcomes realized for the mentor" (489). In this case, the mentor was the graduate or post-doctoral student who was working with the undergraduate on research experiences. In the mentoring research, there has been a failure to not only consider the impact of the expert on the protégé, but also the novice on the mentor. Setting the study at a research university offered several advantages in accordance with mentoring theory, including the triad of mentoring relationships (undergraduate-graduate-faculty), the nested nature of those relationships, and the fact that the laboratory developed its own environmental characteristics.

This study did not use a learning theory as its basis, but instead was looking at the experience as a mentorship. Mentorship was different from, though related to, apprenticeship. Mentoring was defined as a relationship between two individuals where one was an experienced mentor and the other was a novice protégé. The key aspect of a mentorship, rather than a relationship or friendship, rested on the fact that mentoring was specifically done in the context of advancing the protégé in a work-related capacity (Ragins & Kram, 2007). Although apprentices were also new-comers to a field, working with old-timers to advance in their work, the sociocultural basis of apprenticeship made it a much more complex situation. In apprenticeship the focus was not on a single relationship. Mentoring focused on the interactions

of the mentor and mentee; however, apprenticeship did not separate this explicit relationship from others that influenced a pathway of learning to become. In addition, apprenticeship was a much longer process, spanning the whole learning experience of a newcomer, versus a single short-term relationship. Here, the assumption was made that mentorships would form between graduates and undergraduates and that these relationships reflected the typical definition of mentoring.

The questions for this research were threefold: 1.) What motivated graduate students to act as mentors? 2.) What did graduate students gain from the mentorship experience? 3.) What challenges did graduate students face in mentoring? Seven graduate students and one postdoc involved in a large molecular biology laboratory in the United States were studied. This lab was chosen because it had an atmosphere that encouraged and actively sought undergraduate researchers. A mentoring relationship was defined only when it was explicit and sustained over time. Eleven students were identified as having served as mentors and all were offered the opportunity to participate in the research; eight students agreed. These eight had mentored anywhere from one to five undergraduate students during an initial observation period which was not explained or defined. No formal protocol was in place for matching students with mentors. By the time the study took place only one of the eight mentors was still doing research in the laboratory. Four had moved on to faculty positions and the other three had positions in non-academic organizations.

All eight participants were interviewed only, as the authors claimed that it would not have been feasible to do observations or videos of the actual experiences. The interviews were semi-structured and done in person or over the phone, lasting around one hour each. The questions revolved around the mentoring experience. It did seem that not having observations of the actual experience, or interviews from the undergraduate mentees, was a significant

short-coming in the methodology. There was no way of being able to triangulate any of the information given by the mentors using the interview protocol only. The goal of this research was only to speak to the mentors' perceptions of the events, and therefore, though it would have been useful to have the extra data it was not necessary to answer these specific questions. The authors used a constant comparison method across all interviews to analyze the data. They organized pertinent quotes into categories that revealed something about graduate student mentor experiences.

There were three questions the researchers were interested in and so the results focused on the motivations of graduate student mentors, what they gained from the experience and what challenges they faced during the experience. Each student reported at least two different reasons for wanting to mentor undergraduates. Most of them were referred to as instrumental, meaning they met a specific end goal, or as socioemotional. Primarily, these students thought that by mentoring undergraduates they could better meet or exceed the goals of their research. All but one had been explicitly asked by the faculty advisor to serve in a mentorship role or felt that it was implied that this was part of their responsibility within the lab. All believed that it was positive, important, and beneficial for them to serve as mentors to undergraduates. Some suggested that they became mentors because they thought they would enjoy the experience.

The graduate mentors reported many different types of gains resulting from their mentorship experiences. These included instrumental gains, socioemotional gains, interpersonal gains, professional gains and cognitive gains. Interestingly, despite seven of the mentors suggesting that they were motivated by the possibility of increasing their production load only five of those claimed that actually happened. Two more, though, suggested that although more work was not done, they knew the work they wanted to do was getting done in the lab. Another

benefit was that the graduate students had more interaction with the faculty member in charge of the lab. Several of the students found they enjoyed the experience, and took pride in helping their mentee succeed. Four also said they gained confidence from the experience.

Mentors also felt as though they improved their communication, teaching and/or mentoring skills through the process. Only two of the eight mentors suggested that the experience helped them to realize the responsibilities inherent in become a faculty researcher, which led to a clarification of career interests. Seven mentors also made cognitive gains by deepening the understanding of their own work, though this was not what they had originally been motivated by.

There were fewer challenges reported than gains. Challenges fell into the categories of interpersonal challenges, socioemotional challenges, instrumental costs and external challenges. Mentors had trouble trying to gauge undergraduates' knowledge of topics, to explain concepts to them or to show them techniques in ways they could understand. Several mentors noted frustration that their protégés could not be trusted to perform tasks appropriately because of earlier mistakes. This led to micromanagement, which further limited production. The mentors also had problems trying to balance their own production with helping their mentees. The expectation of increased productivity was not realized and mentoring slowed down progress. One mentor was aware that they would lose productivity by taking on an undergraduate mentor, however they still chose to do so, indicating that there must be additional gains that outweighed the challenges. Finally two mentors were affected by things beyond their control. For example, the faculty member overrode the mentor's directions for the undergraduates, which made graduate students question their understanding of what needed to be done.

These results suggested that mentoring experiences contributed to a gain in learning to become a scientist, as part of their duties eventually became supervising students below them.

Experiences were positive overall, as reported by the mentors, and they found their experiences to be valuable in preparing for their careers. This study, therefore provided a stronger example of the interactive nature of the new-comer/ old-timer relationship than did the article discussed previously (Hsu & Roth, 2008). Not all students chose to or were able to act as mentors. It would be interesting to consider the general role of mentoring within the apprenticeship experience. This paper presented only what the mentors chose to tell interviewers. In the paper it was mentioned that the faculty member in charge of the lab was well-respected, and it was possible that the interviewees downplayed problems and accentuated gains out of deference to the lab leader. The mentorship process might have been improved had it been made more explicit, defining roles of all parties involved and having the graduate student mentors participate in training programs. It was acknowledged that this was an exploratory study with limited participants and data.

A second paper looked at how undergraduate research contributed to students' cognitive, personal and professional development (Hunter et al., 2006). Undergraduate researchers in the lab had substantial impacts on those mentoring them. The question was how undergraduates were impacted by this arrangement. This research considered both the faculty mentors and the students' perceptions of the experience, rather than focusing on a single perspective.

The need to expose undergraduates to scientific research was spelled out in the literature and large amounts of money have been spent on instituting programs designed to provide research experiences for these students. In light of this, the research described here looked at how a research experience for undergraduates (REU) program modeled after apprenticeship contributed to the growth and development of the students involved. This study took on a blended socio-constructivist view of learning, specifically highlighting Vygotsky's



(1962) ZPD theory, Lave and Wenger's (1991) LPP theory and Collins et al.'s (1989) cognitive apprenticeship. The epistemological reflection model (Baxter Magolda, 1999) converged with the idea of communities of practice because the role of the teacher in learning was to facilitate students' understanding about the ways of knowing within a community.

The goals of this study were to identify both immediate and long-term benefits and costs of an undergraduate research program, from the student perspective. In addition, the research also investigated the benefits and costs to faculty, as well as what they perceived students' gains to be. The authors were also interested in the process by which gains were made by students. The research took place in four universities that employed an apprenticeship-like approach to a 10-week undergraduate summer research experience. This meant that students were accepted into labs, were mentored, and scaffolded until allowed to begin working independently. It did not imply that the experience was anything like true apprenticeship because there have been no studies that define the process of learning to become a scientist. Students chosen to be a part of the apprenticeships had to go through a rigorous application process. A problem with this was these students were already exceptionally high performing, meaning any gains may have been hampered by a ceiling effect.

A total of 76 students across four campuses participated, along with 62 students in a control, non-REU student group. In addition, 55 faculty involved in mentoring undergraduates and 16 faculty not involved in mentoring were also studied. Data from the experimental groups included interviews covering gains from experiences in the labs and what problems arose. Those in the control group were asked to comment on a variety of factors found from data analysis from the experimental group, as a way to determine what might have been lost to those unable to participate in such programs. The use of a control and an experimental group would have generally suggested the use of quantitative design. However, the goals in this study were not to

directly compare the two groups. Instead, each group was used as a way to gather data to answer different parts of the research question. Therefore, despite using control and experimental groups, the data gathered from this study was analyzed qualitatively.

In a previous study, the same authors found that students reported gains in seven categories: thinking and working like a scientist, gains in various skills, clarification/confirmation of career plans, enhanced career/graduate school preparation, shifts in attitudes to learning, working as a researcher, and other. Therefore, these categories were used as a comparison for findings in this study. Faculty believed that students made gains in all of the same categories, except one. Shifts in attitude were more commonly described by faculty as students becoming scientists. Because of this difference, the student data was reanalyzed and evidence was found for the becoming a scientist category in student responses as well. Even though responses fell into the same categories, the perspectives of faculty and students were different. Students were looking forward towards careers, while faculty looked back at a pathway they thought students might take.

Each of the seven categories was then considered in more detail. Most (86%) faculty observations on possible student gains fell into the category of Thinking and Working like a Scientist. Faculty believed students made intellectual gains in understanding scientific processes. Students also believed they made cognitive gains, but this was not their most talked about category. Both faculty and students mentioned gains in critical thinking or problem-solving skills. Most students did not formulate their own questions for their research experience, and faculty believed that students were not ready to be able to do this. However, nine percent of student comments reflected the idea that they made gains in developing questions.

Therefore students did make gains in practical skills, but not in such things as formulating questions. However, these skills were never actually tested, rather faculty and

student *perceptions* of gains was probed. Faculty did not believe students were capable of gaining the skill of formulating questions as undergraduates, and when asked, did not claim students made any gains in this. Students felt they did make those gains, even without significant experience of having done so. This was a situation in which observations of actual practice would have benefited the data analysis as a way to triangulate the data. Both students and faculty felt students made conceptual gains in the form of content knowledge and increased understanding of connections within science. The level and detail of knowledge acquisition was different for different students. Some thought they gained a more general understanding and other felt they gained more detailed knowledge. However, the perception of gaining knowledge was different from a measured gain, which was not part of this research.

The second category both students and faculty identified was of becoming a scientist. Students more frequently phrased it as gains in confidence in their ability to do science, rather than as specifying it as learning to become. The responses in this category revolved mostly around the attitudes and behaviors associated with scientists, as well as gaining an understanding of the nature of research, the practice of science, or developing students' image as scientists. Faculty emphasized students becoming more curious, gaining initiative to do work on their own, or being willing to take risks. Students emphasized weaning themselves from relying on the faculty for help and increases in being mindful of their work. Both faculty and students mentioned gains in recognizing that scientific work could be boring or tedious, that sometimes it failed, and that it required having a certain attitude to be successful.

Faculty believed that students made many gains in understanding what scientific work involved beyond just research, such as publishing or presenting data. Although students also recognized this, they cased it in terms of personal versus professional accomplishment. Attending a conference was an interesting experience for one student, because they recognized

it as something that they might be doing someday, but they did not describe it as a regular activity of scientists, as if it was optional, and scientists could choose to go if they found them interesting or useful.

Most of the gains mentioned by students fell into the category of personal-professional gains, generally emphasizing confidence in doing science. Faculty also mentioned this, but they commented on the benefits of developing relationships with faculty. Although students mentioned their relationships with faculty, they did so in terms of being taken seriously. Students' growth in confidence often led to more independent work or progress in learning concepts associated with their research, indicating that these gains were interconnected and mutually dependent. Much of the confidence students gained came from the realization that the research was pertinent and would contribute to the broader field. Students emphasized the personal nature of gains in confidence, while faculty suggested these gains would contribute to being a professional. This was especially the case with the professional presentations students gave at conferences, which faculty valued and took seriously as a function of effecting careers, but students mentioned only on a personal level.

The relationship between the student and the faculty was also important. Both suggested that interactions grew beyond that of just student to teacher, to become equals or colleagues, in some respect. Students appreciated having faculty available as resources and faculty embraced that role. The faculty, but not students, reflected on their own long-term relationships with other faculty they still interacted with, and projected this possibility for their students' future. Some talk was also centered on relationships with peers, and faculty talked about gains in maturity and the benefits of belonging to a community of learners.

Another category discussed by both students and faculty was a refining of career or school goals. This was more popular with students than faculty. Students showed an increased

interest in science resulting in continued research past that of the summer experience. Although some students gained interest and continued in science, the research experience also forced others to consider whether they would want to do this as a career. Some decided that this was not something they would enjoy. Both faculty and students seemed to view this as a positive because it prevented them from pursuing a career that would not fit them well. However, these experiences were encouraged as a way to improve retention in the sciences. There was some argument to be made that rather than act as an effective approach to encouraging students to become scientists, they may have actually reinforced to students who were not explicitly interested that science was not a career they would like to pursue. Most of the students involved in this study had already made plans to go onto graduate school, so not only did the experience change some students minds about becoming professionals, it negatively affected strong students who had already planned on making this their career.

Both faculty and students mentioned the positive effects of the program on career or graduate school preparation. These comments were not common and for students generally reflected real-world experience. Faculty emphasized the importance of publications and presentations on careers. Students also felt that their resume or graduate school applications would benefit from the program, but none said that it might improve their career prospects. Students did recognize that the program provided valuable networking opportunities, a sentiment also expressed by faculty, but at a much lower rate. Faculty also noted several value-added type benefits, such as having someone to write letters of recommendation, which students did not mention. This may be contributed to faculty needing to document their involvement with undergraduates for their own positions. Faculty appeared to have a much less altruistic reason for having undergraduate researchers, than the desire to contribute to educational or professional development.

Finally, students believed they gained skills through their experience, but this was also ranked low on percentage of responses, though students ranked it higher than faculty. Many of the skills discussed were communication skills, along with time management, computer skills, and ability to read literature or find information. Some students also did well in developing arguments and understanding ways to defend their research, but despite the emphasis put on preparations to handle presentations and feedback, according to faculty, few students excelled at this. Since students did not get the opportunity to do any scientific writing or to help with any publications, these were not included in skills learned. Faculty often suggested that these were things students would learn how to do later in graduate school. Another emphasis was on gains in techniques and learning how to use equipment.

This research gave the perspective of the faculty advisor, on research experiences. Faculty expectations, understanding, or perceptions of the experience were different from those of the student. The faculty tended to view the experience long term, as a way to contribute significantly to the student's future career as a scientist. They emphasized the community over the individual. Students on the other hand, tended to view the experience as personal, contributing to decisions about the future. The study also suggested that old-timers in the community had developed certain expectations about student abilities based on their understanding of the discipline. For example, students were not, at this stage, capable of designing their own research questions, or that learning to write publications was something students would learn later. It was these expectations that kept them from being able to fully experience science as a true apprentice might, and it appeared to stem from innate, shared conditions within the community. Finally, this research suggested that exposing students to such programs could produce significant gains in attitude and skill acquisition, but it was also not without its risks to both faculty and undergraduates. These were not the conclusions drawn by

the authors, but those, though appropriate to address the questions of the study, did not lend themselves to the discussion here in a significant way.

*Affective gains.* The final article that was considered for this section looked at how different types of research experiences affected students' attitudes toward science (Frantz, DeHaan, Demetrikopoulos, & Carruth, 2006). This study suggested that although undergraduate research experiences might be valuable, they may not meet the needs of enough students because of the low ratio of willing research mentors to students wishing to participate. There was also still a failure in the sciences to recruit underrepresented groups, which may be ameliorated by research experiences, were they available. Another type of experience, specifically a collaborative learning model (CLM) program, "in which students worked together in small, student-driven research teams under the guidance of faculty, postdoctoral fellow, and graduate student mentors to design and conduct original experiments..." (177) might have the same effect as traditional apprenticeship model experiences.

This paper, therefore, was not advocating an apprenticeship model, but rather suggesting it was limited and other options needed to be considered. Apprenticeship was not defined here other than suggesting that students joined a lab for a short time to do research under the guidance of the laboratory leader. This research also focused on the role of these programs in retention of females and minorities, another issues not addressed in any of the previous studies.

To determine if other models of research experiences might be just as effective as "normal" apprenticeship models, a 10 week summer research program was developed with two separate research opportunities. One was a traditional experience where students joined one of 27 different neurobiology labs in the area, all led by experienced researchers, involved in independent research opportunities. The other was a collaborative experience where students

all met in a single lab and conducted pre-determined experiments, which culminated in an original research opportunity. Although there were few details of the traditional model, the description of the CLM project appeared to be more apprenticeship-like than the other. Students were given many opportunities to interact with the science, but did so in a highly guided way with sufficient amounts of scaffolding.

A total of 42 students were chosen from a sample of applicants. Students were chosen on merit, but participation was skewed to include high numbers of minorities and females. In addition, students were able to choose the type of opportunity they wanted to pursue, so they were not randomly assigned to a research model. The authors admitted this was problematic, but said they decided to forego random sampling for ensuring students were involved in a project design they were comfortable with. A total of 31 students opted to do traditional research, while 11 entered into the CLM program. Students were paid up to \$3000 for their participation.

Students in both groups agreed to spend ten weeks during the summer for the program, and were required to spend 35 hours a week on their research. The first two weeks were spent in basic classroom instruction that introduced students to neuroscience concepts. In addition, everyone was required to attend four-hour professional development workshops each week. These focused on topics such as graduate school preparation and designing effective presentations. After the class students had eight full weeks of research, which culminated in a written report in either a presentation or a journal article format.

All students were asked to complete four assessments meant to measure their attitudes toward science and neuroscience, the perceptions of their own understanding of neuroscience-related concepts and their perceptions of their abilities to perform science-related functions. Students took the surveys on-line before beginning the program, after the initial two-week



course, and at the end of the program. All four assessments were likert-scale, quantitative assessments that were statistically analyzed using ANOVA. The authors also planned on asking students to take the surveys into the future, offering \$100 to do so, but any data from these long-term follow-ups were not included in this paper.

Results indicated that neither program model improved student attitudes toward science in general. This was probably because students chosen to participate had to apply and their attitudes were already very high, creating a ceiling effect. There were some significant differences in attitudes when ethnicity and gender were also considered. Males had slightly more positive attitudes about science in the apprenticeship groups, while non-minority females did in the cooperative learning groups, but low numbers of males in the latter data was problematic.

However, over time students did significantly improve their attitudes toward neuroscience specifically. Effects of ethnicity and gender were ameliorated over time, but there were no significant differences between groups, other than slightly more negative attitudes of nonminority males in the pre-survey. Students also showed significantly improved confidence in understanding neuroscience concepts. Ethnicity and gender appeared to have no significant contribution toward confidence. Finally there was a significant trend over time in gains of confidence in science skills, with no effect of gender or ethnicity. There was a small, but significant, difference between the traditional model and cooperative model in confidence in ability to design laboratory experiments, as gains were greater in the latter.

Although there were no differences between programs, this was not a negative result for the study, which was attempting to show that a different model of research involvement could still cause gains in attitude and confidence. The net result was that the CLM programs had a similar impact on students to traditional programs and could be used since they service more

students with fewer resources. However, the study here was problematic as only 11 students chose to participate in the cooperative learning model, while 31 opted for the apprenticeship experience. This not only showed that more students preferred the traditional model, but it also did not provide a strong argument that the cooperative programs could potentially deal with a higher student to mentor ratio.

## Conclusions

The literature about apprenticeship experiences in classrooms and research labs pointed out several important items to note when conducting research in this area. First, there were several possible benefits to these kinds of activities, even if they had not all been well documented. Gains in confidence, attitudes, science skills, concept knowledge and nature of science have all been studied and to some extent verified. Like any learning experience, exposure to new ideas or activities generated cognitive change for students and novices. Not only did the new-comer or protégé benefit, but also the mentor or teacher, as they picked up on new ways of negotiating interactions with learners. Herein lay the importance of continuing to study how people apprenticed to become scientists and how that understanding was used to improve experiences in the classroom or the research laboratory.

However, despite the benefits demonstrated through this literature base, there were several shortcomings of it. First, there was confusion over what was meant by apprenticeship and how to interpret apprenticeship models of learning. Sometimes inquiry was taken as being authentic and therefore apprenticeship-like (Glynn & Winter, 2004; Nicaise et al., 2000; Roth & Bowen, 1995). Other times the ideas of legitimate and/or peripheral participants were ignored in favor of a broad view of who was considered apprentices (Hsu & Roth, 2008; Ritchie & Rigano, 1996; Roth & Bowen, 1995). In addition, attempts were often made to study individual cognition as a way to show apprenticeship-like activities were working within a sociocultural framework

(Hsu & Roth, 2008; Nicaise et al., 2000; Ritchie & Rigano, 1996; Roth & Bowen, 1995). These studies became difficult to interpret because the role of apprenticeship was not usually evaluated based on cognitive change. Taking these things into consideration, studies need to be conducted that have strong, clear guidelines for what is considered an apprenticeship experience, applying the appropriate theoretical framework to the questions being asked.

A second problem in implementing apprenticeship programs that can be found within this research was the limiting factors for participation. In classrooms, resources or time were limited and so only students that had enough motivation were able to participate fully (Kolikant et al. 2006; Nicaise et al., 2000; Roth & Bowen, 1995). In laboratories, space was at a premium, so only the best candidates for research programs were chosen, almost guaranteeing success or at least full compliance or completion (Bell et al., 2003; Frantz, et al., 2006; Hunter et al., 2006). Considering these programs were touted as a way to encourage more students to join the ranks of science, to increase interest in underrepresented groups, to boost attitudes in students who generally dislike science or to fulfill AAAS' mantra of Science for All Americans, the exclusivity of participation was disconcerting. A higher number of students should be involved in authentic apprenticeship-like activities that better prepare them to become scientists. New ways must be explored to make these experiences available for all students and not just the best future scientists.

Finally, there was little that can be said was certain in findings from the literature. Gains in learning outcomes were generally modest. Few studies measured content gains from such programs, favoring science skills or attitudes. Some used methodologies that asked participants to report back their thoughts, which did not allow for the measurement of actual gains (Bell et al., 2003; Dolan & Johnson, 2009; Frantz, et al., 2006; Hunter et al., 2006; Lewis et al., 2001). Sciences as a discipline, has a strongly developed community of practice. Ignoring this forced

researchers to guess about what the best way to implement such programs might be. There was currently no description of the community of science *as an apprenticeship* in the literature. Apprenticeship-like programs were implemented in classrooms and laboratories without an understanding of the process of learning to become a scientist.

## Descriptions of College Science Education and Scientific Research

### Overview

The next three sections of this chapter focuses on literature about educational and research experiences of future scientists. The literature that described college science classrooms and laboratories was included. These studies met the following criteria: First, preference was given to literature that was based in either the United States or Canada, as the educational systems and laboratories in other countries, as well as research labs, were not always similar. Second, they needed to be empirical or peer-reviewed, but not necessarily experimental. Instead, the literature used here was often descriptive, meant to provide information about what each setting might contribute to the overall apprenticeship experience.

### Descriptions of the College Science Lecture

Although there have been no studies that aim specifically to describe typical college science education experiences there were several ways in which information was gathered about this topic. One was to consider the resources encouraging reform in science education aimed specifically at college science lectures and laboratories (Nilson, 2010; NSTA, 2002; NSTA, 2006; Siebert & McIntosh, 2001). These books and manuals encouraged faculty to change how they taught, recommending inquiry, active, and authentic approaches to science education. The implication was that the current pedagogies inherent in college science teaching were inadequate for students learning. There has even been a new movement in science education,

suggesting faculty remove lectures from college science classrooms altogether, referred to as classroom flipping (Berrett, 2012). Classroom flipping recommended that class time be spent on activities and problem solving, with lectures being outside of class work students watched or read about independently. From an apprenticeship standpoint, however, college science lessons would have developed as they currently exist because they specifically contribute knowledge necessary in learning to become.

According to Lord (2002) college science lectures were breeding generations of couch potato students, which he ascertained from watching a colleague teaching in a large lecture hall. The instructor of the course believed it to be challenging, but during the informal observation Lord found that students came in and sat passively, some feverishly wrote notes, and only paid close attention when a humorous anecdote was relayed by the instructor. From the description given here, lectures were clearly faculty centered, and involved no student input. The only reprieve from this was humor.

The short book the proceeding story came from (NSTA, 2002) contained a collection of ideas college science faculty used to make lectures more student centered. Lack of student involvement in the classroom was the root cause of students not learning enough science and the book encouraged an array of active learning strategies from group work, to peer review, to interactive notebooks. But, despite all the suggestions, other than the unsubstantiated claim that students cannot learn in passive settings, there was nothing to suggest that all college science classrooms looked the same way, nor anything to explain why lectures still looked this way if it was so bad for the students' educational advancement.

Another NSTA press book, *College Pathways to the Science Education Standards* (Siebert & McIntosh, 2001) also suggested that college science was currently a passive process that did not promote learning. They suggested that college science should be taught with the same goals

that were currently used to drive reform at the K-12 level. From an apprenticeship perspective, though, the goals of college science were not the same as those for K-12 students. Students enrolled in college science courses were going on to become scientists, and they had to be trained for that job. It was difficult to compare an elementary science curriculum to that of a university science curriculum.

Knox (1997) echoed the fact that somewhere between 70% and 90% of college science courses were predominantly lecture, indicating that extreme reform efforts would be needed to remove it from the classroom. However, he suggested that it was not the lecture that was the problem, but rather the format of the lecture. What students needed, based on a study by Tobias (1990), was storytelling versus fact-based components. Students were unable to follow lectures because they lacked a strong narrative, and had historical components in which to situate new knowledge. In addition, Lord (2007) suggested that because lecturers asked students to read the material for the lecture before coming to class, students came in with a closed mind. Often, the reading was too difficult for students to understand so they immediately perceived the lecture as being difficult as well. Alternatively, students did not read at all, and faculty lectured in such a way that assumed they had. All of these indicated a need for reform in college science teaching, but none of it suggested why faculty continued to use these teaching techniques if they were so poorly adapted to learning.

Another area of research that could be used to provide information about the nature of college science lectures was classroom learning environments. According to Fraser (2007) this area of study focused on how the environment and personal characteristics interacted to influence behavior or learning. There have been a variety of quantitative questionnaires developed to measure aspects of the learning environment, such as teacher support or student responsibility. However, the literature associated with classroom learning environments did not

lend itself to this study for several reasons. First, much of it was focused outside the United States or Canada. Studies that compared learning environments across nations suggested that each country differed considerably in its characteristics (Aldridge, Fraser, & Huang, 1999). Therefore, using data obtained in other countries as a way to describe the US educational system would be problematic. Of those studies found from the United States alone, none were used to describe *college* science, as they all focused on K-12 settings. While these might be useful in providing some information about what high school lectures might look like, research on learning environments tended to compare, rather than describe. For example, asking whether males or females had more positive perceptions of the learning environment (Fraser, 2007).

A final type of research that can be used to contribute to an understanding about current practice in college science lectures were empirical studies looking at interventions or best practice reforms. This body of literature was problematic because it was so broad. Reform came in a variety of ways, and so examining the literature was tedious. Considering research from only one common reform, inquiry, pointed out the main problem with using this literature to develop descriptions of college science lectures. One was that reforms were often implemented without the use of a comparison to “traditional” teaching (Haskett, 2001; Reeve, Hammond, & Bradshaw, 2004; Minderhout & Loertscher, 2007; Rogers & Abell, 2008). These studies sought to evaluate the reform effort on its own terms, but did not provide any information about the alternative the reform was meant to replace. In addition, when studies did specifically seek to compare reformed courses to traditional courses, they often failed to describe the traditional course (Gill, 2011; Gregorius, 2011; Lewis & Lewis, 2005; Quitadamo, Faiola, Sanger, Johnson, & Kurtz, 2008). An example of this was a study that sought to compare community-based inquiry (CBI) approaches in general biology to traditional lectures (Quitadamo

et al., 2008). The authors take an entire page to explain what CBI was, as well as what the CBI program developed for their study looked like. There was no description of the traditional courses the control students were exposed to, apart from a chart explaining that they utilized lecture and small group work.

Overall, there have been studies conducted on what was currently wrong with college science education (Tobias, 1997), conducted from the student perspective. There have also been books and studies published to encourage college science faculty to reform the way they currently teach (Nilson, 2010; NSTA, 2002; NSTA, 2006; Siebert & McIntosh, 2001), implying that current college science education was inadequate for learning. However, there have been no studies that considered the current state of college science education in terms of how it contributed to students learning to become scientists.

#### Descriptions of College Science Laboratories

Like college science lectures, much of what was recorded about college science labs were the negative aspects that educators wished to change through reform. There have been no studies conducted on science classroom labs that considered them as a normative feature of education and described them outside the context of reform. The inherent bias in the reform literature made it very difficult to accurately describe what happened in a traditional college science lab or to provide an explanation as to why they were conducted the way they were.

Classroom labs were often referred to as “cookbook,” meaning they followed a set protocol similar to that of a recipe. Students were engaged less in problem solving and practical application of methodology, than they were in making sure they followed the right steps to get the right data. In an article described in detail later (Krystyniak & Heikkinen, 2007), traditional labs resulted in students relying heavily on the instructor for guidance, and in focusing only on being able to respond to post-lab questions at the end. The goal in reform literature was to



move labs away from this traditional cookbook style and replace it with a more inquiry approach to teaching (Krystyniak & Heikkinen, 2007). This inquiry approach was meant to more appropriately reflect the way science was actually performed in the research setting. However, as described by Latour and Woolgar (1986) research labs also, in fact, sometime focused quite heavily on prescribed methodologies that must be done correctly.

Given the differences in goals between science educators and scientists, it was difficult to know if the descriptions given in reform literature were accurate representations of what was actually happening in the classroom, or just assumptions made about pedagogies that ultimately did not coincide with constructivism. It was clear, though, that in order for reform literature to make a strong case in favor of more inquiry-based design, there should be evidence that demonstrated that classroom lab settings not only did not meet the goals of science educators, but they also did not meet the goals of scientists.

#### Descriptions of Research Laboratories

The studies described here do not focus on University level laboratories, but there have been several research projects that described scientific research laboratories as a community of practice. Three were both well-known in the field and provided detailed accounts of what happened in the research setting. All three came from early science studies research conducted in the 1970s and 1980s. Therefore, although they were not specifically related to science education, they did provide observational descriptions of scientific research.

The first study described was Knorr-Cetina's report *Epistemic Cultures* (1999), which sought to identify how scientific practice, as a culture, produced knowledge. Two sciences were examined in detail, High Energy Physics (HEP) and Molecular Biology. The goal was to investigate how these cultures worked, how they created knowledge and how that knowledge was transferred to other systems, such as societies or cultures. Most specifically, Knorr-Cetina was

interested in the “construction of the machineries of knowledge construction” (3). In other words, she looked at the *resources* used to construct knowledge, where they came from and how they provided meaning.

Knorr-Cetina first explained her own understanding of sociological research, along with providing a definition of culture, which will not be described here. The methodology for the research was described as a field study, which took place in two separate locations. The first was at CERN, which was home to a hadron particle collider. Observations here took place starting in 1987. The second setting was at the Max Planck Institute with a lab group studying the mechanisms of transcription. Observations here began around 1984. Both continued for many years. Including the author, three researchers were involved in the project. One was stationed permanently at each setting and the other coordinated the material between the two.

Beyond observing each setting, the researchers also audio-taped meetings and discussions, were granted access to all of the notes associated with those meetings, and had the opportunity to interview scientists as needed. Observations were not made constantly over years, but rather as intermittent visits, corresponding with important activities within the labs. This worked well for this situation because the time between could be spent analyzing data, the results of which were used to focus or identify further aspects to study. The result of the study was a book of over 250 pages, something impossible to provide close scrutiny of here. The focus was on the machinery of knowledge acquisition, and so the discussion here focused on this as well.

The field of particle physics used machinery that produced only signs, images that represented not the actual thing itself, but an electronically produced negative image. The image produced was not of something that currently exists, but rather of something that did exist for only a very short period of time. Therefore scientists must be able to make meaning out

of these signs, and they must do so even though the important signs were often interspersed with background noise. In addition, each detector that was used had its own kind of background noise, therefore know how to interpret data from one detector did not automatically allow interpretation from another. These were just some of the distractions that caused difficulty in understanding output in HEP.

What this meant, according to Knorr-Cetina, was that measurements were meaningless without considering the context of the machine the data was measured on. The implication was that the machine acted as an intermediate between the experiment and the outside world, and it meant that scientists working with these detectors must intimately understand how they worked. Therefore in HEP labs, more time was spent designing and constructing detectors than was spent actually running experiments. The focus was not on the actual output itself, but on the machine and how it contributed to that output.

The result was that social interactions in these research labs focused on understanding the equipment being used and monitoring human behavior with respect to that understanding. In the end, the HEP laboratories were run as closed systems, rather than open systems. Scientists in HEP settings had to create their own detectors, interpreted them on their own, as no other scientists would be able to understand the vagaries of that machine, and used their own resources as a way to check their data.

This internalized structure was then compared to the molecular biology labs, which did not maintain such an enclosed system of work. In the HEP lab, the natural world was rarely let in. However, there was a constant interaction with nature in molecular biology labs. Unlike the single large experiments, often taking years to complete in the HEP setting, the biologists participated in many small scale experiments all leading to a more complex understanding. Where the HEP scientists designed and implemented their own experiments in their own way,

the molecular biologists followed very standardized protocols which came from outside of the lab.

However, from a resources perspective, perhaps the biggest difference between the HEP and molecular biology labs was that the equipment in the biology labs was not the focus, but rather a tool to keep or store what was important. Warm rooms held specialized shakers that maintained bacterial cultures; refrigerators kept media cool; and hoods ensured that cell cultures did not get contaminated. The activity here centered around two things: One was making sure that the laboratory itself had the resources needed to maintain what was used for the second type of activity, which was experimentation. The equipment was standardized, but the object of study (mice, cells, bacteria—all living things) was the unit of noise, which caused scientists to go off script, learning new ways to trouble shoot problems.

The implications were that the protocols enlisted by the scientists produced a data output that was interpreted through cooperative talk. Everyone was accustomed to seeing the same signals, which had the same meaning if produced on the same type of equipment. They therefore took those signals, discussed them and came to a shared understanding of what was happening. This type of cooperative talk did not happen in the HEP labs because the signal was the result of allowances and limitations of a detector and therefore only understandable in those terms.

Knorr-Cetina developed a much more in depth look at the workings of these two settings, but the short descriptions above suggested what was most important for this project. Talk in different settings or different cultures, even two within the bounds of science, will be focused differently depending on what the roles of the resources are in that environment. Resources were an important part of laboratory work, and understanding how and when to use those resources led to success in the sciences.

The second book discussed in this section was Latour and Woolgar's (1986) *Laboratory Life: The Construction of Scientific Facts*. In this case the authors did not focus on one aspect, such as the equipment, as Knorr-Cetina did, but rather tried to describe the research laboratory generally, as a way of making knowledge. They focused on the social interactions of the players in a laboratory and looked at how these players deal with the environment itself and each other to produce new knowledge.

The research data for this study was taken primarily by Bruno Latour, an anthropologist, who sat in, as a stranger, on a laboratory at the Salk Institute. He made observation and took notes of what was happening around him, along with audio recordings of the events. Latour and Woolgar used this information to develop an impersonal and purposely skeptical view of scientific developments. Latour positioned himself as a complete new-comer, working under the guise that the idea of scientific research lab was wholly foreign, never seen or heard of before. This arrangement was justified by suggesting that it was important to begin learning more about science without asking scientists directly, but rather through simple observation of what was actually happening.

According to the observations made by Latour, the laboratory was composed of a variety of men and women doing a variety of jobs, each taking place in its own specific area. Those working in one area, doing one type of job, rarely went to other areas. In addition, each type of activity had some sort of output, often alphanumeric or symbolic. The ultimate goal was to coordinate these outputs, combine them with resources from the outside, and produce an article that was publishable. The problem with this, from Latour's perspective, was that writing an article for publication did not appear to be equal to being a neuroendocrinologist, which is how the scientists within the labs identified themselves. Therefore, the culture under study here became readers and writers of neuroendocrinology literature.

Interest lay in how those pieces of written information were produced and accumulated. Though certain pieces of equipment seemed important in producing written information, not all were. The example used in the book was that pipetting could still be done by hand, even if the automatic pipette was taken away, but if the gamma counter was removed, there was no other way for the scientists to measure radioactivity. However, the equipment itself was a certain indicator that this lab focused on neuroendocrinology, which included things like “bio- and radioimmuno-assays, the Sephadex columns, and the whole gamut of spectrometers...” (65). This particular field of study was also deeply entrenched in the sciences that existed before them. Culturally, they took the most pertinent parts of those disciplines and applied them directly to what was needed in this new field. Neuroendocrinology could not exist without the existence of past scientific culture.

An understanding was developed that the output of publications was the main focus of the laboratory and that much attention was paid to how that information was being received by others outside of the lab. In addition, information published from other places was also taken seriously. Output from individual devices was used to produce those publications, and it was those publications that eventually decided what new knowledge was incorporated into the larger community. If it was convincing enough, it was integrated, but if not, it sat there, known, but not accepted.

However, the question then became, what was it about one piece of information or another that allowed it to become a fact of science, accepted by the community, versus simply disregarded. The development of a fact became difficult to categorize. In order to do so the authors had to consider facts in the context of which they were before they became facts, with an uncertain future. Another problem was that each fact could be used differently by different communities. Therefore, there was no sure way of inferring how or if any one community would

see its worth the same way as any other, let alone a single researcher within that community. Facts were developed through a back and forth struggle of acceptance, denial, and refinement, until they were taken for granted.

How decisions were made of whether to accept or reject information was also considered. This happened regularly through social interactions. Discourse was used to evaluate decisions through a variety of means. One was to refer to known facts, especially those that were more recent and had not been fully integrated into the community. Therefore, discussions about whether something had already been done, if it was done recently and what would happen if X took place, were meant to help identify what course of action or what piece of information might be worth looking at. Long-known facts, on the other hand, were rarely discussed, as these were already well understood by most members.

A second way discourse helped to identify what one should or should not believe was through asking questions about the correct way a protocol should be run. In the example given in the book, one scientist came to speak with another lab about a possible collaboration, but after asking several questions, one of the team members had decided that the argument for collaboration was unconvincing, though he could not say so because his boss, who was in favor of working together on this project, was also present. Not only did this interaction provide enough information for one person to decide not to want to work with this scientist, but it also showed the importance of the political relationships between scientists.

In addition, colleagues would discuss the abilities of other researchers directly, which would help them make decisions about what routes to take next, or what literature to believe. Whether or not a certain tech was reliable enough to produce the data needed to publish was important or if the data published by another group was reliable given their past tendencies, were examples of this type of talk. Finally, purely theoretical discussions could also lend

themselves to decision making, if it was clear that current theory and practice were heading in opposing or accommodating directions, which should be either avoided or reinforced.

Most of these discussions focused decision making on non-objective aspects of current work, such as situational and contextual clues from past impressions. Who was involved in the discourse was also important, but researchers in a position of power, because they held the money or the resources, might be addressed differently than those with less control. The implication was that facts, in essence were socially created because it was these social interactions that determine whether or not to put out information in the first place and to accept it once it was there.

The rest of the book continued to focus on the social interactions of players in the research labs as they contributed to things such as crediting sources. Scientists were often driven by the possible reward of being credited for their findings, and they were happy to report situations in which another prominent scientists' work or even a whole field may be tapering down and therefore no longer deserving of credit. Credit was a situational conversation, being discussed in some cases, but not others. And, while scientists were looking for credit themselves, they were also very cognizant to give credit to others where it was due, or at the very least, to share it. They could also be very upset when credit was taken from them, assumed by someone else who had not done the work. The reason that credit was so important in the research lab was because it lent itself to credibility, which in turn provided confidence for trusting ideas as facts.

The overall implications of this research pointed out the critical importance of the social interactions between scientists and the perceptions individual scientists have of their own social positions within the community played in the development of new knowledge. Facts were not created through objective understanding that something must be real, but rather by constant



negotiations of past and current knowledge, positioning, credibility and discourse. This indicated that a study of the scientific lab should include looking at the individuals within those labs, how they interact with each other and how they are positioned within that environment.

The final text discussed here was *Beamtimes and Lifetimes: The World of High Energy Physics* (Traweek, 1992). Traweek was also an anthropologist who immersed herself in the field of HEP, this time concentrating efforts at a lab in Berkley, California and another in Japan. This book, although making observations within the same field as Knorr-Cetina, went into more depth about the things that scientists were doing while working in the laboratory. Traweek also pointed out, almost immediately, that the detectors were the objects of interest in these settings, but the interest for her was in the actual process of developing those detectors and the negotiations that occurred in order to use them.

Therefore, running an experiment in the HEP lab was not simply a matter of setting up shop, purchasing supplies, hiring a crew and getting started. The colliders at each lab were shared entities, and they had only a limited amount of beam-time available to all of the different projects on-going at the site. Therefore, in order to be able to use the beam-time, each group had to propose their project to an oversight committee, which chose the projects that had the most likelihood of producing viable and important results. This meant that detectors had to be carefully produced to be able to accurately measure what the research sought to understand.

The implications of this were that most of the time spent in research at HEP labs was focused on designing, modifying, building, and adjusting detectors, while actual data collection took very little time. However, inherent in this system, lay competition, as each group attempted to have their detector and proposals in good enough shape to be accepted for the next round of beam-time allocation. The committee in charge of beam-time often had difficult decisions to make as well, because sometimes they had to choose based on theoretical

assumptions of what may or may not be possible, as planning for beam-time could take several years prior to any data collection.

However, HE physicists were constantly vying for advancement within what was a very small community that held little room for movement. This influenced how they interacted with each other, with senior personnel, and even with technicians. One scientist may move to another lab, where they felt they had more opportunities, or another may stay where they believed the social structure was ideal for advancement. Some, struggled to get into labs that afforded them a chance to excel, while others were unable to go where they needed to make a significant impact on the community. This became a constant struggle for high energy physicists and their work ethos generally reflected this.

The focus on building detectors was not the same for theorists in HEP as for experimentalists, nor was it the same in Japan as it was in the United States. Theorists worked in a world of numbers, developing ideas to be tested, but without actually testing them. The detectors, to the theorist, were simply tools to collect the data that would “prove” their theories right or wrong. To the experimentalist, though, the detector was a reflection on themselves. How well or how poorly it performs was a direct measure of the men who designed, created and implemented it. No two detectors were the same, and no one would want to create a detector exactly the same as another, as there was no glory in copying someone else’s design.

This was the case, at least, in the United States, but not in Japan. In Japan, resources were allocated quite differently, which meant that beam-time was also allocated differently. Japanese researchers were interested in sure-things versus cutting edge, and therefore the physicists there sought out detectors that had already been produced to get a signal. They did not need to build their own, nor did they need to understand how it worked. In addition,

promotion in Japan depended less on success in the field and was more traditional, with scientists being promoted as a function of time put into the community.

This book overlapped many of the themes found in the first two books discussed in this section. Resources and social interactions were very important in determining what knowledge was produced. However, it also reflected the important aspect of what kinds of tasks were most highly valued by different members within the community of practice. The tasks that were deemed most important and most indicative of advancement (credit) were those that the most time was spent on and were taken most seriously by those in the same position.

*Conclusions.* In summary, research labs reflected authentic settings of scientific endeavors. As such, during study of them, it was common to focus attention on such aspects as the role of the resources or equipment available, the role of the individual players within the community and the role of the tasks those individuals were assigned. These studies indicated that resources may be integral or peripheral players in research, depending on the setting, but that they contributed by producing the signs which must be interpreted into knowing (Knorr-Cetina, 1999). Social interactions dictated what knowledge was accepted and rejected and why, but they also influenced things like credit, credibility and advancement in the field (Latour & Woolgar, 1986). Finally, tasks focused on those that were most important for achieving success. Therefore, in HEP labs, the detector was the most important piece and therefore the tasks of scientists revolved around making suitable pieces of equipment (Traweek, 1992). However, in the neuroendocrinology labs, publishing was the main goal of the scientists, thereby putting focus on the written outputs and the tasks associated with integrating it into publishable papers (Latour & Woolgar, 1986).

Notice that all of these studies needed something specific to observe, in order to draw conclusions about their research. This “something” was often related to language because it was

ubiquitous throughout almost all setting types. Language was a trait that was reflective of the culture it was found in, and as all of the previous literature reviewed thus far suggested, both science and science education were considered cultures in themselves. If this was the case, what does language look like within those two cultures and do they compliment each other? The next section considered the idea of language use in science and science education.

#### Descriptions of Language in Science and Science Education

This section considered descriptions of language use in both science research and science education settings. It also complimented the comments above about descriptions of classroom and research laboratory settings. The goal was to establish if there were known norms in patterns of talk in each setting, and to identify overlap in language use between the settings. This provided information about where science education appropriately reflected science practice as well as where talk in classrooms differed from talk in scientific research settings.

Two types of literature were described here. One type was descriptive, in which general overviews of language use in each setting were presented. A second was investigative studies in which researchers analyzed talk to establish nuances in meanings. The literature included here was based in English-speaking settings. In addition, it did not include research that used discourse analysis conducted at the level of word meaning or finer. This level of detail was too fine-grained to provide relevant information for this study. Finally, only studies involving oral language use, versus written language use, were included.

#### Language and Learning in Science Education

In his book *Talking Science*, Lemke (1990) used many observations he had made in middle and high school classrooms to draw generalizations about language in science education.

He began by claiming that individuals learned to speak the language of science in science classrooms. He used a two-minute excerpt from a chemistry lesson to establish that dialogue in the classroom followed established patterns based on the political positioning of teachers and students. The result was a series of talk turns where each party responded to the other following a set of unwritten rules. These rules included teachers providing context to questions, while students fulfilled their obligation to respond to those questions. Both parties followed these rules because they kept the social atmosphere consistent. However, by following them, the power in the classroom remained with the teacher.

While students learned the rules of the game, allowing them to play it, they also had to learn how to talk science at the same time. This involved extracting meaning from the dialogue used in the classroom. At the same time, teachers had to negotiate the same dialogue to ensure the science content was being delivered appropriately. In addition, teachers had to balance teaching content with maintaining control of the classroom. Therefore, along with establishing rules of dialogue and teaching content, discipline was a third important aspect of language in science classrooms.

More generally, however, Lemke pointed out ways in which teachers talk science in the classroom that reflected the way scientists talk science. For example, teachers tended to use passive rather than active voice, preferring nouns over verbs and abstract verbs over material action verbs. In addition, employing analogy or common rhetoric to describe phenomenon was common. Finally though not discussed in detail here, written forms of language also followed standard patterns, such as the format of lab reports or note taking.

A second text considered here was *Doing Science: Images of Science in Science Education* (Millar, 1989). This was a compilation of studies, some of which used sociological or constructivist theory to frame research on discourse in science classrooms. The goal of the book

was to relate school science education to scientific practice. There were nine studies included in the book, but only those that were relevant here were reviewed.

The first provided information about discourse patterns in laboratories (French, 1989), specifically chemistry. The practical activities enacted by students, and the teacher's response to those activities were examined to determine how science was represented in classroom laboratories. The teacher in this study was careful to fully explain to students the protocol of the experiment, as well as potential pitfalls and how to solve problems that may arise. When students were able to properly follow the instructions of the lab, the teacher had no need to expound on the findings. However, when the intended outcomes were not realized by students, the teacher had to explain why. These explanations were set up to assume the intended outcome, or scientific fact was right, but some mistake in human behavior caused error.

In this study, there was a consistent attempt by the teacher, acting as science expert, to get the students' perspective to align with their own. She did this by first telling students the right way to conduct the experiment. Then by reinforcing expected outcomes by accepting them without comment, but explaining away unexpected outcomes by attributing them to human error. Error, in school science, was therefore accounted for by appealing to authority. Conversely, according to French, scientists ameliorated error through continued investigative research. The data presented here suggested that school science provided students with an introduction to scientific endeavors, but did so without the pretense that they were in fact doing the work of real scientists.

A second paper from the Millar (1989) book considered how students used language in classroom settings to develop or construct scientific knowledge (Driver, 1989). This was different from Lemke's (1990) observations in which students had to seek science content

embedded within standard classroom dialogue. Driver focused on the students building scientific knowledge via peer to peer discussion.

The findings indicated that while students working together were able to discuss scientific conceptual knowledge, they also relied on the teacher to help them develop explanations. Driver found, like French (1989), that despite careful planning, students did not always interpret information the same way the instructor had intended. These discrepancies led to continued discussion where the teacher had to facilitate learning. These conversations then fell into the discourse patterns described by Lemke (1990), which followed a set of rules meant to move students toward the desired content understanding. Again, in classroom discourse the instructor was trying to balance their authority, and the authority of science, with student-directed construction of knowledge. However, despite the reliance on the teacher to develop understanding, students played an important role in the learning process, ultimately dictating final outcomes.

Russell and Munby (1989) focused their research on how the nature of science and scientific knowledge were reflected in classroom discourse. They found that there were often differences between scientific meanings of language and everyday meanings of language. Conflict occurred when teachers insisted the scientific interpretation was correct without attempting to explain the difference to students. When the teacher explicitly acknowledged possible confusion inherent in scientific language, students were able to co-construct knowledge together with the instructor. In addition, scientific knowledge was not viewed as separate from every day knowledge when the teacher worked toward explicitly explaining the language.

The difference between asserting scientific truths and explaining scientific language as a construct of every day knowledge also reflected differences in perceptions about the role of authority and argumentation. In the former science was a known authority and there was no

room for arguments. In the latter evidence held the authority, and arguments were formed around various lines of evidence. The implication was that how teachers presented science linguistically provided insight into their views of the nature of science in general.

Gee (2004) also sought to describe language in science classrooms. This paper was taken from the book *Crossing Borders in Literacy and Science Instruction* (Saul, 2004), which was a compilation of theoretical and empirically based articles focusing on language use in science and science education. Gee suggested that literacy should be learned within each discipline that students were taught, versus as a generic discipline in itself. Science, in particular, demanded that students be able to understand not just oral and written language, but also symbols and figures, which represented language. There were six ways in which language was critical to science education. First, school success was dependent upon students' abilities to deal with academic language. Everyday talk was different from scientific talk, and to be successful students must be able to transition between the two. In addition, to acquire an academic language, students had to accept losing aspects of their social language. Scientific language differed from other social language because it generally lacked empathy, used objective evaluations, and quantified knowledge.

Gee next suggested that students must be able to situate social languages, including science, into an appropriate context. This was because words and phrases not only have basic definitions, but their meanings may be dependent upon the situations in which they were used. To be able to use language effectively in any one context learners required practice. It was actually the situation that gave meaning to the language. Not only did learning language in context take experience, but it also required interaction with more advanced speakers. This was necessary because the words and grammar used in language convey perspective or experience.



Students could not know what the attitudes of the discipline were without language cues from more expert members of the community.

However, as Gee suggested, students must be willing to forgo other social languages to learn and understand scientific language and attitudes. One suggested way to do this was to allow students to speak everyday language in science classrooms. Doing this, though, obscured the science behind storytelling, which was often associated with everyday language. Students might learn word or phrase definitions, but they did not learn the norms and attitudes in the context of the discipline. Finally, another limiting factor was that face-to-face dialogue tended to undermine scientific talk because dialogue could be truncated, causing confusion of intent. Oral language could be acceptably vague or ambiguous because it was supplemented by gesture and immediate context. Therefore, students who happened to understand the intended meaning of the language were successful, and those that did not understand it struggled. This supported the pedagogical use of cognitive apprenticeship-like pedagogies, which advocated heavy scaffolding and overt, explicit instruction.

Brown and Spang (2008) considered talk in the elementary/middle school setting and its effect on scientific literacy for underrepresented groups. The theoretical framework of the paper rested on the recent transition of representing language as a sociopolitical formulation. Social referred to interactions between self and others within a community or culture, and political referred to the social positioning of those individual interactions. The typical definition of political, as affairs within a system of government regulation, was not intended here. Rather, the definition of political, used by Lemke (1995) in his book *Textual Politics*, was reflected in the Brown and Spang (2008) paper. The implication was that language could be used as a way to identify oneself with a social community or culture.

In science education, research has indicated that certain students have a difficult time trying to identify with the culture of science. Therefore, if language could act as bridge between the everyday talk of students and the formal talk of science, than it might be possible to give students the ability to identify with science, even if they might normally have a difficult time doing so. However, the problem was that students actively avoid using the language of science so as not to take on the identity of science, and as a result maintain their own, non-scientific identities. The idea that students preferred their everyday language over that of scientific language echoed the findings of Gee (2004).

To combat the resistance from students in using scientific language, one instructor began to qualify his statements, using several equivalent phrases to the “science talk” and translating it into everyday language for students. This is referred to as doubletalk, and it was used as a premise for defining discursive identities for students that were inherently scientific. Ultimately, Brown and Spang sought to have students acquire scientific literacy through modeling and scaffolding using directed discourse in the classroom. Directed discourse had several steps that instructors planned for in their lessons:

1. Instructors pre-assessed students’ understanding about the topic came to understand their students’ preconsisting ideas. They also addressed early misconceptions. Student talk was undirected and open.
2. Instructors developed the content, providing students with appropriate and accurate version of events, without using detailed and difficult language. Big ideas were introduced without technical jargon. Activity in the form of hands-on/minds-on manipulation was allowed.

3. Students used specific, well-defined scientific language when speaking and writing. This was teacher moderated, and students were required to employ proper terminology during explicit opportunities for language use.
4. Finally, students were scaffolded into scientific discourse on the topic, by the teacher. They had multiple opportunities to discuss their understanding of the material with and without instructor guidance. Assessments gave students the chance to use scientifically appropriate language, without teacher input.

This purposefully designed use of double-talk was employed in a fifth-grade classroom at an urban Charter school (K-12) in Detroit, MI as a way to determine how it affected patterns of students talk and to see if student identity was developed in coordination with classroom instruction. The study took place over eight months, with twenty-seven African-American students. The teacher and the researcher worked together to develop the proper teaching approach for implementation in the classroom. The first part of the research concentrated on teacher training. Observations consisted only of two sessions, each lasting 90-minutes. Both sessions were videotaped and transcribed in full. Though this may appear to be a limited amount of time for research, language literature was often focused on rather short periods of time that were analyzed at a high level of detail.

Analysis consisted of creating event maps of the data, which were essentially time-stamped recordings of the major talk turns that happened throughout the observation, along with larger groupings of what kind of episode that talk fell under. For example, talk might revolve around review of activities or small-group discussion. The event maps were then quantified by episode. Within episodes of interest, individual words or phrases were further categorized as by the action that they accomplished. The single-word phrase, "Ok" might have indicated a change in topic or a way to get student attention.

The results provided a detailed summary of the types of talk most often used in the classroom. The two most common episodes were Questions and Responses, which reflected the emphasis in the classroom on assessing student understanding. It was not clear from the project description, however, what level of understanding students needed to have. For example, in a sample of talk transcribed in the paper, the teacher at one point asked a student what they classified in a previous activity. This was a question, but it did not imply that a student responding to it understood anything about classification, other than what object was classified, which was an arbitrary unit.

This research looked specifically at how the teacher connected themes, allowing for students to be able to use the language of science. They found that the instructor was able to use a variety of techniques for connecting the science language to the activities being conducted. This included task parallels, where actions were connected to scientific terms, or word definition, and where teachers discussed word meaning. Also of interest was how students responded to questions. A total of 46 of the 148 Response episodes consisted of one-word answers that ended the discussion. This reflected Gee's (2004) suggestion that students and teachers needed to use language more explicitly during fact-to-face discussion. Students also used other types of responses, such as written responses, those with multiple contexts, and answering with examples.

The analysis also revealed that the instructor used doubletalk to integrate everyday language of students with explicit scientific terminology. This was also picked up by students, as well, who used it to respond to questions by the teacher, indicating that they were able to connect scientific terminology to their appropriate definitions. This suggested that language and identity impacted student learning, though the examples used to support this claim were vague. Looking at the student's and teacher's examples of doubletalk it seemed that students were

doing little but repeating definitions for objects. For example, one student said, “An invertebrate is someone without a backbone, living is someone who can interact with everyday life, and the nonliving thing can’t interact” (728). There was nothing to suggest this student gained knowledge versus having just remembered facts, something that could be done using basic vocabulary practice.

In terms of data analysis, it was possible to consider meanings of paragraphs, sentences or words, but making meaning from those individual patterns became complicated. For example, students appeared to gain knowledge because their talk reflected the explicit talk of the instructor. However, an increased ability to define terms did not mean students had learned through specific language use patterns. The problem was that the research questions were broader than the analysis and conclusions drawn here. The questions revolved around finding patterns, comparing approaches to language use and seeking connections. They did not seek to elicit cause and effect of talk. Data analysis should occur in such a way that all of the data was manageable, but also so that large scale trends could be identified without believing that any single exchange was fully significant.

Another paper focused on the use of metaphor and functional grammar in college level quantum mechanics physics and how it affected students’ comprehension of the material (Brookes & Etkina, 2007). Both Lemke (1990) and Gee (2004) noted that the language of science often involved the use of analogy and metaphor. The level of analysis in the Brookes and Etkina paper focused on linguistic patterns of speech, rather than a general description of what was being said. Therefore, it did not reflect the type of research described thus far. It did provide an argument for why studies on language use in science education were important.

This article suggested that students in science education spent time representing, or trying to understand models such as graphs, tables, pictures or words, that were meant to

represent real things. Each individual representation was unable fully describe the item of study, and students must assimilate all of the models together to create a full understanding. Part of the problem students had with understanding the words scientists use to represent real things was that they did not always share the same “codes” for those words. For example, the word “state” in the phrase “the electron is in the ground state,” was taken by physicists to mean that the electron a certain amount of energy, but students may interpret this as a spatial representation that the electron was at the bottom level.

This paper was interested in the metaphors that physicists used to describe events that were impossible to see, noting that part of the need for these metaphors lay in the understanding that the English language did not have the power to describe what was actually happening. Language used to describe quantum mechanics has changed from the time of its “invention” to the present, as it was currently taught. Early descriptions were cautious, with explicit analogies, rather than generalizations. However, over time the material was turned into factual statements of knowledge, and analogies were ignored. Brooks and Etkina began looking at how these analogies, and how the current metaphors used in teaching, were interpreted by students. They described the various types of analogies used in quantum mechanics and discussed the features of metaphors that made them attractive for scientists to use. Physics and physical models had an ontology that could be identified within the grammar, and it was this ontology that determined whether a metaphor was used. The framework rested in the interconnected relationships between analogy, metaphor, grammar and ontology, where analogy was encoded in metaphor, and ontology was encoded by grammar and was inherent in analogy.

Students often had difficulties interpreting metaphors and understanding the underlying analogical system they stem from. Part of this had to do with the lack of shared meanings of

terminology used in metaphors, but it was also because students misclassified the ontology of things. For example, to physicists heat was a process, while to students it was matter. While physicists may understand that heat was a process, they talked about it as though it might be any number of other things. For any one concept they used multiple metaphors each implying a different ontology. Scientists were able to reconcile each of these and used them as they were most beneficial for understanding in that context, but students did not know what to do with these multiple representations.

The Potential Well metaphor and the Bohmian metaphor were commonly used in quantum mechanics. Brookes and Etkina described both in terms of how they were currently used in physics education, as well as their analytical origins. They compiled descriptions of each through interviews with physicists as well as through their own research of physics literature. They identified within each, all of the possible metaphors used to explain the same analogic concept. There were three for the potential well and two for the Bohmian. They video recorded a study session between a group of four physics students as they worked cooperatively on problem solving homework questions that focused on the potential well metaphor. They compared the types of metaphor used in these discussions to the deconstructed understanding of the topic in general.

For the potential well metaphor, students used an ontology of “physical object,” rather than what scientists would classify it as, which was of a process. Students discussing the question attempted to compare the situation to something tangible, such as a step in a pool of water or a megaphone, rather than what professors typically used, which was a change in optical media, for example, light moving from glass to water to air. For the Bohmian metaphor two physics students were videotaped working together on their homework. One student became confused about a question, believing that it was essentially impossible for an electron

to be in the ground state in the given situation. The trouble was that the student was visualizing the ground state to be a location, rather than an amount of energy. This student was trying to fit the electron into a literal spot, which was not where it was at, making it impossible to be there.

The result of this study indicated that students, who looked for overly literal explanations for what was said, did not always interpret the use of metaphors by physicists in the same way. Suggestions to improve this confusion included recognizing it and making metaphors more explicit to students by clarifying why or how they worked in each particular case. In addition, encouraging students to ask why a metaphor was being used or to better explain its use was also possible. Brookes and Etkina also suggested that instructors must be more attentive when asking questions, putting effort into ensuring students understood assumed representations.

While this paper conveyed the point that language use in the classroom influenced student comprehension of science, it was difficult to suggest alternatives for problems. For example, how much time will it take to convince and train all of the scientists who have used metaphors to not only understand the ontological underpinnings of those metaphors, based on grammar and the analogical development, but to also consistently change their use of traditional verbiage? Though interesting from an educational and linguistic standpoint, the ramifications were not as easy to deal with. The need was to balance student learning and interest with classroom practicality.

Another study considered how students interacted in general chemistry laboratories when taught via open-inquiry versus typical instruction (Krystyniak & Heikkinen, 2007). Open-inquiry was a practice of allowing students to design and implement their own labs in order to answer an over-arching question. It was assumed that open-inquiry was most like what authentic research looked like, where a scientist encountered a problem, and then sought a way



to address it. There was not a small amount of debate about whether or not this approach was appropriate (Kirschner, Sweller, and Clark, 2006). Because this paper compared talk in both open-inquiry and traditional settings, it was useful for describing what might be expected in observations of classroom laboratory talk.

Student talk was the focus of data collection and analysis, suggesting that student interactions in groups were an integral aspect of laboratory activity. Other studies have suggested that in traditional labs student questions and general talk tended to focus on procedure. Students assumed that their goal in the lab was to get the answers for post-lab questions, and science content was rarely discussed. In contrast to this, in open-inquiry labs, instructors interacted with students and took an active role in their activities. Also, questions were generally answered by other group members, versus reliance on the instructor. Students also asked higher-level questions in inquiry-type labs than in traditional settings. Generally, speaking, talk in inquiry settings was more focused on the topic and of higher quality than that found in traditional settings.

This study used a program called the Independent Chemistry Project (ICP) and implemented it in second-semester chemistry labs in order to study interactions between students and instructors as a way to determine the effectiveness of the program. The research took place at the University of Northern Colorado, a mid-sized institution with about 10 chemistry faculty and 15 graduate students. Graduate students taught the laboratory sections of the chemistry courses.

The ICP was a semester-long program where groups of three to four students completed an investigation of their own design. Throughout the semester students designed a question, found literature, designed an appropriate methodology, provided a list of supplies they needed and figured out how to dispose of waste. They then had time to complete their investigation,

followed by an opportunity to revise and then an additional six hours of lab to finish. Students had to produce a poster and do a 15-minute presentation of their project, along with having two 15 minutes meetings with their laboratory instructor. Graduate students in charge of labs were given an instructor's manual which outlined their role for each stage in the process. They also had to meet with the researchers prior to the lab starting to discuss the open-inquiry format and they had weekly meetings to discuss the course. According to the paper, students started work on their investigation during the 7<sup>th</sup> week of class, along with two weeks after spring break. It was not clear what was done before the 7<sup>th</sup> week and after the 10<sup>th</sup> week, but it appeared that the same students participated first in the traditional setting and then in the ICP following several weeks of normal lab work.

Two traditional labs were observed. One was on Le Chatelier's principle and the other was on acids and bases. The format of these was not described, but the activities and basic methodology for each were provided. For both, students were given explicit directions, except for a small portion of the acid-base lab where they had to design a procedure to prepare and measure the pH of several solutions.

A total of 24 students enrolled in the course agreed to participate in the study. Two teams from each of three lab sections were audio-taped specifically during the three weeks they carried out their projects, along with three instructors, one from each lab. Only the data from one of the six teams from the ICP labs was transcribed and analyzed. The decision for which group's data was included was based on audio quality and ease of transcription. The TA for this class was an ICP experienced female, and the students in the group were composed of two females and two males. They were considered a typical group by the instructor. Their ICP project centered on finding the pH of three carbonated beverages, when left open over time. They used

three techniques to measure pH and judged carbonation by the number of bubbles in the sample. They found that pH increased as carbonation decreased.

All talk in the group was transcribed, along with pauses of over 15 seconds. Data was analyzed to develop categories of interaction, using a constant comparison method. Each interaction was coded, and codes were continually refined as data analysis continued. Each interaction was coded three times to begin with. Codes were then triangulated with other researchers. Some excerpts had to be double coded because they fit into more than one category.

Analysis showed that students in the ICP portion interacted with the instructor fewer times than the group from the traditional class. For the traditional labs, student interactions with instructors spanned all of the codes, from discussing procedures, to safety, to off-task talk. However, in the ICP settings, talk focused only on what the students were working on at that time. Students in the traditional setting asked many questions, mostly about procedure or data recording. However, very few questions were asked of the instructor in the ICP setting, and those focused on safety and data-analysis.

Students in the traditional class referenced chemistry concepts much more than those in the ICP class. This suggested that there may be a conflict of goals when discussing open-inquiry versus traditional labs. While an open-inquiry lab may fulfill one type of goal, making students less reliant on the teacher, they may fail in fulfilling other types of goals, relating content to activity. The question, therefore, should not be which type of lab was more like science, but rather which type fulfilled the goals of the course.

Student to student interactions in the traditional labs tended to focus on doing calculations and devising chemical formulas. Making predictions was also discussed more often in the traditional labs versus the ICP labs. Discussions on data analysis, calculations and

conclusions were discussed regularly in all settings, but most frequently in the traditional acid-base lab and the second ICP session. Different team members also contributed differently overall to the conversations, with some very active and others much quieter. This was dependent on whether or not the instructor was present. Data also indicated that the instructor took on the role of facilitator during the ICP exercises because of the way they handled questions, allowing students to respond rather than giving them the answer.

Krystyniak and Heikkinen suggested that the ICP lab encouraged students to work independently, rather than relying on the instructor to help them understand. However, part of this might have been an artifact of the design. Since students created the project there was less need to rely on the instructor. This did not mean that students were doing what would be scientifically acceptable. In addition, one particularly marginalized student during the traditional labs, was much more interactive during the ICP activities. The authors contributed this to the fact that because he helped design the project, he felt more comfortable talking to his group and the instructor about it.

The fact that students talked about content more in the traditional lab was mitigated because this talk was limited to just that needed to respond to questions, not necessarily understanding the underlying processes. It was suggested that students did not discuss content in the open-inquiry lab because they already knew it, having planned and discussed their projects in depth already. However, this claim was not tested, nor was there any way to confirm it. Since students had already completed labs in a traditional way, it was possible they learned content from those, or from the lecture, rather than from designing their project.

Higher-level thinking might have been revealed in student discussions during project planning meetings. These sessions were not recorded so the data was not available to substantiate this claim. Another problem was that only one group was studied, which was

limiting. It was suggested that traditional labs should be adjusted to focus on allowing students to deal more intimately with content and analysis, rather than on detailed procedures.

However, it was not clear *why* students were better off being able to design and implement their own lab. Would this help them if they became scientists? Was this expected of them when they reached the research setting? Were the traditional labs teaching them things that were unimportant or not useful? If this were the case, then why would faculty set the labs up in this way at all? Were the scientists in charge of designing classroom labs ignorant of the goals they had for students and were they asking students to complete irrelevant tasks? From a sociocultural perspective the current state of classroom labs were normal and have been developed over time to be the most effective way of producing science students that could become scientists.

### Summary

Some key points arose from the descriptions of this literature. First, Lemke (1990) and Gee (2004) suggested that the language of science was different from everyday language. This was also seen in the study by Brown and Spang (2008). The problem science teacher faced, then, was bridging the gap between the two. This struggle was further complicated by teachers needing to maintain discipline, which consequently allowed the instructor to maintain authority in the classroom (Driver, 1989; French, 1989; Lemke, 1990). Therefore, one aspect of learning science content and language was being able to manage the sociopolitical atmosphere of the science classroom.

In addition, the language in science education mimicked that of science and success in either required an understanding of the patterns inherent in the language (Brookes & Etkina, 2007; Gee, 2004; Lemke, 1990). These patterns included the use of passive versus active voice, objective quantifications, and analogy. It was important to consider both how teachers used

language in science classroom and how students interpreted this language. Inappropriate interpretation caused student failures in understanding (Brookes & Etkina, 2007; Gee, 2004).

Student also constructed their own understanding of science content through shared talk, but doing so presented problems. First, without interactions with the instructor it was difficult to know what, if any, learning goals were being met (Krystyniak & Heikkinen, 2007). Also, language fell into patterns of everyday talk that conveyed appropriate definitions of terminology, but not necessarily appropriate contextual meanings (Gee, 2004). Conversely, teacher talk that was directly authoritative also created conflict, undermining students' understanding of everyday knowledge and giving a false impression of the nature of science (Russell & Munby, 1989).

Finally, these studies provided insight into methodologies used in research on language use. First, it was important to consider scope, based on research questions. Data analysis on language use and dialogue ranged from investigating basic patterns of talk, such as Lemke's findings on talk turns in the classroom, to finding meaning inherent in the single use of words or phrases (Brown & Spang, 2008). The level of analysis used to study language in any setting must be appropriate to that of the questions being asked. Also, to be useful in education, research on language should result in findings that can be directly translated into classroom settings. Although it may have been interesting to investigate student interpretations of metaphor use, the implications of the study were to suggest that college faculty should understand all of the possible ontological origins of the metaphors they used and explain these to students (Brookes & Etkina, 2004). Given that college science faculty were not linguists, the practicality of translating the findings of this study into actual classrooms settings was limited.

## Language in Science

Some aspects of previous discussions were relevant in describing language use in the discipline of science. The books by Knorr-Cetina (1999), Traweek (1988), and Latour and Woolgar (1986) all focused on using language to describe science. These studies provided information about the types of things scientists talk about while interacting within the community of practice. However, they did not describe the language itself. Lemke (1990) and Gee (2004) both suggested that scientific language consisted of regular and normative patterns that can be studied, but neither explicitly studied science itself.

Lemke (2004) provided a more comprehensive look at language in science. He mentioned the use of symbols, textbook, printouts, graphs, numbers and all of its visual representations. It was not a natural language in itself, but a hybrid of languages, which included natural language, mathematics and the representations mentioned above. It was a combination of meanings of kind, such as classification, and meanings of degree, such as amounts. To be literate in science individuals must be able to make meaning from the integration of both.

Yore (2004) suggested that language in science was used as a means to do science, as a way to construct knowledge, and as a way to communicate findings. Echoing Lemke (2004), he also claimed it was a combination of mathematics, representations, and natural language. In addition, both oral and written language served purposes in science, but those purposes were not necessarily the same. Oral language contributed to a sharing of ideas, while printed language was used as a way to document those ideas. Scientists used language to debate and present, to write reports and teaching materials, and to read what others have written. They did not tend to use language outside of their own discipline, either for personal benefit or for the benefit of others.

In learning to become scientists, students were first faced with an image of science as a noun, or an organized set of facts and concepts. However, most scientists viewed science as a verb, an inquiry into the nature of the world. Both views were integrated into oral and written scientific language. When speaking, scientists adjusted their language patterns to fit the audience they were addressing. They used gesture or common language to ameliorate confusion when speaking with the general population, but formalized their speech during conference presentations. Scientists also used language as a way to argue and discuss science, meaning they must also be effectively able to listen to counter-ideas, evaluate them and respond to them.

These basic descriptions of the language of science indicated a need for a more comprehensive analysis of the discipline. The implication, however, was that the language of science was complex and came in two distinct forms, written and oral. Knowing about one did not necessarily reflect knowledge of the other. The inherent complexity suggested that research intended to study language in science must focus on a small number of aspects in order to be manageable.

### Conclusions

The review of the literature described here raised several questions that could be addressed to fill in gaps. First, several of the studies that sought to analyze apprenticeship in science education, chose to use a constructivist approach to their research, either integrated into the framework or as part of data collection and analysis (Etkina et al, 2010; Kolikant et al., 2006; Nicaise, et al., 2000; Ritchie & Rigano, 1996; Roth & Bowen, 1995). What was missing from the literature was a study of apprenticeship that maintained a sociocultural perspective throughout. In this sense, integration of an apprenticeship-like activity in the classroom required two factors. First, the activity itself must reflect the legitimate and peripheral nature of



apprenticeship. Second, the analysis of data should focus on describing and analyzing the experience, versus measuring or evaluating individual responses to it.

A second problem raised by the literature review was one of access. Students were limited in their access to apprenticeships because of time or resources (Bell et al, 2003; Frantz et al., 2006; Hsu & Roth, 2008; Nicaise et al., 2000). These studies highlighted the benefits of such programs on student learning or performance, but with only limited opportunities, they were unable benefit all students. The question was whether there were apprenticeship appropriate activities that can be introduced into science education settings in which all students had equal access.

The question above was difficult to answer, however, because there was no clear idea of what apprenticeship-appropriate might mean in science. The discipline itself has never been studied as an apprenticeship and so it was not clear what apprenticing to become a scientist looked like, or how it might be incorporated into the science classroom. Descriptions of college science lectures and labs were rare. Although there have been some comprehensive descriptions of research laboratories (Knorr-Cetina, 1999; Latour & Woolgar, 1986; Traweek, 1988), the entire apprenticeship experience of scientists should be described before aspects of it can be appropriately integrated into science education.

In general, there were simply so few studies that provided any kind of apprenticeship-like description of learning to become a scientist, that research on this was unable to work towards filling a large gap. There were problems with assuming this process looked a certain way, without formally studying it. First, educators might implement a program that brought authentic science into the classroom, but what did authentic science actually look like and where did it best fit in the classroom? Second, college classes could be reformed, but without an understanding of what should be changed and why it needed to be reformed, there was no

reason to do so. Finally, bringing students into research settings earlier was difficult without first ascertaining what they should know before they get there and what they actually learned *in situ*. It is time that science educators looked at science from the perspective of apprenticeship, to study what exists right now and *why* it looks that way, before they attempted to reform it.

## CHAPTER III

### METHODOLOGY

There were two research objectives for this project:

1. To describe faculty scientists' discourse across apprenticeship-like opportunities in a university chemistry department, specifically taking into consideration the role of the learner, the task and the environment.
2. To analyze these discourse patterns in order to identify key components that might indicate ways to successfully integrate authentic research opportunities and classroom science education.

This research was focused on describing and analyzing the current state of science education as it exists today, at the college level. The goal of this study did not take on the perspective of the individual, but rather the community as a whole. Therefore, it focused on non-participant observations and video-recording of several educational situations, intended to provide information about the breadth of experiences students encountered when learning to become a scientist. The three major settings that were observed and recorded were: Undergraduate or graduate level lecture-based courses, undergraduate or graduate level laboratory-based courses, and research lab group discussions.

#### Background

As Lemke (2001) pointed out, communities of practice were complex and difficult to define. They were, themselves, composed of sub-committees, or overlapped with other related, but different communities. To effectively study communities of practice, it was necessary to look at individual examples and study them in-depth (Lave & Wenger, 1991; Wenger, 1998). In this case, the study was focused on faculty science language use in university science settings.

However, science in any one university was still composed of many sub-communities of practice, such as Biology or Physics.

There were several possible approaches to take in this study. It was possible to take a broad look at natural science, investigating faculty language in each of the four major disciplines of biology, chemistry, physics and earth science. This, however, presented a problem from a sociological perspective because individuals within communities often viewed them quite differently than those outside, or even from others situated at a different position within the community (Lemke, 2001). The background of the researcher was in biology, but not the other three, which would have made it difficult to maintain a consistent level of data interpretation across all four disciplines. Therefore, choosing just one discipline to investigate was most appropriate. However, because this study also dealt with discourse and language use, it was also necessary that the researcher have a basic understanding of the language associated with the discipline.

In addition, there were two possible population sizes that could be investigated during this study. One was to look at a small population of participants, but study their actions in depth. For example, it was possible to spend a significant amount of time with three faculty educators, each acting within a different context. Alternatively, it was possible to spend shorter amounts of time with several faculty in many different contexts. The latter arrangement met the needs of this research better because it provided a broader set of possible student experiences while learning to become scientists.

This was because movement through a university science program toward expertise was a time consuming process. It included participation in both undergraduate and graduate level courses, including both lectures and laboratories, as well as working on authentic science in research labs (Feldman, Divoll, & Rogan-Klyve, 2008). As such, this study needed to consider as

many of these aspects as possible. In addition, sociological theories also pointed out that although there was an underlying normative mode of discourse in a community of practice, individuals within the discipline did not always adhere to them in the same ways (Airey & Linder, 2009). This implied that the total number of faculty scientists used may not be as important as the number of different settings they were observed acting within. Therefore, the emphasis was on the overall number of experiences, rather than on the particular instructors involved. It was imperative, to be able to make claims about a process of learning to become, that as many of these experiences were documented as possible, even if for only short durations of time.

### General Methods

This study was conducted at a medium sized, Midwestern university, offering a range of programs and degrees, including doctorates in the sciences. The school was located in a mid-sized city with approximately 80,000 full time residents. The university hosted about 25,000 students at all levels, full and part time. There were approximately equal numbers of male and female students and minority populations were not different from national averages at either the university or in the community. The area was unique in that it was home to a tuition incentive program that will pay tuition to any public higher education institution in the state for all students who attended the public school from kindergarten through 12<sup>th</sup> grade.

### Subjects

It was important to consider who the basic unit of study for this research would be. According to LPP (Lave & Wenger, 1991) there were two major players within community structures, the learner and the expert. Discourse analysis in classroom settings often considered both of these (Driver, Leach, Millar, & Scott, 1996; Lemke, 1990). However, successful attempts at simulation type apprenticeships relied heavily on the teacher having the expertise to model

authentic science (Collins, Brown, & Newman, 1989). In addition, it was the experts that often acted as gate-keepers to communities (Lave & Wenger, 1991). Therefore, this research focused specifically on discourse of faculty scientists in universities, as opposed to students.

The main focus of this study was on science faculty in a chemistry department at the University described above. A total of nine individuals were observed, with six of them being full time faculty and the other three graduate level teaching assistants. Four of the faculty were observed in multiple settings. One of the teaching assistants was observed both in a role as instructor of a laboratory class and as a students in a research lab discussion session. All faculty except one, were male, and all but two were Caucasian. Of the three graduate assistants, one was female and minority. Of the two males, one was Caucasian and the other minority.

Teaching assistants played an interesting role in this research, because they were considered both faculty and students depending on the setting. It was therefore necessary to define what was meant by instructors and students to maintain consistency. Students were considered to be anyone who was in the primary role of learner in the setting under observation. Faculty were those who maintained expertise in the setting. Therefore, teaching assistants were faculty in one setting, that of the classroom laboratory, but students the research lab setting. In addition, teaching assistants were also essentially learning to become both scientists *and* professional science faculty. However, only the former was of interest here, so the TA talk in the classroom lab was not analyzed for its contribution in them becoming science faculty, but only in how it contributed to the students in their classrooms becoming scientists.

The number of settings was limited because of the purposeful inclusion of faculty from only one science subject, chemistry, that were asked to participate. There were two reasons for limiting the study to the single subject of chemistry. First, previous research has indicated that

although science as a whole has general language rules (Lemke, 1990), individual disciplines within science also each have their own specific nuances during communication (Traweek, 1988). In order to help eliminate the possible noise associated with differences between subjects, only one was considered here. Chemistry was chosen over other possible science subjects because the researcher was not a chemist, but was familiar enough with the subject to recognize vocabulary and theory. This was intended to reduce one source of bias from the research, as described by Patton (1990).

A total of fourteen settings were observed for various amounts of time. These settings included six different college science lectures, five different classroom laboratories and three different research lab settings. Table 1 shows the instructor in charge of each setting (given a pseudonym), the level and type of setting (coded) and the approximate amount of time spent in observations. Note that the time recorded here was the total time observations and recordings were made. It did not necessarily indicate the total time transcribed from the video. Transcription will be described further below, but some tasks, such as test taking, were not transcribed at all.

#### Research Process

Non-participant observations were made of classroom lectures, classroom laboratories, and research lab meetings, with permission of faculty and instructors coordinating in each setting. Based on the data from a pilot study described below the goal was to observe at least three hours in each setting. Note that this was possible for all settings except for one, and most settings were observed for substantially longer. It was also found from the earlier pilot study that after three to five hours of observation within one course, the various types of discourse modes most often used by that instructor had been established, and new modes were rare.

Table 1

Listing of Observed Instructors, Settings Observed in, and Amount of Time Observed

Instructor	Setting (Code)	Time
F. Alpha	1000 Level Lecture (L1A)	5:39:38
F. Beta	1000 Level Lecture (L1B)	3:44:58
F. Gamma	2000 Level Lecture (L2A)	9:06:36
F. Delta	3000 Level Lecture (L3A)	7:02:28
F. Epsilon	3000 Level Lecture (L3B)	10:00:30
F. Beta	5000 Level Lecture (L5A)	7:06:13
T. A. Zeta	1000 Level Class Lab (CL1)	9:30:41
T. A. Eta	2000 Level Class Lab (CL2)	9:23:45
T. A. Theta	3000 Level Class Lab (CL3)	3:56:14
F. Iota	4000 Level Class Lab (CL4)	5:55:30
F. Alpha	5000 Level Class Lab (CL5)	5:32:22
F. Alpha	Research Lab (RLA)	1:22:23
F. Iota and F. Delta	Research Lab (RLB)	4:44:10
F. Iota and F. Delta	Research Lab (RLC)	3:40:20
		86:45:48

In general, an attempt was made to observe a single tested unit in the lecture sessions, coming in either the first day of class or the first day following an exam and staying until either the day of the exam or the day before the exam. Because of weather and other extenuating circumstances this was not always possible. For classroom labs the goal was to observe at least three sessions, which was approximately the span, in weeks, typically seen between exams in a traditional lecture. This was possible in five of the six labs observed. The CL3 observation began with only two weeks left of class because of communication miscues with the instructor.

Research settings were more difficult to observe because they were often not scheduled, as courses were. As a result, and based on the literature described in Chapter II, only laboratory research meetings were used for data collection. This arrangement was beneficial because often faculty attendance in the lab was scattered, whereas group meetings were generally planned. It was assumed there would also be more verbal interactions during group meetings than in the laboratory proper. Three different lab groups were observed, but two of



the lab groups were co-led by the same two faculty members. The amount of time spent in each lab meeting was dictated by the faculty, with the one led by F. Alpha (RLA) scheduled for one hour and those led by F. Iota and F. Delta (RLB, RLC) scheduled for one and a half hours. Note that the RLA meetings lasted less than 45 minutes each time it was observed.

During all observations except for those in the Classroom labs, observation notes were taken, which included thoughts and ideas about what was being said, and any clarifications that might be useful during transcription. They were not taken in the classroom labs because it was impossible to both hold the video camera in order to follow the instructor around the room, and take notes at the same time. In the CL1 setting, however, there were occasions when it was possible to set the camera up in place for the observations, and so field notes were taken during those lab sessions. All classroom and laboratory experiences were videotaped, focusing primarily on the instructor.

Portions of the video tape that focused on verbal episodes of teacher talk were transcribed and analyzed using critical discourse analysis (Fairclough, 2003). Results from the pilot study indicated that when faculty were speaking to a class, video was important in order to identify context. The video-tapes were used to collect two types of data. The first type of data was a categorization of language use in each setting. This data was used as a way to describe each setting. During the pilot study a total of six categories were developed that described the types of discourses encountered. Initially, these categories were used as a way to separate video data into talk turns. For example, the speaker of a verbal discourse might be the teacher (T) or a single student (S). However, over time a simpler system was developed that was integrated into the transcription process.

The second type of data gathered by the videotaped sessions was used to provide information about the roles of students and faculty, the tasks and the resources available.

Because the focus of this study was on the verbal discourse of college science faculty, the sections of video tape where the faculty member took on a role as speaker were transcribed in full. Student talk, where discernable and necessary was included to keep the flow of conversation, but was not directly analyzed (see the section on data analysis below). The transcribed sections of discourse were then analyzed separately according to the setting in which they were found.

### Data Analysis

The data gathered from the observations were analyzed in a three-tiered approach. First, initial notes were taken during or immediately after observations that provided thoughts and ideas about what was happening in the classroom. After observing each setting, the videos were transcribed. These transcriptions had several purposes. First, they allowed each video recording to be divided into talk turns. Talk turns were defined as segments of talk with different meanings. For this study five types of talk turns were used. One was instructor expository talk. A second was instructor questions. In order to be counted as a talk turn the question had to be clearly answerable by students. Therefore, questions such as, "Ok?" or "Right?" which were rhetorical and occurred frequently within expository talk were not counted as questions. However, a question asked by the instructor, but then immediately answered by them, essentially a rhetorical question as well, were counted if there was some reasonable expectation that students would be able to respond, had they been given time to do so.

The third type of talk turn was student talk, either as statements or questions. In addition to student talk, however, any time students were given the opportunity to work independently of the instructor was considered a turn for students. In other words, students were the focus of the environment at that time. All student talk was put together because this research focused primarily on the instructor, not the student.

The fourth was miscellaneous talk, which generally took place when both students and the instructor were speaking at the same time and neither was audible. Finally, based on the pilot study, silence was also recorded. Based on transcript data, there were three major types of silence. One was wait time, which instructors utilized after asking a question to allow students to respond. All wait time instances of silence were recorded to the second, no matter how long or short they were. The other two types of silence were distracted silence and transitional silence. Distracted silence was recorded when the instructor was busy doing something else, such as writing on the white board, and was therefore distracted from talking. Transitional silence was recorded when the instructor was moving across the room, between slides or preparing to talk about the next topic. These two were often difficult to separate from simple pauses in expository talk and so to be consistent, silence was counted as either distracted or transitional if a minimum of three seconds was spent in silence. Three seconds was determined after several transcripts in several settings. It could be considered quite a long pause for some instructors, but quite short for others, and therefore seemed to be a modal compromise. Other pauses less than three second in length (other than those of wait time) were not recorded.

In addition, the time spent on each talk turn was included in the data, and was used to determine proportionality of time spent on each type of discourse. Note that although this was done in all settings, only the times spent in the lecture setting were useful in data. The percentage of time spent on anything other than student talk was so low in the lab settings that there was no way to compare these. This data provided descriptions of discourse, but not statistical differences between settings. The descriptions were used to identify similarities and differences between the authentic research settings and the classroom settings.

The data gathered from the transcripts of teacher verbalizations was also analyzed using Fairclough's description of critical discourse analysis, as a way to answer the second question.

Critical discourse analysis was different from other types of discourse analysis because it considered the political and social relationships between the individuals involved when doing the analysis. This was useful in this research because it focused on the faculty, who often maintained a one up position compared to students. Therefore, it was important to consider the political relationships between the faculty and students when analyzing talk in order to establish the role of learners, the task and the environment.

Fairclough (2003) used the general process of having three levels of language analysis, moving from broad to detailed. The benefit of using this analysis was that it was customizable to the research in question. In other words, it was possible to choose the delicacy of the analysis depending on the data collected and the results from analysis at previous levels. If, for example, analysis at the broadest level (a basic categorization and organization of line by line talk) revealed little that was directly applicable to the question, then no further analysis on this particular excerpt was necessary. This particular way of analyzing talk was both effective and efficient, as it eliminated distracting or less useful data, while emphasizing pieces that were particularly telling.

This type of critical discourse analysis, however, was no different in essence than any other type of discourse analysis, other than its emphasis on the political and social relationships between the parties involved. Therefore, Fairclough's (2003) general format of analysis was used, but was supplemented by Lemke's (1990) work as well. The reason for this was because Fairclough was generally a linguist, who emphasized language as it applied to social change. Lemke was an educator and a scientist with a background in physics who specialized in language and communication in the classroom. Both shared an interest in political positioning and power in communication.

Therefore, the transcripts that were made based on the timed talk-turns were analyzed by locating segments of talk within each transcript that reflected faculty beliefs of the role of the learner/teacher, the role of the task and the role of the environment/resources. Those specific episodes were considered within their context and the broader context of students learning to become. Major themes identified from initial observation notes and additional notes taken during transcription were then further considered once all videos were transcribed. Some of the themes that came from initial observations were deemed, upon closer analysis, to not be accurate representations of talk, while other themes not initially considered were found later.

The original data analysis plan was to consider the roles of students or learners, the roles of the environment and the roles of the tasks in learning to become (Collins et al., 1989). However, as analysis progressed these themes had to be slightly modified. It was found that the roles of students were often dictated by the faculty. In addition, the roles of students also complimented those of faculty, where each would take on a certain level of responsibility. Therefore, data was eventually analyzed to understand roles of both students and faculty. In addition, faculty rarely talked about the role of the environment, except for resources specifically. Therefore data analysis here concentrated on how resources were accessed and used by members of the community.

Data was triangulated in two ways. First, initial analysis was done on field notes during or immediately after initial observations. This analysis was meant to identify potential areas of interest within the data. A second round of analysis was then done during transcription of each observation, where the original field notes were compared with transcriptions to identify potential patterns. Finally, after transcription, both the originally identified areas of interest and the possible patterns were further analyzed in detail via the discourse analysis. Once strong

themes and patterns were found and described, a subset of data was given to the faculty advisor of the researcher in order to ensure that findings appeared both consistent and realistic.

The second type of triangulation came in the form of analyzing data from three perspectives: the student, the science faculty, and the science educator. Therefore, interpretations of talk might differ depending of the perspective. A constant effort was made, via the use of written notes, to attempt to consider all three positions in data analysis, thereby reducing bias that might result from taking only one perspective or another. This also allowed for stronger patterns to be found because it required that all three perspectives align in order to draw conclusions.

#### Pilot Study

Prior to this research, a small pilot study was conducted on undergraduate biology and chemistry courses, taken primarily by elementary education students. Five biology and five chemistry classes were observed during a summer semester at the same university described above. These classes were also videotaped, with permission of the instructor. Each class was taught on Monday through Thursday each week, and lasted approximately two hours and 20 minutes. The goal of the study was to determine what discourse modes were prevalent in these settings, and to establish a guide that could be used for future observations. Several issues were found and subsequently accounted for during the pilot study. Some have already been discussed above, while other issues are outlined below.

First, it was originally intended that the observations would allow the researcher to obtain real time data on all modes of discourse, continuously through the class. However, early observations in the pilot study showed that keeping track of time and talk simultaneously was not possible. The alternative was to take snap-shot readings every 30 seconds, limiting the amount of data, but allowing for consistent records of language patterns throughout the entire

episode. In order to determine if the 30-second intervals collected data that was approximately equal to that of continuous recording, a video-taped segment was analyzed for continuous record and compared to the 30-second readings taken in class.

This comparison revealed two interesting trends. First, as expected the continuous record provided a richer account of discourse modes, than did the 30-second readings. However, when compared proportionally there was little (not tested statistically) difference between representations of either. The continuous record did have one important advantage over the snapshot method. It was possible to overlap time when taking continuous readings, if for example, the teacher was speaking to one student specifically, while the rest of the students were engaged in a small group activity. In the snap-shot readings, the dominant mode of discourse needed to be recorded if multiple things were happening at the same time. For this reason, all later transcripts were done using continuous talk, versus simply looking at snapshots.

Lemke (1990) provided insight into another reason the continuous record mode of data collection was preferable. He suggested that while an individual is speaking or writing it was sometimes impossible to know what they are actually saying. For example, it would happen, during the pilot study, that the teacher would be in the middle of speaking, and at that moment when data was collected it sounded like a direct statement. However, by the time the teacher had finished, and the moment of data collection passed, it turned out that a question had actually been asked. Therefore, taking records at timed intervals did not always provide an accurate account of what was being conveyed.

A second issue resolved through this pilot-study was the type of language data that was apparent and useful. Originally, it was determined that only two categories were needed to establish the speaker (writer) and the listener (reader) in each setting. However, it became clear

early on, that often the direct listener was not always the intended listener. For example, an instructor may ask a single student a question, by using their name, but the intent of the instructor was that the whole group hears it. By contrast, the teacher may actually be speaking directly to a single student, with the intent that only that student listen and respond. Therefore, during transcription, notes were made indicating times when the faculty member was talking to individuals or groups.

The use of the pilot study also revealed the need for using video recording over audio records. While only the verbal discourse was used, it was evident that some teachers, while talking, used additional resources, such as white boards. Their talk could not always be interpreted appropriately when not put in context of these resources. When using audio tapes only, it was impossible to know what objects or ideas were being referred to by talk, which would make analysis difficult. Though the original intent of this research was to use video, because some instructors may have balked at having their classes videotaped, audiotapes were tested during one class session of the pilot study. It was immediately clear that this would not suit the purposes of the research, and videotape was needed.

Another interesting aspect of the study was the inclusion of two unexpected codes, silence and humor. It became apparent that silence in the classroom was as important as explicit talk or writing. There were four major reasons for silence in the classroom, during the pilot study, which was reduced to three during data analysis of the main study. One was wait time, which was used after the instructor (or student) asked a question, waiting for a response. A second reason for silence was simply a long pause. The teacher or student may be gathering their thoughts, thinking of how to word something or what to write on the board. The third reason was because of a transition between activities or topics. Finally, silence occurred when students were required to work independently on a task. These codes have since been modified,



but the pilot study made it clear that silence was significant part of student/teacher interactions. Humor was rarely used in the classroom, and its use was not easy to categorize. This area was eventually removed and replaced with something called Storytelling, which will be described in more detail in Chapter IV.

The final aspect of data collection to come out of this pilot study was the variety of aspects that should be considered and the possible codes that could be used. Although some were mentioned earlier, there were originally a total of six categories that helped establish the context of discourse in the classrooms, and each category included several items that could then be coded. These initial codes were significantly simplified over time, although at the same time many more complexities arose. These will be discussed further in Chapter IV.

#### Personal Statement

What I, the researcher, believed and understood about this study was important in considering the conclusions I drew after data analysis. I undertook this project because I was unhappy with the current conflict that was often seen between science education and science. I have read several papers where claims were made that science education does not accurately reflect authentic scientific research, and that it should do this more often. However, these claims were bothersome because I was not confident that science education did not reflect scientific research at all. In addition, I supported current informal claims by science faculty at the college level, that the current system has evolved as it has because it must work on some level.

It was my belief that more progress could be made in proposed science education reform, if science educators took time to consider the voice of scientists as they taught. I felt that by identifying the aspects of teaching that were reflected in scientific research, it was possible to shift our level of concentration only onto areas where gaps existed, rather than seeking wholesale change of teaching practices that have been in place for a long time. I,

therefore, identified with both scientists and science educators and as such, hoped to bring both groups into alignment through diligent, purposeful and fair comparisons between teaching practice and research practice.

This summary presented several areas where bias might become apparent. First, I often gave scientists the benefit of the doubt, and I tended to rationalize poor teaching techniques. It was in part because of this that I sought out theory and methodology that did not explicitly seek to value pedagogy or discourse, but simply aimed to describe what presently existed and to interpret talk within a well-defined framework. Second, I did not take into account the non-science major, taking a science course for general studies credit or for a non-science, but related major, for example, nursing. This became one of the major limitations of this research. It was aimed explicitly at considering students who were moving toward full participation in the science community. In addition, I was both an experienced teacher and a science student. Given this, it was possible that I described the talk I heard based on one perspective or the other, rather than on the more neutral perspective of researcher. One way I have attempted to account for this potential bias is to observe a science area subject, chemistry, that I was not overtly familiar with. I had enough general understanding of the subject that I could grasp the basic language cues of what was happening in these settings, but I have neither taught nor done research in the area. However, not being a chemist has also led to problems in interpretation of the data. For example, I was not familiar enough with the subject to be confident in identifying question types and strategies.

Finally, I have also been a science student whose goal was to become a scientist. I was able to consider, from the student perspective, what I heard and saw and tried to apply this to their role in the environment. This was very important from a political standpoint and was necessary to situate talk of instructors. But, it also brought another level of bias, in that I may

have recognized my own struggles in succeeding in undergraduate chemistry courses, perhaps being too critical of the instructors.

To help counter these biases, I made a habit of consistently and explicitly trying to recognize each perspective as I went along. My personal notes on the data included notes reflecting thoughts of an instructor, of a student and of a scientist, therefore trying to be fair to all three. Despite the complications brought on by the inherent bias of this project, I believe that I was able to observe these settings most consistently from the perspective of researcher, integrating my understanding of teaching science, my understanding of being a student hoping to become a scientist, and my understanding of science education.

## CHAPTER IV

### RESULTS AND DISCUSSION

#### Description of the Apprenticeship Process to Become a Chemist

This section of data analysis focused primarily on building an overview of what learning to become a member of the community of chemistry entailed for new-comers. Based on apprenticeship theory it did not seek to evaluate this process as being good or bad, but accepted it as what has become a normal and established process for learning a trade. The second section of this chapter considered the characteristics of this process and based on teacher language analyzed talk as a way to explain what different aspects of the experience contributed to the overall apprenticeship of chemists.

First, an example of a dialogue between a faculty member, F. Delta, and students in the L3A setting is presented here to explain the basic aspects of how data was analyzed. This exchange began with F. Delta providing students with the graphical output of a sample using Infrared Spectroscopy (IR). This was the second day that he had been discussing IR in class, and he was now letting students try to interpret the output on their own, with guidance. After displaying the graph, he provided a basic overview of what the students were seeing, pointing out several peaks and their location, but without telling them what those peaks meant. He began asking students questions about how to interpret the data, and together they developed an idea of what this molecule might be. The following exchange took place part way through the large class discussion:

1. F. Delta: We already know, we've, we've got a double bond and probably carbon is on one end of that.
2. F. Delta: From the frequency, from the frequency of the double bond what would you guess, what kind of double bond would you guess?

3. Wait time (2 seconds)
4. Several students generally reply with: Carbonyl.
5. F. Delta does not hear (or acknowledge) response. Puts hand to ear to indicate to students to respond more loudly.
6. F. Delta: Who wants to answer?
7. Wait time (4 seconds)
8. F. Delta: Acknowledges student attempt to talk by nodding his head at the student.
9. Student responds, but response is inaudible.
10. F. Delta: Ok, so you're going to guess nitrogen. (Writes on the WB)
11. Wait time (3 seconds)
12. F. Delta: Or...?
13. F. Delta acknowledges a second student willing to respond.
14. Student responds, but again, response is inaudible.
15. F. Delta: So, carbon probably. (Writes on WB)
16. F. Delta: Is it, it's probably not a carbon-oxygen double bond. Uh, a carbon-oxygen double bond would be closer to 1700, or more commonly above 1700. So, we have a carbon-nitrogen or carbon-carbon double bond.
17. F. Delta: Um, does that jog with, what about down here in the single bond to hydrogen region?
18. Wait time (3 seconds)
19. F. Delta: What do we see?
20. Student begins to respond, but F. Delta cuts them off.
21. F. Delta: What is the, what is, what does the green peak tell us?
22. Student responds , also inaudible

23. F. Delta: Ok, so that carbon-hydrogen saturated (Writes on WB)

The conversation continued until a resolution was made by the class as to the structure of the molecule. This exchange was typical of those seen throughout the observations. There were several general points to make, which clarified how data was analyzed for this study. First, the conversation itself was typical of those often seen in educational settings, as described by Lemke (1990). Teacher student exchanges tended to follow a basic pattern of talk turns, mediated by discipline and the need on the part of the faculty member to maintain authority. In this example, the instructor posed a question to students and then waited for a response (Lines 2-3). The wait time was the non-verbal trigger to students that the instructor expected a response. Had the instructor not expected a student response he would have simply continued speaking or he might have answered the question himself. Several students, in this case, responded to the question together, and although their response was audible on camera, the instructor did not hear it. To maintain authority, he indicated through gesture that the students were not speaking loud enough, or clearly enough, and to ameliorate the problem he bid for one student to respond. He then called on one student specifically, through non-verbal gesture (Lines 4-8). Although the student's response was inaudible on camera, F. Delta heard it and then evaluated it, calling it a "guess" (Lines 9-10).

So far in the conversation the instructor has asked students a question, but needed to find a way to maintain authority after several students responded at once. He did so by forcing students to raise their hands to bid for a chance to respond. He then evaluated that response. Even though it might not appear to be a negative critique of the answer given by the student, it was for three reasons, two of which occurred later in the conversation. First, F. Delta referred to the student response as a guess, which generally implies that someone does not know the right answer. Later, in line 15, F. Delta suggested that it was probably carbon and therefore not

nitrogen forming the double bond, after another student made a new suggestion. The first student's guess was wrong. In a part of the conversation not transcribed here, F. Delta stated outright that this peak was not representing a nitrogen-carbon bond, but rather a carbon-carbon bond.

In lines 11-12 the instructor made an interesting move in that he implied a question without actually asking it. He did this by looking at students and waiting for them to respond to the unasked question. When no one picked up on this, he had to provide the intended question. However, even then he only said, "Or?" suggesting that he wanted another student to respond to the original question. Again, a student bid to answer the question and was called upon using non-verbal communication. When the student responded, an evaluation came, but this time it was positive, as the instructor referred to it as "probably" what was being represented by the data. Having established what was probably happening with that peak, the instructor provided a summary of events thus far (Line 16) providing both information that was given by students, but also new information. F. Delta then moved on to another peak, and asked students to tell him what that one meant. When one student began to do so, he was cut off because his answer did not match the question posed, and F. Delta was forced to clarify. When the student re-responded, this time with the appropriate response, the instructor evaluated it, by re-stating what was said and writing it on the board (Lines 17-23).

Within this short excerpt, there was a typical educational exchange between faculty and students, where both bid for each other's attention, while the instructor balanced discipline with delivering scientific content. However, also inherent in this conversation was information about delivery of material. This was a problem-solving episode in which students were being strongly guided toward an acceptable answer. In some respects it might have appeared to be a highly guided inquiry, in which students were given the opportunity to think through their

response before having the instructor tell them the right answer. Also, there were several forms of non-verbal communication, including gestures, body language and written notes on the white board. Student had to interpret a subtle clue, such as silence, in order to keep the conversation going. They also had to take in language cues given across time. Something evaluated as a guess, only later was determined to be wrong. In addition to understanding the implications of basic patterns of speech presented by F. Delta, students also had to recognize the scientific concepts being presented, in this case that a certain peak at a certain location was indicative of a certain type of bond.

Any one dialogical exchange, therefore, had inherent in it several lines of data that could be analyzed further. Because talk, especially in the classrooms, tended to follow basic patterns already described (Lemke, 1990) these were not explicitly considered during data analysis. In addition, non-verbal and written cues were also not analyzed in depth, except where they contributed to understanding verbal interactions. This was because they added more complexity than what could reasonably be dealt with in this analysis. Any examples of talk presented below *could* have provided insight into a variety of these aspects of teaching and learning. However, each was presented as an example of only one finding as described. Any other inherent properties of discourse may exist, but were not necessarily discussed.

#### General Description of Research Labs

A wide range of college chemistry settings were observed in order to establish a basic description of apprenticeship. Newcomers into research settings were expected to know a variety of information prior to active involvement in the lab. This meant that the act of learning to become necessarily began prior to the research experience. What was not known, however, was what information was necessary for students to know before they experienced laboratory work, and what experiences they gained during the process of doing research itself. Therefore,



analysis began with considering the research laboratory setting, and establishing the types of knowledge students were expected to come in with and that which they learned along the way.

The three observed laboratory groups were all smaller in student number than the smallest lecture classroom setting, but almost equivalent in the number of students enrolled in the two upper division classrooms laboratories. All three laboratory groups were led by a faculty member, and sometimes included lab technicians, and in one case, an engineer. Meetings took place in locations that provided access to a large table students could sit around and discuss their research efforts. In one setting (RLA) one student per meeting time was required to do a short power point presentation on their progress to date, after which the faculty in charge and other students were able to ask questions. These meetings were scheduled weekly, and were meant to take one hour, but were shorter than this both times they were observed. In the other two lab groups, all students gave a brief update of their research, with discussion that followed each. These updates often included graphical materials on handouts that were passed around, or use of the white board to provide explanations, but never Power Points. Both of these lab group sessions were scheduled for one and a half hours, biweekly, though sometimes they ran longer, and rarely were they shorter.

There were a few cases in which students in the lab meetings were also present in one or more of the observed classes. Since students who participated in the laboratory research were also involved in undergraduate level classes, it was apparently not necessary to have completed all forms of coursework in order to participate in research. In addition, one of these students was considered a valuable resource to other students in the research lab because of her considerable experience with a certain procedure. This indicated that coursework alone was not a prerequisite for success in a research lab. There were, however, other types of knowledge that appeared to be important for students to have before entering the lab. However, beyond

knowledge of scientific concepts, the quality of student and faculty interactions had implications for later analysis of data, as well. Therefore, this section first briefly described faculty and student interactions. The types of knowledge students either did or did not need to generate successful interactions with faculty are discussed later.

#### Faculty and Student Interactions

There were two main, related characteristics of faculty/student interactions in research settings. First, although outwardly these settings may be described as student-centered, much of what happened was actually dictated by the faculty. Second, independence in the research setting was granted to students via the faculty member in reward for completing tasks in a timely manner and gaining expertise in an area of research. Both are described and further exemplified below.

*Faculty centeredness.* Typically, student-centered referred to situations in which the learners dictated what happens, or that learners had some amount of control over what they did. In all of the research lab settings observed, the students appeared to be in control of the meetings involving faculty and peers, either through short informal presentations of data or more formal Power Point presentations. Although talk in these settings was generally dominated by the students, as they presented their work, asked questions, made suggestions or provided input for other students and their projects, ultimate control over what happened was mainly dictated by the faculty member in charge of the research lab.

For example in RLA, a student was giving a power point presentation about their research project. Throughout the presentation F. Alpha stopped the student to ask questions as a way to clarify what she had done. At one point the following exchange took place:

1. F. Alpha: Ok. Have you tried to do the same experiment, except adding a solution of platinum black instead of platinum nanoparticles?
2. Student replied that they have not.
3. F. Alpha: There should be some platinum black in the lab. S- had ordered it this summer, um, when he was testing it with (inaudible). And, so it'll be a good control experiment to try and make sure this is really an effect of the quantum sized particles rather than the bulk platinum. Ok?

In this situation, the student discussed what they had already done in the project, but F. Alpha actually dictated the course of action the student took. Although the student was asked if she had done this step, responding in the negative did not appear to be problematic, because she had not previously been told to do so. Therefore, although the student was the one presenting her data, the faculty member still appeared to be in charge of the activities associated with the lab. Further analysis of the data suggested that this had to do with established roles of faculty and students within the larger community of practice. This will be discussed later.

Another example of the authority of the faculty member, from the RLB setting, had a student presenting anomalous data. In this, situations the student was unable to explain the discrepancy between her results and those obtained from earlier tests. A discussion ensued in which several ideas were brought up. One of the other students then asked a question:

1. Student (peer) asks what other components ash might have.
2. Presenting Student: We don't know.
3. F. Iota: That's a very good question.
4. Student (peer) turns the question back on itself, suggesting they do not know what is in ash.

5. Presenting Student: Yeah.
6. F. Iota: There's silica, phosphorous, but...
7. Presenting student overlaps F. Iota's talk, appeared to end to the conversation and continued on with her presentation of data, which lasted about 20 more minutes.
8. F. Iota: So, what we really need is a total analysis on the ash, on what it is, really.

In this situation the faculty member did not seem, at first, to have any more information than the student presenting her data. Neither he nor the student presenter was able to answer the question raised by another graduate student and both acknowledged that they did not know. However, the student presenter ended the conversation and tried to move away from the conversation, presenting new information. As soon as she had finished speaking, about 20 minutes later, F. Iota immediately went back to the original problem, suggesting that what must be done next is an elemental analysis of the ash. This was the last serious statement made on the data, as after this there was an off-topic, humorous episode, followed by a change in topic completely. Again, although the student happened to have the attention of both the faculty and her peers, she did not have strong control over either the meeting or the research.

This suggested that students did not work as independently within the research laboratory, as might be suggested in some of the literature reviewed earlier. For example, Roth and Bowen (1995) said that students can and should be developing their own scientific questions, designing their own methodologies to address those questions, and interpreting the data they have gathered to find answers. However, research work, at least in university laboratories, appeared to be more guided than this. Students might be encouraged to gather data and present it, but they also must follow the highly scaffolded dictates of their faculty advisor. This led to the second general characteristic found in interactions between faculty and students in research labs: How students gained independence.

*Gaining independence.* Although some students did appear to have a large amount of control over their research action, the data suggested that this leeway was given from both experience in doing lab work, and from work ethic. The following exchange took place between F. Delta, F. Iota, a lab tech with a bachelor's degree and an engineer holding a doctoral degree. In this situation, the engineer had been tasked with designing an appropriate reactor that would act as a scale-up for prior work, but also as a model for what might happen in an industrial setting. The engineer had run into problems deciding the best approach to take in certain aspects of the design, but had definitely settled on using a 20 liter plug flow reactor. The following conversation took place:

1. F. Delta: If we, if we call this, you know, a scale up. Presumably it's a model for a plant, right? So, does, is, is a 20 liter reactor model of a plant (inaudible) a 200 liter reactor? Do we have--?
2. Lab Tech: Interrupts F. Delta and went into a lengthy alternative to using the plug flow reactor. He had designed a spreadsheet to give them information on using a continuous flow reactor, which used a pipe rather than a tank, the length of which depended on the diameter of the pipe and the flow rate. He claimed this was easier to scale up and also cheaper. However, he was not sure how the pipe allowed for mixing.
3. Engineer: Asked about the base reaction in this set up.
4. Lab Tech: Suggested the base reaction was done the same way and then provides details on the system.
5. Engineer: Countered and suggested that this was not the best way to achieve mixing.
6. Lab Tech: Suggested using turbulators to get mixing.

7. F. Delta: So, you're still thinking that the reaction conditions would be the same? So, it would be at reflux temperature?
8. Lab Tech: Explained that he was thinking it would be just below reflux, to keep pressure down.
9. F. Delta: But, you'd still be at elevated pressure. You wouldn't be at atmospheric pressure at the center of the reaction.
10. Lab Tech: Agreed, said that pressure would be at about 10 PSI.
11. ... (Short conversation about temperature and pressure)
12. SB: And, do you have experience with the continuous flow, doing this reaction?
13. Lab Tech: Shakes head no, and reiterated that it was just a thought experiment.
14. SB: Could, could we do it in a small-scale reaction?
15. Lab Tech: Attempted to give numbers for pipe length in linear meters, but the smallest scale he provided them is 60 linear meters.
16. Engineer: Suggested that this was a problem because once they began scaling up they run into pipe lengths in the area of miles.
17. Lab Tech: Counters, saying that was not the case because they just had to balance pipe diameter and flow rate to get reasonable pipe lengths.
18. F. Iota: And, and, your email the other, the other day, B- (Engineer) suggested that the continuous flow reactor, not necessarily the plug flow reactor, (inaudible). That the plug flow reactor is the best strategy.
19. Lab Tech: Conceded that it was just a thought experiment that seemed reasonable (the continuous flow reactor).

20. F. Delta: I guess I would, I would be uncomfortable doing it, without testing it, so that would be at a lab scale before we do the scale up.

In this excerpt, the lab tech, who only held a bachelor's degree, was questioned not only by the two faculty members present, but also by the chemical engineer, who held a Ph.D. His idea to change from a plug flow reactor to a continuous flow reactor was contentious because it challenged the work put in by the engineer. Toward that end, the engineer challenged the design several times (Lines 3, 5, 16), though he was countered each time with logical arguments from the Lab Tech. It was also revealed that the engineer had sent out an email previously suggesting that of the two, the plug flow reactor was the better option (Line 18). Although it was clear that the Lab Tech had put considerable time and thought into his suggestion, for example creating a spreadsheet, the faculty were not convinced this was a viable option. F. Delta was uncomfortable because the Lab Tech had no experience using continuous flow reactors (Line 12) and because given the numbers it seemed unreasonable to try it on a very small scale first (Line 20). In this case, the faculty did not end up pursuing the continuous flow method, despite the knowledge the Lab Tech had developed about it. They chose, instead, to trust the experience and expertise of the engineer and continued investigating the plug flow reactor.

Contrast this with a conversation between a more experienced student and the same two faculty. In this situation, a fourth year Ph.D. student was discussing the work he had done.

1. The student explained that the data on the handout he had passed around was from work he had just done testing saccharides using GC-MS (Gas Chromatography, Mass Spectrometry). He then said he had to derivative the saccharides into alditol acetates, which were volatile enough to run through the GC.
2. F. Iota: What's an aldetol acetate?
3. The student explained how the molecule was arranged.

4. F. Iota: Ok, then you've got a trans--, not transesterification (?), yeah, transesterification (?) from the alditol acetate to making the acetate sugar, sugar?
5. Student affirmed and explained that they were called anhydro-sugars.
6. F. Delta: (Inaudible Clarification)
7. Student: Yeah, basically.
8. F. Iota: Ok.

In this case, the student was doing independent work, just like the Lab Tech in the previous example. Both had knowledge of a system that was unfamiliar to the faculty. Here, F. Iota and F. Delta must ask the Ph.D student to explain to them what he has done, because they cannot interpret the data he has presented without it. However, unlike the previous example, the faculty accepted what the Ph.D. student has explained without question and allowed him to continue his work as he saw fit. Throughout the observations, faculty talk with this particular student was similar to this exchange. At one point during an observation F. Iota asked him what he planned to do next in his project. When told, the faculty member just replied with a shrug and said, "Ok." The implication was that any one student's abilities to design projects and pathways independently of the faculty member was developed through social interactions over time. If a student's knowledge of a system exceeded that of the faculty in authority, that alone did not imply that they were able to work independently or that their ideas would be taken seriously.

The previous examples suggested that faculty significantly contribute to the pathways students take through the research lab setting by dictating the research agenda and monitoring student independence. This was in line with the premise of apprenticeship theory (Lave & Wenger, 1991), which suggested that tasks were scaffolded over time as students gradually learned to become. However, there were also specific kinds of knowledge the students were



required to obtain before entering the research setting, as well types of knowledge it appeared they would learn while conducting research itself. These will be considered in more detail in the next section.

### Knowledge Types and Expectations

There were four types of knowledge that tended to dominate talk in the research lab settings. Three of these, Content, Processes, and Authority were types of knowledge faculty expected students to have upon entering the lab. The fourth, what will be called, Scientific Activities, appeared to be developed by students while in the research lab itself. There was little expectation that student would come in with this knowledge. All four will be discussed in more detail below.

*Content.* The first knowledge type, which students were expected to know prior to entering the research lab was basic content. This included things like vocabulary definitions, theories, laws, equations, typical characteristics of molecules, functional groups or solutions and basic reaction types. Unless specifically asked by a student, faculty did not clarify or define terms or spend time explaining ideas to students. However, for basic chemistry knowledge, the student presenting was expected to be able to respond to any questions that might arise. For example, in the RLB setting, a Master's Degree student asked a question to clarify data presented by a Ph.D. student:

1. M.S. Student: Asked if the data was indicative of phosphate or phosphorous.
2. Ph.D. Student responds: Phosphate.
3. F. Iota: Total phosphorous has phosphate.
4. M.S. Student: Ok.
5. Ph.D. Student: Yeah, I mean...

6. F. Iota: There's basically no...

7. Ph.D. Student (cuts off F. Iota's explanation): They're all the same.

In this case the M.S. student did not have a basic understanding of the molecules being tested, but the Ph.D. presenter was able to clarify for him, along with F. Iota. However, this explanation would not have necessarily occurred unless the original question had been asked. There was no intent to explain the difference between phosphate and phosphorous, as the expectation was that students would understand this given the chemistry. In another example, the same group was discussing possible reasons for some strange data when the idea of the characteristic of the acid was brought up. F. Iota stated, "If it's a Lewis acid, it's a Lewis acid. It doesn't matter what ligand is hanging off of it." From there the conversation continued, but with no explanation of what a Lewis acid or a ligand was, nor why it did not matter what ligand hung off the acid.

*Processes.* The second type of knowledge students were expected to have upon entering the research laboratory were basic process skills and the ability to use equipment typical to chemistry research. This included more sophisticated machinery such as Nuclear Magnetic Resonance Spectrometers (NMRs) or Mass Spectrometers. Again, faculty did not spend time explaining how to do things like properly use pipettes or glassware, how to make dilutions, or how to run basic experiments, unless asked specifically. Although there appeared to be limited numbers of some of this equipment, and it was not always functioning properly, the faculty took for granted the fact that their students were using this equipment to fulfill the purposes of their research and doing so at appropriate times and with the appropriate solutions. Equipment and resources were meant to be used, according to the faculty, and they expressed surprise or frustration upon learning that students were not using them. So, while they may have dictated the overall progress of a research program, faculty did have expectations that

students were able maneuver through their individual tasks using the proper supplies. This was supported by the sheer number of discussions that revolved around ideas such as what reagent was being used and whether specific inputs or outputs from reactions were exposed to various tests.

These discussions were not only common with faculty towards students, but were also often seen occurring between students as well, although this student data could not be transcribed and therefore could not be exemplified here. Faculty almost always described equipment as being useful, despite the limited access and breakdowns that students used as excuses for not using them. For faculty, time, cost and other structural limitations were generally ignored

At the beginning of one session of the RLA meeting, F. Alpha was discussing with the group the fact that the NMR typically used by the students was not working. A student who had needed to use the machine brought this to the attention of F. Alpha, alerting the rest of the group to this disruption. However, F. Alpha was undeterred, and said, "Yeah, ok. If anybody has desperate needs for NMR let me know. We can access the one at K College." For the faculty, even broken machinery was not a barrier to completing research. In another example, from the RLC meeting, a student explained that the data they collected had not turned out as expected. Upon further explanation, it was revealed that it got late into the night, so he stopped the reaction and went home, and then tried to continue it the next day. A fourth year Ph.D. student interjected that the reaction would not work if stopped half way through. The student revealed that he now understood that, though at the time he did not.

Although students were expected to know how and when to use the equipment available to them, they were sometimes hesitant to work independently. The same student who had stopped the reaction to go home had not, as a result, obtained the data the group needed.

A discussion ensued where F. Delta said that the student would have to use the NMR to get information. The student hesitated with this, saying that it was difficult to get in to use the NMR because there was a sign up sheet for it, which limited use to two hours. No one in the group knew how long it would take for the reaction to run. The student gave these as reasons for not having done the NMR sooner, however F. Delta was not concerned. He suggested that they sign out the NMR from 3:00-5:00 pm, which was the last time slot of the day, implying that if the sample was not finished, they could stay until it was. He ended by saying, "If it has to run all night, then you stay all night." Although access and time were limitations for the student, the faculty did not appear to have the same problems. This will be discussed in more detail later.

*Authority.* A third expectation that faculty had of students upon entering the research lab was an ability to defer or appeal to authority, or in other words, to reference their work. The term "defer to authority" was taken directly from Lemke (1990), and was used there to describe how students were required to forgo their own everyday knowledge of events in deference to those presented by an authority, which might be a teacher, a textbook, a lab manual or any other scientific source. It was used here to not only describe the idea of providing citations, but also that students had a more complete understanding of the major researchers involved in their chosen field and what they have contributed to the community of practice. Commonly faculty wanted student to be able to identify literature values for various properties of elements or compounds, to cite individual research, to know what chemists contributed what knowledge, and to have the ability to find information that was already known in the literature. Although literature values or content-based facts were emphasized, this appeal was also made in the form of establishing methodologies or suggesting settings for specialized equipment. In other words, justifying the work students were doing. The implication was that in order for students to be

able to justify their data they needed evidence in the form of already established knowledge or protocols from scientists within their community.

Faculty would press students when information from the literature was not included in discussions. They would ask for clarification, and would expect the student to know the information, even if they had not included it. This information was often considered crucial for being able to continue a discussion, or to know where to go next. In the RLA setting a student was presenting her work via Power Point. Throughout the presentation several clarification questions were asked by both F. Alpha and other students. At the end of the presentation, the following exchange took place:

1. F. Alpha: Going back to the first part of your slide, do you have a reference for boronic acid chalcones being more—
2. Student Presenter: Interrupts and clarifies what she meant about the boronic acid.
3. F. Alpha: Uh-huh.
4. Silence ensued as F. Alpha does not understand the student's response.
5. The presenter tried again to clarify.
6. F. Alpha: Yea, I didn't, so up one more (slide).
7. Presenter tried to explain again, but she was referring to the wrong point.
8. F. Alpha: No, that one. Do you have a reference for your second point?
9. Student Presenter: Nods her head.
10. F. Alpha: You do?
11. Student Presenter affirms again, while looking through her papers for it.
12. F. Alpha: And, also for, I think your first slide you talk about gold nanoparticles having no toxicity. Check in the literature, some, it depends what kind of gold nanoparticles you're working with.

Here, F. Alpha points out two areas where the student had failed to use the literature base appropriately. Once she lacked a citation for a claim, and though she had the literature to support the claim, she did not use it in her presentation. The second time she failed to consider the broader literature in making a generalized claim.

However, although it was common for faculty to ask about literature values, there was often little or no explanation of where or how to find the information or what problems might be encountered in interpreting it. In the RLC setting, the Engineer was voicing frustration because the literature values he found for energy outputs in various systems all used different labels. This forced him to go through and try to convert each value to one common form. Most frustrating was that one value he needed to use was in units he had never heard of and had no idea how to convert. The faculty did not provide him any explanation of what this value meant or how he should deal with it. In fact, F. Delta changed the topic and asked him a different question, avoiding the discussion altogether.

*Scientific activities.* This term was used to describe generalized activities scientists or researchers do as part of conducting experiments or other studies. These were things such as developing questions, designing methodologies, interpreting data, or presenting results. This was the only one of the four characteristic types of knowledge found in research settings, which faculty did not seem to expect students to be able to understand prior to coming into the research lab. Rather, these were things that students learned to do as they interacted with both faculty and other students during their research experience. Take the following exchange as an example of this. One student was discussing her results from several tests she has done on water samples looking for levels of phosphorous, silica and other inorganics. The rest of the lab group was referring to a handout she had given them with a graph and several data tables. At the end of the discussion, the following conversation took place:

1. F. Iota: But, no, this is great. Thanks for this. You know, there's a lot of data here.
2. Student: Yeah.
3. F. Iota: It's a good, great, 'cause—
4. Second student: Makes a joke about making the rest of them look bad.
5. Everyone laughs, but F. Iota remains serious and shakes his head.
6. F. Iota: Well, she had a finite, well, very well defined analytical methods. Once you got your hands into it, because there's nothing to worry, the inorganic, not worrying, not handling the mass spec, which you know can be—
7. Student: Yeah.
8. F. Iota: So, um, but also, you've become very efficient I think.
9. Student: Yes, I have. Something that would have taken me hours before takes me minutes now.
10. F. Iota: That's good. So, so, uh, that's great!

The instructor seemed pleased by the progress the student had made, not just in producing data, but in understanding how to run the tests for each inorganic molecule effectively. In another lab meeting, he actually referred another student to work with her because of the gains she had made in expertise. There was, it appeared, no expectation that this student enter the lab already knowing how to run these tests, as she suggested that “before” it might take her hours to run them, but she was allowed to learn this in the lab setting, and now that she has progressed she got praised for her work. And, this occurred with what the faculty admitted was a very well defined analytical methodology, further suggesting that analytical methods, even very straightforward ones, were acceptable things to learn on the job.

In the RLA setting, a student had presented her work on gold nanoparticles. On different occasions, F. Alpha interrupted asking her if she had done certain tests for controls. At the end

of the presentation, F. Alpha made the following comment, “Cool. So, now you’ve got two experiments to do. The platinum black and the water experiment. And, then finish the paper. Ok?” Here the student was provided a plan for her overall research goals. She could not work on the paper until she had completed some controls to verify her original results. However, it was also clear throughout the dialogue that F. Alpha was not concerned or frustrated that the student had not thought to do these experiments already.

*Summary.* Individual student research tasks were the main focus of the research labs. To be successful in these tasks students were expected to have a strong grasp of the general vocabulary, facts and theories of chemistry. In addition, they needed know what resources, in the form of equipment and supplies, were required to carry out their research tasks. Furthermore, faculty expected that students understand that all of the previous knowledge about their topic was important and should be identified and used as a basis for their research. However, general research tasks, such as planning out broad sequences of research or interpreting data were done cooperatively as a group. Individual students were not expected to know what pathways to take in developing their research. Each of these four types of knowledge will be discussed and explained further later in this chapter, as the classroom lectures and laboratories were analyzed further to consider if knowledge students were expected to have in research laboratories was developed through earlier experiences.

#### General Description of Classroom Lectures

As noted in chapter three, a total of six lecture settings were observed, with five different instructors, ranging from one thousand level introductory chemistry courses to a five thousand level inorganic course. All classes were held in the same building, and in fact were all held in one of only three different rooms, meaning that for any advanced students the settings



were both normal and familiar. All rooms were in a newer building, and therefore had up to date equipment such as document cameras, overhead projectors with multiple screens, automated equipment, microphones and large periodic tables hanging on the walls. They were also all tiered, so rows in the back were higher than those in the front, with the main doors toward the front of the room. Although there were also several white boards in every room, only two faculty members used them to any extent and only one used them as their primary teaching equipment.

All lectures were teacher-centered, though the amount of student involvement in the class through small group work, asking or answering questions, or independent problem solving varied extensively by teacher. In fact, there were no trends that could be found in the level of student involvement based on course level or number of students enrolled. The number of students also varied per class, but trended towards having more in the lower introductory level (upwards of 200) and having fewer as the course number increased. This was not a perfect trend, however, as the 2000 level course had fewer students than both of the 3000 level courses observed. The 5000 level, though, did have the fewest of all six.

None of the classes instituted a seating chart of any kind and few appeared to have any explicit rules other than not allowing cell phones and some did not allow lap tops, though others did. Supplies and equipment provided by the faculty included handouts, along with the periodic tables on the walls and the desks students sat in. Calculators, pencils, paper, books or other study guides were assumed to be provided by the students. More information about resources available to students will be discussed later. All instructors used at least one form of multi-media in addition to basic lecturing. These included power points, writing notes or problem solving on the document camera, using the white board for notes or problem solving, or using clicker questions. Some faculty used several of these, while others used only one.

Lectures revolved around five main types of talk, along with other miscellaneous types of talk: content, problem solving, story telling, methodologies and motivation. Each of these will be discussed in more detail later. First, however, a general overview of each of the six settings is provided. From these, it was clear that faculty were extremely different in teaching style and therefore using any one of them individually to define “normal teaching practice” would be misleading.

#### Basic Characteristics of Each Observed Setting

*Lecture L1A.* This was a first semester introductory chemistry class, taught in a large lecture hall, by F. Alpha. This class met twice a week for one hour and 15 minutes each time. Over 300 students were enrolled, though the exact number was not known. Students sat throughout the room, being highly concentrated near the front and middle. There appeared to be no major biases in gender, with males and females being approximately equally represented. There was a Teaching Assistant usually present in the classroom during the lecture. He would walk around the room, quieting students who might be distracting others either because they were talking or using their computers inappropriately. He also started class for F. Alpha on two occasions when she was late.

F. Alpha interacted with students regularly. She asked many questions and would often call on students by name. She also allowed students to ask their own questions regularly. There were several occasions in which she would have one-on-one conversations with a single student or group of students during class itself, to ensure concepts were being understood. She used Power Point regularly, which appeared to be standard documents available to any instructor who might teach the same course. She often skipped material, and refused to play any of the videos embedded in the slides. She told students they would not play on her computer, but

students did not believe this and often pressed her to show them the videos. She also used the document camera for problem solving. She never used the white board. F. Alpha made herself available for students after class, as well as for extra review sessions on top of her normal office hours. She would threaten taking away these extra opportunities in exchange for good behavior in the classroom. Her lectures, though highly interactive, were still direct and teacher-centered. The following chart (Fig. 1) provided an overview of time spent in the classroom, divided into four categories: Instructor focused, Student focused, Silence or Other.

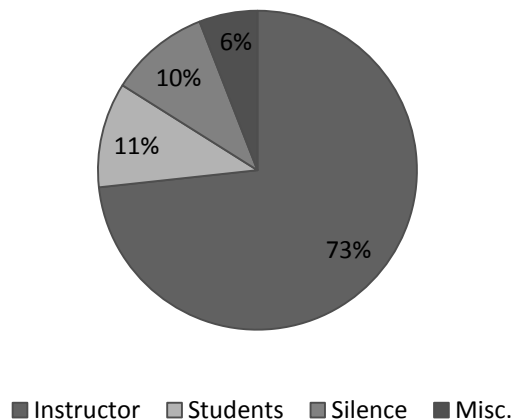


Figure 1. Talk time allocations in the LIA classroom taught by F. Alpha.

This graph showed that although the instructor dominated talk in the classroom, because large amounts of time were spent in lecture, students also had ample opportunity to talk. Silence was also well represented and much of that was spent in wait time, waiting for students to respond to questions, or in transitioning across the room, because F. Alpha moved around regularly, especially when speaking with students. The six percent allotted for miscellaneous talk could mostly be contributed to the high number of side conversations F. Alpha had with students, which were inaudible to the camera and most of the rest of the class, as well.

*Lecture L1B.* This was a second semester introductory chemistry class, taught in the same large lecture hall as the L1A class. The instructor of this course was F. Beta, who was also observed in the L5A setting. This class met three times a week for 50 minutes each time. Over 300 students were enrolled, though the exact number was not known. Students sat throughout the room, being highly concentrated near the front and middle. There appeared to be no major biases in gender, with males and females being approximately equally represented. Unlike the L1A class, this section did not have a teaching assistant to help maintain control. Discipline was sometimes a problem here, with student regularly carrying on conversations while F. Beta was lecturing.

F. Beta rarely interacted with students, choosing to stand at the front of the room most of the time. Though he asked many questions, he had short wait times and generally answered the questions himself, rather than allow time to force students to respond. F. Beta regularly encouraged students to ask their own questions, but few did. He also answered questions much more directly than F. Alpha did, avoiding any drawn out conversations with individual students. He used only the document camera, as a medium for giving student notes. He would actually transcribe onto the camera the notes he wanted to go over, which he had already written out for himself to refer to. He also used this for problem solving episodes as well. F. Beta encouraged students to come to his office hours and made himself available after class, but not before. He disciplined students as a way to maintain control of the classroom, usually by either generally announcing that students needed to pay attention, or in one case directly addressing students talking. His lectures were highly direct and teacher-centered. The following chart (Fig. 2) provided an overview of time spent in the classroom, divided into four categories: Instructor focused, Student focused, Silence or Other.

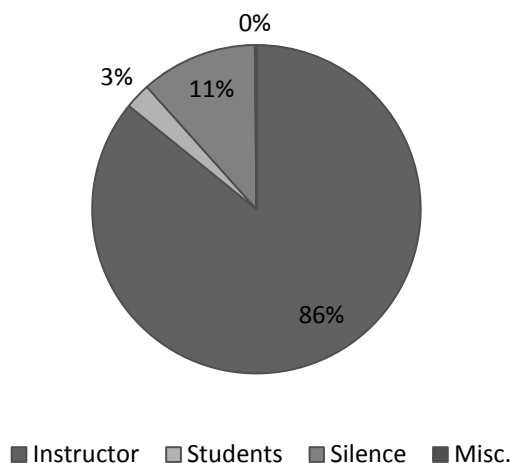


Figure 2. Talk time allocations in the LIB classroom taught by F. Beta.

This graph showed the teacher-centered talk of F. Beta, with very little input from students. The high percentage of time spent on silence was attributed to his use of the document camera to write notes on. It often took longer to write out notes than to speak them, so he would be silent while writing out his statements. There was also no significant amount of miscellaneous time spent, indicative of the fact that F. Beta was efficient in his approach to teaching, with very little downtime or off-topic talk with students.

*Lecture L2A.* This was a 2000 level specialty chemistry class, taught in somewhat smaller lecture hall than either of the 1000 level courses. The instructor of this course was F. Gamma. This class met twice a week for one hour and 15 minutes each time. There were only around 30 students enrolled in this class, and so the room was much larger than what was needed. As such students sat mainly in the front or middle of the class, with no one in the last few rows. There was also a definite male gender bias in the class. Because of its small size, F. Gamma had no problems maintaining discipline, and the atmosphere was more relaxed than in larger settings.

F. Gamma interacted regularly with students, but these exchanges tended to occur during off-topic, casual talk, rather than during content delivery. He asked some questions, but

they tended to center around clarifying student understanding or asking what they already know. F. Gamma did not tend to encourage students to ask their own questions, but he was open to answering any questions they might have had. He did not mind students leading the conversation off topic, and at times he used storytelling as ways to break up lecture time. He used the document camera to display pre typed notes on, and also used the white board for additional explanation. Students were given copies of these notes ahead of time so they could follow along with the lecture. Most of the time in lecture was spent going over problem solving as opposed to content or factual information. Despite the casual nature of the class, it was still faculty centered, with students contributing little to the overall course. The following chart (Fig. 3) provided an overview of time spent in the classroom, divided into four categories: Instructor focused, Student focused, Silence or Other.

This graph showed how faculty centered this classroom room, with the instructor doing almost all of the talking, with some input from student. Despite the fact that the instructor involved students regularly, they had very few sustained periods of time in which the focus was entirely on them. When F. Gamma started to lecture, these were long periods of expository, uninterrupted talk. This led to the small percentage of student involvement seen in the chart. The silence was mostly from F. Gamma thinking about what he was saying. He tended to use long pauses in his speech to orient himself or to refocus talk away from off-topic conversations back onto content. This class also had several episodes of equipment troubles, in which the instructor spent time trying to figure out how to fix the document camera. This also contributed to the miscellaneous talk in which several students at once would try to help him readjust the settings and talk became too overlapped to record.

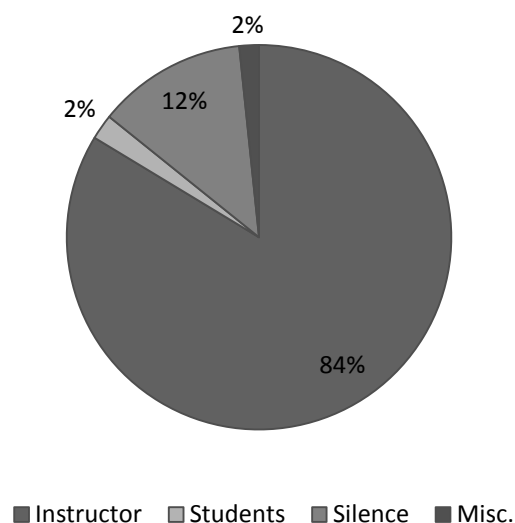


Figure 3. Talk time allocations in the L2A classroom taught by F. Gamma.

*Lecture L3A.* This was the second semester of a 3000 level organic chemistry class, taught in a room identical to the L2A class. The instructor of this course was F. Delta. This class met three times a week for 50 minutes each time. The room accommodated the number of students in the class, so that they were spread throughout, though slightly more concentrated near the front and middle. There appeared to be no noticeable gender bias in this class. F. Delta had a good rapport with the students and despite the moderately large class size he did not have any discipline problems during the observations.

F. Delta interacted regularly with students, and also called students he remembered from previous classes by name. When speaking to students he did not know he would ask their name before continuing. He asked questions regularly and encouraged students to respond by having long wait times and continuing to reword questions until students responded. F. Delta also made himself available for questions during class, and beyond his required office hours, he scheduled an extra hour of meeting time per week that students could use as a recitation-type setting, for homework help or questions. He used power points during the first several class

sessions, but this was mainly because the topic required he show many pictures of different types of spectrophotometry data outputs. Once the subject changed to more traditional chemistry, he stopped using power point and used the white board instead. He rarely used the document camera and equipment gave him problems because he was unfamiliar with it. This was the only class in which students were given multiple opportunities to work independently, or in small groups, to solve problems before it was discussed as a large group. Also, students were heavily involved in large group discussions about problems. Though still mainly instructor-centered, students had more involvement in this class than any others observed. The following chart (Fig. 4) provided an overview of time spent in the classroom, divided into four categories: Instructor focused, Student focused, Silence or Other.

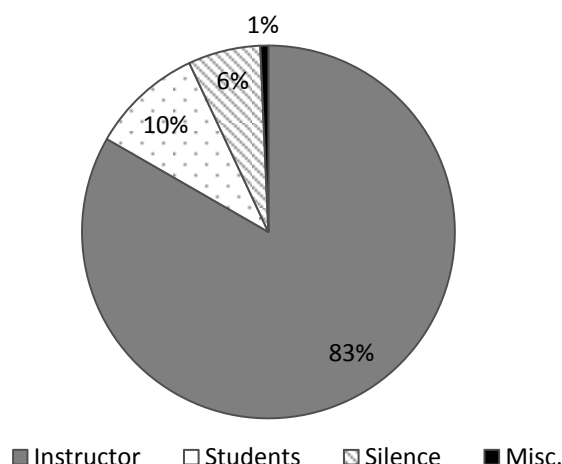


Figure 4. Talk time allocations in the L3A classroom taught by F. Delta.

The graph indicated that although F. Delta was the primary speaker in the class, students did have the floor 10% of the time. Although F. Alpha in the L1A course allowed students to talk slightly more, at 11%, the quality of student talk between the two classes was very different. Students in the L1A setting were asked so many questions that even short responses added up to measurable time. Student talk in the L3A course, however, included



opportunities where they worked cooperatively in groups, or came to the front of the class to help F. Delta go over problems. The silence in this setting was generally attributed to time spent in transition, because the instructor tended to move around the room quite often.

*Lecture L3B.* This was a 3000 level specialty course, taught in a room identical to the L2A and L3A classes. The instructor of this course was F. Epsilon. This class met three times a week for 50 minutes each time. The room was slightly small for the number of students enrolled in the class, so that almost all seats were taken, even those in the back of the room. There appeared to be no noticeable gender bias in this class, though males may have outnumbered females, it was not a dramatic difference. F. Epsilon appeared to be friendly with students, though he interacted with them very little. The combination of his teaching style, and the fact that most of the students taking the class were juniors or seniors resulted in no observed discipline problems.

F. Epsilon interacted with students before class, but rarely during class time itself. He was, what might be referred to as a typical lecturer. He rarely asked students questions, and when he did they tended to be rhetorical, or he had very short wait times before responding himself, so students were never obliged to respond. When students did respond to questions he evaluated responses by directly stating if it was right or wrong, which did not work to encourage continued student input. He rarely asked for questions from students, he often ignored or did not see when students had questions and when students did ask questions, which he appeared to welcome, his responses were either short and to the point, or long and unclear. F. Epsilon had office hours, but did not come across as welcoming students to contact him beyond those. He made several comments that would suggest that he was too busy to be able to provide students more time or resources than what he already provided them. He used mostly power points for his lessons, which he provided to students prior to lectures. He also used the document camera

to show students handouts, which he also provided them. Rarely he would use the white board to illustrate a point. F. Epsilon rarely did anything other than lecture, and he covered content in the form of facts, equations, laws, and theories almost exclusively. He did almost no problem solving, although he did tell stories sometimes as a way to exemplify his lecture points. The following chart (Fig. 5) provided an overview of time spent in the classroom, divided into four categories: Instructor focused, Student focused, Silence or Other.

Talk in the L3B class was clearly dominated by the faculty member. The two percent of time focused on students added up to less than 10 minutes, approximately six of which was actually a short quiz that they took. There was also little silence because there were so few questions, and very little wait time associated with them. In addition, F. Epsilon did not tend to pause in his lectures. He spoke almost continuously. This was the most teacher-directed of all lectures observed.

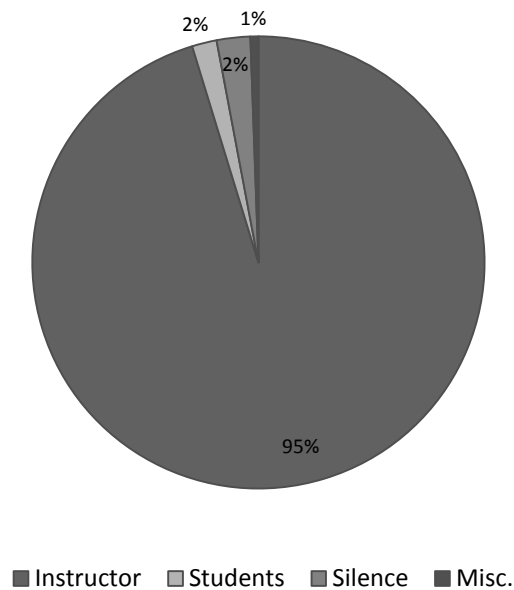


Figure 5. Talk time allocations in the L3A classroom taught by F. Epsilon.

*Lecture L5A.* This was a 5000 level specialty chemistry course, taught by F. Beta, who was also observed in the L1B course. This class met in the same room as the L3A, and L3B classes, and met twice a week for an hour and 15 minutes each time. There were only about 15 students in the class, all of which were either upper-class undergraduate students or graduate students. There was a definite male bias, with only two female students in the class. All students sat near the front of the room, and because of its small size and the level of students, there were no discipline problems in the form of talking out of turn or failing to follow rules. However, this was the only setting in which a student was observed to outwardly challenge the instructor and not accept their authority.

F. Beta acted in this class almost identically to his actions in the L1B class. He rarely interacted with students, choosing to stand at the front of the room most of the time. Though he asked many questions, he had short wait times and generally answered the questions himself, rather than allow time to force students to respond. F. Beta regularly encouraged students to ask their own questions, but few did. He also answered questions directly, avoiding any drawn out conversations with individual students. He sometimes had difficulties explaining difficult concepts, often choosing to simply repeat what he had just said when questioned, as opposed to seeking new ways of explaining. However, he made several mistakes during his lectures, and when pointed out by students he offered praise to those who found the mistake. He used only the document camera, as a medium for giving student notes. He would actually transcribe onto the camera the notes he wanted to go over, which he had already written out for himself to refer to. He also used this for problem solving episodes as well. F. Beta encouraged students to come to his office hours and made himself available after class, but not before. His lectures were direct and teacher-centered. The following chart (Fig. 6) provided an

overview of time spent in the classroom, divided into four categories: Instructor focused, Student focused, Silence or Other.

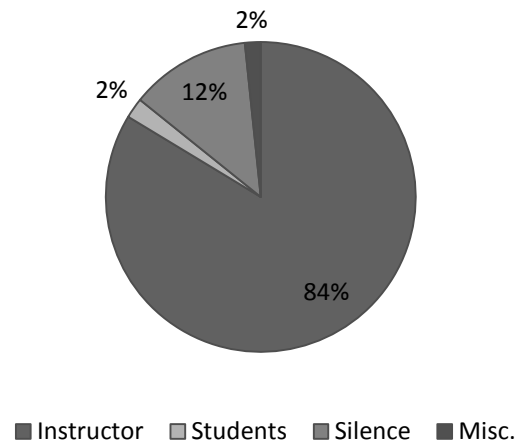


Figure 6. Talk time allocations in the L3A classroom taught by F. Beta.

Comparing this graph to that from the L1B class, it was clear that they were very similar. F. Beta taught in a faculty-centered manner. Student input was limited to responding to questions and sometimes asking their own questions. Silence dominated over student talk because of time spent at the document camera writing out notes. This indicated that instructor behavior remained fairly consistent, no matter what level course they were teaching, though differences between instructors of any other course varied greatly.

*Summary.* These general descriptions of each lecture setting indicated that faculty differed greatly in their approach to teaching and how they balanced student involvement with the need to cover concepts. Trying to suggest there was one “typical” college lecture environment created difficulties. Lord’s (2002) description of a college science lecture might best be represented by F. Epsilon, but he was the only one of the five faculty who taught this way, making this approach of didactic, expository, teacher-directed lecture the exception, rather than the norm. In addition, faculty appeared to teach consistently no matter what setting, or

level of course they were in. F. Beta's time allocations were almost identical when teaching a 1000 level introductory level course and when teaching a 5000 level specialty course. Therefore, aspects of learning, such as student involvement or autonomy were not scaffolded over time in the lecture classroom setting, but rather were dependent on teacher characteristics.

The next section, however, attempted to look beyond differences in faculty presentation of information to find patterns across settings. By looking at what was talked about by faculty in each of these classes it was possible to notice trends in what was taught and how it was presented. Analysis of the observational data found that faculty focused on five major topics during lectures. These were Content, Problem-Solving, Storytelling, Methodologies, and Motivation. Each of these will be discussed further below.

#### Describing Talk in College Science Lectures

*Content.* Most of the talk in the chemistry lectures revolved around content. Content included basic theory, scientific facts, and vocabulary words. All of this was generally, though not always decontextualized. Context was defined as any way of situating the content being taught. For example, F. Epsilon, in the L3B course was describing the importance of the hydrogen bonding between water molecules and he added context to this by saying, "This is ice, in the form of a snowflake, and the hydrogen bonding is going to contribute to the kind of structure that's going to give us the hexagonal shapes that are characteristic of snowflakes." Different faculty added context to discussions on content to various degrees, with some adding almost none, while others, such as F. Epsilon, consistently using context as a way to exemplify talk.

Looking specifically at what content was taught, almost all of it could be categorized into one of three broad topics. First was the basic structure and function of atoms, molecules and

compounds. Second, was developing understanding how chemical reactions take place, both ideally and practically, including knowledge of equations, which define energy input or output of those reactions. Finally, they focused on acid-base reactions, neutralization and buffers. Note that this was consistent throughout all of the six courses, no matter what their specific topic or nature, though they all differed in the amount of each taught or the level at which it was explained. For example, the idea of the activity series, which describes how reactive elements are as you move down or across the periodic table, came up in both the L1A course and the L5A course, though they were only briefly mentioned in the former, but fully described in various contexts in the latter. In addition, reactivity of elements across or down the periodic table was mentioned in the L2A and the L3A course, even though the term “activity series” was not used. Coordination complexes were also discussed in the L3A course, the L2A course and the L5A course, though all in different capacities.

Other examples of this include the concept of acids, bases and buffers. The L1A course first mentioned this in the second observation, when F. Alpha said, “Because in this particular case you have an acid reacting with a base, you have an acid-base reaction, ok, to give you salt and water.” It was mentioned again, later in the same lecture and again during the third observation of the same course. The same concept was also mentioned in the L2A course, when F. Gamma mentioned that strong acids and bases do not make useful buffers. It was also brought up twice in the L3B lectures as well and was briefly discussed in the L5A course. Another example was the Henderson-Hasselbalch equation, which was discussed in the L1A course, the L2A course, and the L3B course.

Another characteristic of the way content was presented was that attempts were consistently made to connect new learning to previous or future ideas, rather than as a disjointed array of facts strung together. For example, F. Epsilon in the L3B course gave students

concept maps, which he would then use as review of where they had been as well as to show students what they will be discussing later. In the L1A lecture, F. Alpha mentioned on more than one occasion that students going onto the next course would need to know the material they were learning to be successful in that course: “You’ve got to know the difference between an electrolyte and a non-electrolyte. Especially if you plan to take Chemistry 2. It’s all about solutions.”

Content was consistently covered in lectures and the same basic content ideas were covered repeatedly in different courses. This was in line with the findings from the descriptions of the research settings in which students needed to have a basic understanding of basic theories, laws, definitions, and facts prior to entering the lab. It also accounted for why students who had not yet completed their undergraduate studies could still be at least partially successful in the research setting, as even very early courses covered much of this information, even if in a more broadly defined way. Because content was generally presented without context, it may have been easier for students to transfer what they had previously learned about each topic to new settings, and ultimately into the research lab. Also, content knowledge appeared to be at least somewhat scaffolded through college level lectures, with each new setting adding on more information about the same three broad topics, along with concerted effort from faculty to connect knowledge not only across topics, but even across courses.

*Problem Solving.* Beyond basic content, though, students were also taught how to apply what they had learned. This was done in two ways. One was through problem solving and the other was through faculty story-telling. Problem solving was extremely common during daily lectures and it was one of the few places during class time when students had the opportunity to participate. Generally problem solving took place after a central concept or idea had been

presented and students were then given the opportunity to work with the instructor to solve a problem associated with that concept. According F. Alpha in the L1A course:

1. F. Alpha: Alright, so now that we know our balanced equation...what do we do with the balanced equation? We always solve problems with them, right?
2. Students groan audibly

Problem solving was the natural extension to learning content. The following exchange looked at a typical problem solving exercise. This occurred during the L3A course after the instructor had described via lecture how to interpret proton NMR spectra. F. Delta put up an example on the overhead and gave students several minutes to find out what they could about it on their own. During this time he consulted student groups as they worked and addressed problems they had seeing the spectrum. When finished, a student volunteer was encouraged to come to the board to help with the discussion.

1. F. Delta: What's your name?
2. Student responds.
3. F. Delta: Ok, good luck. Alright, S- tell us, tell us what you think it might be. And, or at least what information, what information, how you got, how you got there.
4. Student draws the structure of the molecule on the board that he believes is represented in the spectrum and begins to explain what he has.
5. F. Delta clarifies: Ok, the doublet that's furthest downfield?
6. Student affirms and continues.
7. F. Delta evaluates: Ok, so the, the signal that's at about three and a half parts per million is which proton?
8. Student points out which proton it is.
9. F. Delta: Ok, why?



10. Student explains his choice.
11. F. Delta: Well, but why don't you draw, draw in all of your atoms. Draw in all of your atoms explicitly. Right on that structure that you have.
12. Student complies and corrects his drawing.
13. F. Delta: So, how many, how many chemical environments are there? Well, first of all, how many degrees of unsaturation are there?
14. Student responds with zero.
15. F. Delta: Ok, zero. So there are no double bonds, there are no rings. How many chemical environments do you see in the, from the spectrum.
16. Student respond with three.
17. F. Delta: Nope. There's one, two, three, four different chemical environments.
18. All students begin to talk because most missed one (Discussion continues for another seven minutes).

This passage was typical of problem solving in other settings in that the instructor asked many questions as they worked through the problem and student input was highly encouraged. It was atypical, though in that a student was actually asked to come to the front of the room to solve the problem with guidance from F. Delta. Generally, the instructor would solve the problem with input from students. However, there were four other aspects of this exchange that made it typical of problem solving episodes in other classes. These included the following: Decontextualization of the Problem, Student Input, Algorithms, and Teacher Attitude Toward Mistakes. Looking back at the exchange above from the L3A course, the spectrum was presented without context. There was no discussion of who obtained the spectrum, where it came from or how it was obtained. The reason for needing to solve this particular problem was also left open, with the central question being only what must be found given what was known.

A significant amount of time, over fifteen total minutes, was spent in solving this problem, yet it was never placed in any specific context. In another example, F. Beta in the L1B class was talking about state functions. He suggested that water be used as an example of this, which initially put the problem in context. Students were then asked to think about what the temperature would need to be for water to be in any one physical state. The following was the problem solving episode itself:

1. F. Beta: Ok, now let's see, let's call these states, name these states. Ok? We'll name them A, B, C, D. If we want to address them, then we first name them and talk about them. And, now let's consider the temperatures. Going from one state to another, the change, if we think about temperature, you will see that this applies to many other things as we go ahead with this class. Change will be described by this very simple formula:  $\Delta X$ , (and X is something that we will be studying) is  $X_{\text{final}} - X_{\text{initial}}$ . So, in order to get the change we need to know the, whatever state in final form, and the function in the final form and the initial form. So, let's apply that to our case. X equals any state function. Temperature, or pressure or other properties. Let's look at the temperature change. Notice that X is now T, temperature. We're going from A to B. This is a very simple example, but this is what is the basis for what comes next.

We are using this formula, ok?  $\Delta T = T_{\text{final}} - T_{\text{initial}}$ . It's important here that we recognize which one is initial, which one is the final. B, A, where do I put them? Right? We are going from A to B, so the final will be B and the initial we will say A. Once we know that we need to get the actual number.  $T_{\text{final}}$ , B, is 20 degrees Celsius, minus  $T_{\text{initial}}$ , that was zero degrees Celsius. That gives us the

difference, which gives us 20 degrees Celsius. So, going from A to B, temperature changed 20 degrees Celsius.

Although originally the instructor began putting context to the question, by associating state changes with water, he removed the context of water once actual problem solving began. In fact, F. Beta went through several examples using this data, another three minutes of class, and the word “water” was never mentioned again. The data had become completely decontextualized and was now only used as a way to demonstrate how finding changes in state was done in chemistry.

Another general characteristic of these problem-solving episodes was that students were given opportunity to participate, as shown in the L3A example above. In addition, the discussion around finding Delta T from the L1B course also included student input after the didactic statements recorded here. Generally, the instructor asked students to fill in information, as problems were solved in a step-by-step fashion, until a final answer was reached. The following example was from L1A where F. Alpha was discussing how to solve acid-base neutralization reactions:

1. F. Alpha: So, we have a hundred milliliters of HCl, and it turns out that the concentration of HCl in this particular case is 0.01 M. Ok? So, now we have to go back to molarity calculations. And, then, for NaOH we have the same thing going on. A hundred milliliters and 0.01M concentration. The question that we have now is what is the molarity of the NaCl that’s going to form? Ok? What is the molarity—what is the concentration of the NaCl that we will form? How do you go about solving this problem? What did we say was fundamental to whenever we’re solving problems in chemistry? What is the important thing you need to find?
2. Students begin to generally respond with “Moles.”

3. F. Alpha: Very good! We always have to look for the number of moles. Right? You guys remember that? Moles? Or is that foreign?
4. Students respond generally that they remember.
5. F. Alpha: Do you remember moles, guys?
6. Students say "Yes" louder.
7. F. Alpha: Yes? Ok. How do we find the number of moles if we have volume and molarity? What was the equation? We learned in this class?
8. Students begin to respond but without confidence.
9. F. Alpha: Remember we said that molarity (inaudible), the basic reaction, molarity is equal to moles divided by the volume in liters. Right? Meaning that moles are going to be molarity multiplies by the volume in liters.

This problem-solving episode continued for another four and a half minutes with continued back and forth between the instructor and the students. F. Alpha used questions to continually guide students to the next step in problem solving. She encouraged student participation, even when students were hesitant to respond to questions. Problem-solving was one of the main areas in which students were actively encouraged to contribute to the lesson. F. Epsilon was the only faculty member who did almost no problem-solving, and as Figure 4.4 showed, he also had the lowest amount of student involvement.

The problem presented in the L1A course also lacked context. Other than noting that students were to hypothetically think about being in a lab (not transcribed here), there was nothing to suggest why someone might want to combine HCl and NaOH together in these quantities or the importance of finding the final concentration of NaCl that forms. In addition, the problem was solved via algorithm, or a known step-by-step procedure. In the example F. Alpha began by asking what the most important thing to find was. In this case it was number of

moles. In the previous example from the L1B course, F. Beta explicitly points out that they were using "...this formula, here." In the example from the L3A course, the instructor had the student at the board draw in all of his carbons and then one by one asked where they were represented in the spectrum. The following took place in the L2A lecture, when the instructor was beginning a problem-solving episode regarding titrations: "Ok, um, so we want to calculate the molarity of the HCl. What do we start with? Balanced equation. Always write the balanced equation. That's where you start to get your partial credit, guys."

The implication of this was that understanding the process of solving problems was not emphasized as much as simply finding ways to get the right answer, though this was not what the faculty claimed. For example, F. Beta in both the L1B course and the L5A course would spend time showing students how equations were developed or how to solve problems without using a formula:

1. F. Beta: You might have, even, ways of solving these types of problems. I'll tell you about what I find the easiest, and the most logical one, so you don't need to memorize any formulas, what comes above, what comes below and those fractions. Just think about this. Write it down. Stoichiometry tells me, right, that two moles of octane give you, I mean react with twenty-five moles of oxygen. That's right off the reaction. You don't have to memorize that, just look at the reaction.

However, two lectures later, F. Beta says, "Again, you need to attack the problem from the easiest part. Right? What's the easiest to calculate?" And, later, "What can we do next?" The instructor of the L3B course, also suggested that students should concentrate on learning the material broadly and understanding concepts, but then in the same lecture said that they would need to memorize many things, including vocabulary terms.

Finally, during problem solving faculty seemed to have little problem when students did not respond, or responded incorrectly to questions that asked them to input previously learned information into the problem. In the example from the L1A course, F. Alpha spent several talk turns ensuring students remembered the fundamental concept of moles. Although, it was impossible to translate to a written transcript, the tone of voice during this discussion was not one of frustration or annoyance, but rather concern that students did, in fact, remember the concept. In some respects faculty expected students to be continually building their knowledge, and putting it into the larger context of what they had already learned, but there was little evidence to suggest that a lack of content knowledge caused the instructors to become frustrated.

Of the five faculty that were observed, three actively sought student input during decontextualized problem solving in a similar way to those described above. F. Gamma did not structure his problem solving in the same way. Rather than present students with some sort of basic content, which was followed by problem solving, his lectures were much more fully integrated. Students really learned the content through solving these decontextualized problems, all of which were already presented to students in handouts, and projected on the overhead. F. Gamma would walk students through the problems, covering content ideas as he went, allowing for student input along with questions or other comments. The following was a typical example of problem solving in the L2A course, where it was essentially built into the structure of the lecture, rather than pulled out as a special exercise. After speaking for some time about the relationship between  $K_a$  and  $K_b$ , F. Gamma immediately moved into the following:

1. F. Gamma: Um, so we want to find the pH of a solution of the weak acid, and um, its base. So, we have, um acetic acid plus sodium acetate. We look at what is the

concentration of, let's just call it acetic, acetic acid for example. The concentration of HA is this undissociated acid minus what, however much dissociated, which has got to be equal to the hydronium concentration, which coincidentally, if there was acetate added with the sodium acetate, this concentration would be the same as what?

2. Student responds

3. F. Gamma: Ok. So, we have minus the hydronium ion concentration, plus the hydroxyl ion concentration. That tells you, because this times this has to be  $10^{-14}$ , they're approximately in the range of  $10^{-6}$ ,  $10^{-7}$ . Right? If your pH is between six and eight then hydroxyl ion concentration, hydronium ion concentration are right around  $10^{-6}$ ,  $10^{-8}$ . Ok?

Although F. Gamma still made a point to involve students, this problem solving episode in which students were asked to find the pH of a weak acid and its conjugate base was integrated into the lecture much more and sometimes it was difficult to distinguish between simple lecture and actual purposeful applications of the content. For example, in Line 3, F. Gamma began by talking about adding two concentrations together, a step that led to solving the original problem. However, in the next line he provided more generalized information about how acid-base systems work, describing a relationship between pH and ion concentration.

These problem-solving episodes contributed to students' general content knowledge gains by providing them with two things. First, they learned the basic equations needed to understand typical chemical reactions. Second, they learned how to apply the factual knowledge they have developed to generalized, non-contextual problems. Again, the lack of context allowed students to transfer knowledge from setting to setting, including into their future research labs. Unlike, content, however, problem-solving did not appear to be scaffolded.

Knowledge needed to successfully solve problems in each setting was re-explained, even if the students had seen the same equations in previous classes. For example, although the Henderson-Hasselbalch equation was presented in three different settings, each time it was introduced, the equation and the steps to solving it were explained to students in detail.

*Storytelling.* The third type of talk, and the second way application was presented in the classroom, was storytelling about real-world experiences. All of the instructors did this, regardless of course level or general teaching style. These storytelling experiences provided most of the context within the lectures, since basic content and problem-solving talk was generally decontextualized. Storytelling was apparent from early on in observations. They were first categorized as “anecdotes,” suggesting they were episodes of extra, extraneous information that did not directly relate to the content. An example of this was in the L2A, where the instructor began talking about Dow Chemical making shingles with photovoltaic cells. There was no discernible connection between this topic and the content being covered at the time in the lecture.

However, during more explicit data analysis it became clear that in addition to these anecdotes, there were additional talk turns dedicated to telling a story, but about things related to the content. For example, immediately preceding the talk on photovoltaic cells, the instructor had just been talking about the problems with Chinese wallboard smelling like sulfur when it got wet and the reasons for this, which was directly applicable to the current lecture topic of differential solubility. Therefore, storytelling was defined as any episode in which the instructor left the main content to talk about ideas or issues outside of it, whether directly related or not. However, although storytelling provided context it was not equal to context. Faculty could, and sometimes did, provide context within their talk on content. For example, when explaining about differential solubility F. Gamma noted that sea-water from the Atlantic and that from the



Pacific were different. This was contextual information, but not a story. To be distinguished as a story, the talk had to be personalized or valuated by the instructor.

The following excerpts were from two different faculty, with very different teaching styles. In both, the instructor was trying to explain to students why it was important for them to learn the information being presented. The first one was from L2A, and F. Gamma explained possible sources of error in scientific research, specifically as a way to exemplify a question off the students' first unit exam.

1. F. Gamma: Um, the other ones are the method itself, could be biased high or low. Um, sampling could be one. It's not, strictly speaking, part of the method, but the sampling, let's just say, as oceanographers did for decades. They took water samples. If you take water samples in a bottle that's on a cable, ok, and it's open. It's called a Nansen bottle. For decades they took samples by, this is this cable going down, usually to another water bottle, and, the what, when you take the sample you put that bottle right through this microlayer. Well, associated with the organics in that top layer are also metals. And, so, for years the concentration of copper in ocean water, twenty-five micrograms per liter, sixties, seventies. It was, it was like the oceans are terribly polluted. The problem as, copper was in this microlayer. Or the chromium, or the lead, or the zinc, or whatever else was there. It was enriched in that layer. So, when the bottle went through that layer, it picked up the copper. And, when you go to take a sample, you drop the messenger, down the wire, it trips this one. This one moves, comes over and they fall and close themselves. Ok. It's an ingenious system. It works quite nicely. Um, the problem is, people gave talks for years about all the metals being in the microgram per liter range. And, then one, one renegade, Clair Patterson from Cal Tech put his bottle in a plastic bag. When it got below surface, he ripped the bag off. He was getting nanogram per liter numbers for copper, chromium, cobalt. It was quite interesting in the seventies to watch two people give talks on

chromium in ocean water. The first guy would go, "It's all microgram per liter." Clair Patterson would get up and go, "No, it isn't." He showed, he showed the whole field exactly what was going on. So, it was amazing. Um, but the sampling had a major impact. Three orders of magnitude.

The second excerpt was from the L5A lecture where F. Beta was trying to explain the differences between cis and trans structures in compounds, in this case platinum with two ammonia and two chlorides.

1. F. Beta: We can put the two chlorides and the two ammonium molecules in trans to each other, right? So, it's on opposite sides. Or, we can put them next to each other. It doesn't really matter which side we put them on, these are equivalent. But, you can clearly see the difference, right? Here it's across, here immediate neighbor. So, this one is trans and this one is the cis. The cis compound cures cancer. The other one kills you.
2. Students laugh
3. F. Beta: Ok, so it is very important that we recognize these isomers and we separate them. When you take the drug, you will only want the cis in that pill. And, to do the reaction, you mix everything together, you might end up with a mixture of the two. Cis platinum is the most accessible, although it's not the best, but it's probably still the most used anti-cancer drug. Now-a-days we have substituted a second, third generation derivative. This is called cisplatin. The drug.

Note also that, unlike the problem-solving sequences, students were often not involved in these story-telling experiences. Even in situations where students may be able to contribute to a story about real-world chemistry based on their personal experiences, they were

sometimes unable to understand what part of the story was important to tell as revealed by the following short discussion between F. Beta and his students.

1. F. Beta: You've probably never seen hydrogen burning, but you've probably seen gasoline burning. What is always associated with burning?
2. Student try to respond, but do not provide the response F. Beta is looking for.
3. F. Beta: Why do we make a fire?
4. Students again respond, but again, not in the way he expected.
5. F. Beta: With the fire wood? What do we feel?
6. Students finally suggest that it's heat.

Notice that although this was simple context rather than pure storytelling, the goal for F. Beta was to involve students by allowing them to contribute to the story by providing the idea of heat being released when something burns. However, the students were unable to devise this, because this was F. Beta's story, not theirs, and so he had to lead them down an explicit path to get them to go where he wanted to go.

A similar problem occurred when the L1A instructor asked students to think about what happened when silver was associated with a halide and exposed to light:

1. F. Alpha: So, whenever you take a silver halide, so silver chloride or silver bromide and you (inaudible) with light—this is the basis of what process?
2. Three seconds go by as SO waits for a response.
3. F. Alpha: What (inaudible) process uses silver?
4. Students begin to talk, but they have no clear response.
5. F. Alpha: Where is silver used a lot?
6. Students again respond, but with no clear response.

7. F. Alpha: Photography. You guys don't know anything about this because you all just use your phones now to take pictures. But, typically what used to happen in the olden days is you'd actually have a roll of film, right? And, you'd stick it in your camera, take pictures and then you'd have to go into a dark room to actually develop the photos. Ok?

In this case, the instructor attempted to pull students into the story, but because they had no experience with this particular process they were unable to adequately respond to the questions. F. Alpha made very few attempts at storytelling, but had one of the highest levels of student-talk. Rather than tell stories, this instructor chose to do problem solving instead and heavily involved her students in those problems. Story-telling did not appear to contribute significantly to student knowledge that was needed for success in the research setting. Instead, faculty tended to use it as a way to keep student interest during lectures, and to counter the decontextualization of content, providing students with real-world examples of chemistry in action. There was no indication that this material would be tested. There was also no instance in the research lab setting in which students or faculty relayed stories from their classroom experiences as exemplars. In general, though common, story-telling served the purpose of providing students with examples of real world application of content and as a technique for re-focusing student attention when lecture became tedious.

*Methodologies.* The three aspects of content, problem solving, and storytelling, were the most common types of talk in the lectures. However, there were also two smaller, but still significant topics covered. One was acquainting students with some of the common methods used in collecting data in chemistry. This was often done as part of teaching students how to apply what they had learned. Therefore, when part of problem solving it was often

decontextualized and when part of storytelling it was placed into context. Examples of each follow.

A good example of a contextualized methodology discussion was the one recorded above by F. Gamma about sampling on ocean water surfaces. The main point of the discussion was to point out problems in methodology that can lead to error, but at the same time, F. Gamma was able to teach students something about sampling methods.

In the L1B course, though, the instructor was explaining to students about the very beginnings of bomb calorimetry, which was further discussed later in the course.

1. F. Beta: We will be considering, first, a system that we study. Right? A system that we do an experiment on. And this system could be, for example, a test tube, or a round-bottomed flask. It is contained. This is what I call the system that is under study. The system has something around it, right? Unless we are in a vacuum, but even then there is vacuum around it. Whatever is around the system, we are calling, simply, the surroundings. This is important. Why?

Because the energy transferred might not only happen within the system, one component to the other, but also the surroundings. I mean, there is air around that flask and the reaction is exothermic, the surroundings will heat up, too. So, the two together, the system together with the surroundings. This will be called what?

2. F. Beta waits for a response, but there is none.
3. F. Beta: We have a flask. We have air around it, and we have the walls of the building, and we have more air and we keep going and what do we have around us?
4. Several students reply, but do not give the answer F. Beta is looking for.
5. F. Beta: The whole universe. So, this is what we call the universe.

F. Beta gave a general description of what will be used later as a description of how to use a bomb calorimeter, but it was mostly described without context. In this case, the methods for determining heat released from a reaction were part of understanding the content. This was not a story, but rather a description of a system. Bomb calorimetry itself appeared to be a common method used in chemistry to measure energy production of reactions. It was one of the labs students conducted during F. Iota's CL4 course. However, L1B was the only lecture setting this methodology was described in.

Faculty rarely referred to the laboratory students could take in association with the course in order to help situate student thinking about chemical processes. There were no significant exchanges with students in which the instructor used what was done in the classroom lab to exemplify the lecture content. Sometimes an instructor would mention that the content they were about to learn in lecture, they had already seen in lab. In lecture L2A, F. Gamma said, "Now, unfortunately, you probably already did the titration experiment in the lab, and you'll sit there and act like everything I'm telling you is new, but it's not. Ok?"

In the L1A class, F. Alpha, also talking about titrations, asked the students if they recalled doing it in their classroom lab and then reviewed what should have happened if they did it correctly. The L3B instructor mentioned the lab several times, but more in reference to housekeeping activities, such as adding the lab late, training the TAs or how the lab manual was divided. F. Epsilon also mentioned several times that students will make buffers in the lab, that they will do an electrophoresis in order to separate amino acids and that there will be changes to the lab in the future, given newer technologies, but very little of it was explicitly related to content.

The most extensive talk revolving around methodologies was in the L3A course, where F. Delta spent the first week and a half of class going over different forms of spectroscopy,

including Infrared and NMR. However, most of this revolved around how to understand data output from these machines, relating it back to an understanding of the behavior of elements, as opposed to describing the step-by-step methods of using the equipment.

Although faculty did, at times, talk about methodologies, they did not do so to such an extent as to account for the expectation that students have a strong understanding of basic chemical processes and procedures. If this was scaffolded for students prior to entering the research setting, it must be done in the classroom lab setting. Talk about methods in lecture settings was not repeated in any other lecture. For example, IR or NMR spectroscopy was not discussed outside of the L3A course and water sampling was not mentioned outside the L2A course.

*Motivation.* Finally, faculty also spent some amount of time giving students advice, promoting self-motivation or in some cases, extrinsic motivation. Generally, students were forced to take on the primary responsibility of learning, which the faculty consistently and firmly insisted on. However, this might not be obvious to students unless they paid close attention to what was actually being said. Extrinsic rewards tended to be explicitly and strongly stated, and therefore might appear as dominant to students. Examples of extrinsic motivators included mostly points or grades for exams or quizzes and the need to know the material for future courses.

Intrinsic motivation was found mostly in implicit cues in instructor language, such as, "And it's very important that we be writing this, right?" (L1A). In this case, the instructor wanted students to be taking notes, but rather than explicitly tell students they must write this down or face consequences, the suggestion was simply made, but not enforced. The assumption was that students that heeded F. Alpha's advice would be more successful than those that did not. Another example of this was in the very first class of the L3A course. The instructor was trying to

tell students where they will start since it was the second semester of a two course series. At one point F. Delta suggested that students block out study time for the course in their schedules, just as they would for the actual course. The following rationale was then provided:

1. F. Delta: But, wherever is convenient, block it out and keep it sacred, like you do for times for your learning, right? We'll talk a little bit about some things here, but it's when you sit down and work the problems and take notes from the book, that's when you're really going to learn, learn this stuff. And, at least two to three hours outside of class for every hour that you are here, listening to me, ok? That's my recommendation. *But, you're all adults. Take it or leave it* (emphasis added).

F. Delta offered no extrinsic reward for following his advice, nor was it a requirement for the course that students do as he suggested. The onus for success was placed clearly on the shoulders of the students, and failure could not be attributed to the teacher. Essentially, the students had been given advice, but it was their responsibility to use it. In the L3B course, F. Epsilon assigned homework problems, but offered no points to hold students responsible for doing them, but he expected students to carry through in doing them. "You're going to have to practice. It's not going to, you'll have to do the calculations, and the homework will help with that."

In various lecture settings, students were encouraged to set up their own study groups, to read the text, to pay attention to special problems, to make sure they used the extra resources available through the text book (e.g. CD-ROMs), to learn how to use their calculators, to purchase certain types of pens for note taking, to find, print out and use the posted power points, to use the study guides or practice tests developed by the faculty before exams, to go to office hours and to attend extra study sessions. However, all of these were optional and rarely were students given explicit instructions in what would be most valuable for their time or how



to use those resources appropriately. The idea of self-motivation or intrinsic rewards was seen consistently in all settings, though not quite as clearly as it was in the lectures.

*Summary.* In general, although lectures were certainly teacher-lead and directed, they were generally not without student involvement. Students were consistently encouraged to participate during class by responding to questions as well as by asking their own. However, depending on the overall atmosphere or the way the questions were asked, students did not always use these in class opportunities for participation. Student involvement was mostly sought during problem solving episodes, but encouraged at other times as well. Most of the lecture was decontextualized, with the exception being stories told primarily by the faculty as a way to orient students to the valuableness of learning the material. Student input was generally not solicited during these stories.

Although faculty did provide some information about basic process skills, it was not enough to account for expectations of student knowledge in research lab settings. In addition, faculty regularly talked about learning being the responsibility of students, but they did so in such a way that it was often implicit in their talk. It was not clear that students would necessarily understand this. The idea of student responsibility and roles will be discussed in more detail later in this chapter.

Generally speaking, content knowledge, which students were expected to know in research labs, was well established and scaffolded in chemistry lectures. In this case, the expectations from the research setting would be unproblematic, as students were regularly exposed to content in their prior coursework. However, the lectures did not account for knowledge of basic process skills or for an ability to refer to the previous work of scientists. Although faculty mention scientists and their contributions to the field, they did so to such a limited amount that this talk was categorized as being part of basic content knowledge, rather

than being a different type of knowledge students should have before entering the lab. Also, consistent with findings from the research setting, students were never really taught basic Scientific Activities, such as developing research questions or methodologies. This knowledge was not expected for students in research settings and it was not taught to them in the lecture settings.

#### General Description of Classroom Laboratories

The five laboratory sections observed, ranged from a one thousand level lab through a five thousand level lab. All five were taught by different instructors. The three lower division labs were taught by teaching assistants, two with prior teaching experience and pursuing doctorate degrees and one new to teaching and having just completed his bachelor's degree. The two upper division labs were taught by full-time faculty at the university, and both instructors had been observed in at least one other context.

All five labs took place in different rooms, but all were in the same building, which was newly constructed and therefore had modern equipment and many new supplies. The rooms all generally had bench space for students with several fume hoods around the outer perimeter. The room for the four thousand level lab was arranged slightly differently, which will be described later. Equipment was all kept in drawers and cupboards throughout the room. The three lower level labs were all conducted in a similar fashion. At the beginning of the class the TA described what students were doing that day. This discussion took anywhere from ten minutes to over thirty depending on how complex the lab was. After, students would all form into groups, usually established from the first day of class, and began to work independently. Students had full access to all of the equipment and supplies available in their lab as well as supplies brought in by the TA or the laboratory technician on a cart. In all cases the TA made

themselves available throughout the lab for questions or problems. In all cases students were expected to come to class having read the lab or done a pre-lab.

The four thousand level lab was run slightly differently than the others. In this lab there were several pre-designed experiments, but each group worked on a different experiment each week, rather than all groups working on the same experiment. Because of this, the room was set up differently than other labs, where each bench space contained a set of specialized equipment, one bench per lab students would do throughout the year. Also, because each group was doing a different lab, the instructor would go from group to group to explain what they needed to do and to go over any specialized equipment. Therefore, the first class session in this lab was a lecture, in which the course was explained, and unlike CL1, CL2, and CL3 there were no pre-lab lectures. Students were all expected to have not only read the lab they were going to do that day, but they were expected to have done extra research on it, because not all of the information was provided in their manual.

The five-thousand level lab was run most like a research lab. The students were all given a variety of projects to choose from and then allowed to form their own groups around those projects. One student was doing research in a different lab that qualified for the theme of the class and so she was allowed to do her study outside of the classroom lab days and times. Students were given some articles to read and use to help inform their study, although specific research activities were explained to students ahead of time. Students had the time allotted for the course to work, but in several cases students asked to come in early or chose to stay late in order to work on the project. Aside from the primary faculty instructor, there were also three teaching assistants available to help students. Students worked independently on their projects, but were closely monitored by faculty and TAs, especially near the beginning of their work. Students were required to present a research proposal to the class (included in observations)

and at the end of the semester to present their results (not part of observation period) via a formal poster presentation.

All of the labs settings, with the exception of the five thousand level lab, could be described as highly structured. Students followed prescribed methodologies for completing the assigned lab and variations from protocol were not generally encouraged, though they were not always discouraged. Labs might have been contextualized in the manual, but in terms of instructor talk were highly decontextualized. The one exception to this occurred in the one thousand level lab and will be described later. It was assumed in the four and five thousand level labs that students would find their own context for developing a coherent story about the purpose of conducting certain experiments. It was not clear if this happened in the four thousand level lab, as it was never discussed. The student presentations in the five thousand level lab showed that some students contextualized their work very well, but others did not.

The purpose of the laboratory revolved around three major types of knowledge acquisition. One was learning how to effectively use equipment and resources, as well as when to appropriately use each. The second was to learn how to handle data. The third was how to convey what was learned through writing. Learning how to develop questions, how to design good methodologies, and how to interpret results beyond statistical evaluation was not emphasized in any of the lab classes, with the exception of a strong focus on statistics in the four thousand level lab. Each of these will be described in more detail below.

#### Equipment and Resources

Most of the talk in the labs revolved around how and when to use equipment, solutions, supplies and other resources. The instructor reiterated important safety measures, such as mixing certain chemicals under the hood or wearing safety goggles. Changes to directions were made explicit and equipment students could not have been expected to have used before were

thoroughly explained, for example, pH meters or barometers. Even in cases where students would have had much experience with pieces of equipment they were still highly supervised. In the CL5 class, F. Alpha went with students into the weigh room on the first day of lab to watch them weigh out samples, making sure they did so properly. Sometimes instructors expected students to be familiar with equipment that they were not, as exemplified by the following exchange, which took place in the CL5 course, as well. F Alpha was giving two students in one group an overview of what they would be doing over the next several class periods. One step was using the NMR to ensure they had synthesized the appropriate molecule:

1. F. Alpha: Does that sound good?
2. Students both say that is fine, but also both point out that they have never used NMR.
3. F. Alpha: Really? Oh.
4. One student explains that none of the classes do this, and in one class where it was supposed to be done the instructor skipped it entirely.
5. F. Alpha: What about in 5700?
6. Both students respond that they did not take that class, and so the last time they saw an NMR was in organic.
7. F. Alpha: So, organic, organic? Sophomore organic?
8. Both students: Yes.
9. F. Alpha: Oh, wow. It's been awhile. Ok, that's fine. We'll learn it.

Later in the observation, F. Alpha clarified with one of the TAs whether they knew how to do an NMR in order to show the students, and she gave the group members a tutorial on what they should expect to see once they ran it. In another observation of the same class, F.

Alpha mentioned again that students might need to be taught how to do the NMR because it was skipped over in the class she had expected them to experience it in.

Once students were allowed to start working on their own, they had control over their resources. In some cases, students wanting to get done early would set up multiple pieces of equipment to be able to run more than one test at the same time. Others would substitute one type of equipment for another, which seemed to have little impact on them completing the assignment. TAs and faculty rarely commented on this, unless it prevented other students from having resources. For example, in the CL1 class, one student group decided to use two hot plates so that they could do two different parts of the experiment at the same time. However, there were only enough hot plates to have one per student group, leaving one group short. The TA immediately identified the group that took two, and made them give one up to the group missing one.

Although for the most part resources were readily available, there were several situations in which supplies were short or even when something required for the lab was not available at all. These cases caused frustration for students, although the instructors did not seem to mind. One extreme case of this occurred in the CL3 class, when students were required to run samples through an IR (Infra-red) spectrophotometer. Although there were at least two of the machines in the equipment room, only one was turned on, and students were allowed to have only two salt plates despite needing to run at least three samples. Soon, it was discovered that the machine was not set up properly to display the data how the TA wanted it displayed, and they had to turn on the second machine. With up to nine groups needing to run multiple samples and only two salt plates, backups were immediate. Students became so frustrated by the process that rather than waiting to run their own samples, they simply printed out the data

from the first group that went. The TA was aware of what they had done, and suggested that this was inappropriate of them, but not directly to the students who had done this.

Similar to what happened in the research lab, in classroom labs resources were meant to be used by students. When students did not know how to use resources it was a problem, though sometimes surprising. The classroom lab appeared to be the place where students could learn how to do basic chemical procedures, such as measurements, titrations and dilutions. However, when students used resources or supplies inappropriately, or did not use them at all, the instructor would become frustrated. It appeared that while students gained some of their knowledge of processes in the lecture, most of it was gained from experiences in the classroom lab.

#### Analyzing Data

Much less time was spent on analyzing data obtained through laboratories than talking about process skills, but it was a significant part of the CL4 class. F. Iota spent the first lab period going over basic statistics and giving students several problems in which they were required to apply stats to various data sets. All of the labs in this course required that students take data on sophisticated electronic equipment and then be able to analyze their results. However, students appeared to be highly scaffolded to get to this point. The CL1 course had students filling in pre-made worksheets with their data and then simply responding to questions. The CL2 course forced students to go through some simple statistics after the labs, and turn in data and analysis as lab reports. The CL3 course had students doing both pre and post-lab questions as well as filling in data on neatly structured charts. Students in the CL5 course had to determine on their own what data they should collect in order to provide evidence towards answering their questions, as well as how to interpret the data they did measure.

In the research lab setting students were required to know how to use the basic equipment and supplies of lab, along with general procedures for data collection. Part of these procedures included data analysis, which students discussed along with their projects. They learned how to analyze data in classroom lab settings, and had enough experience with it that they could be expected to be able to do at least basic statistical analysis in the research lab. However, interpretation of the data was rarely talked about in the classroom setting, and this was not included as part of data analysis.

### Writing Results

Finally, there was some discussion of how to write up results, but this was rarely a topic of discussion. Often it was only referred to when discussing how students missed points on their lab reports. It was mostly emphasized in the one thousand level lab when talking about how to write the pre-labs, and CL4, when the instructor explained that their lab reports should look like a Communication Paper from the Journal of Physical Chemistry. Because of the presentation, and associated paper, in the CL5 course, there was discussion about this, including some specific talk on what should be included in both a proposal and in an end-of-work paper. However, talk about this occurred for only about ten minutes on the first day of class and so was not enough to interpret anything significant.

### Summary

There was much less talk in the classroom laboratories than in the classroom lectures. Most of the talk took place in the introductory lectures, most of which focused primarily on ensuring students would follow protocols, housekeeping issues such as taking roll, or in some cases going over data analysis. The labs were all very structured, even at the 5000 level, and they were also very teacher-centered, despite students having a high level of independence



over their resources. In this respect they mimicked what was observed in the research labs quite well. Students were given tasks to do by faculty and expected to appropriately carry out those tasks. Also, similar to what was seen in the lecture, students were not required in the classroom labs to develop their own questions, design their own methodologies or interpret their data beyond what was requested via guiding questions in their labs.

However, what was also missing from talk in the classroom labs was discussions about using literature as a basis for research, citing sources or deferring to authority. This talk was completely absent in the CL1-CL3 courses. In the CL4 course, F. Iota did take students to the library and he mentioned that in order to justify their work students needed to use the literature, but it was not mentioned again during the observed class times. F. Alpha talked about the literature when describing the possible projects students could work on during the CL5 course, and she gave students copies of some of the research she had cited, requesting that they read over them carefully. However, during student presentations of their proposed work, she never asked them about citations or questioned their sources. This was very different from her talk in the research lab setting where she asked students several times about previous work by other chemists.

There were four major types of knowledge that was discussed in research labs: Content, Processes, Authority and Scientific Activities. Of those four, students were required to have some grasp of the first three before coming into the research setting, but the fourth was learned as they worked in the lab. Consistent with this, content and processes were emphasized in the classroom lecture and lab settings, giving students adequate opportunity to learn about basic chemistry concepts and processes, including data analysis. However, referring back to authority, in the sense of literature citations was rarely encountered in either the lecture or the classroom laboratory. There was some discussion of literature and citations in the upper level, 4000 and

5000 level courses, but very little opportunity for students to locate this information on their own. Finally, scientific activities such as planning methodologies were rarely discussed in any setting, consistent with the idea that faculty allow students to learn this type of knowledge as they work in the research lab, rather than needing to know it before they begin lab work.

### Explaining the Apprenticeship of Chemists

The data presented above provided several important aspects of learning to become. First, since the research setting did not require that students understand how to design or implement experiments, but did assume students came in with an understanding of basic content as well as knowing how to use basic equipment, it made sense that the classroom portions of apprenticeship focused on just those. However, this was not a complete description of the authentic apprenticeship experience because it did not provide information about how students might be encouraged or discouraged from moving through the community of practice. Using the definition of authenticity provided by Barab et al. (2000), the next section analyzed faculty talk in terms of the roles of students and faculty, the resources available and the tasks.

The actual definition provided by Barab et al. (2000), was based on an educational perspective, in which they attempted to define an in-class activity as authentic. The original definition said that authenticity could be defined based on the roles of the student, the environment and the tasks. This definition had to be slightly altered in light of the data gathered in this study. First, it was found that student roles were dictated, at least in part, by the role the faculty took on. The less responsibility the faculty took on, in any one setting, the more responsibility required by the student. Therefore, it was impossible to separate the role of instructor from that of student, and in the discussion below, both are considered together. Second, the environment was a very broad thing to describe. While there was some talk about general environmental factors, most of the talk relating to the environment was focused on

resources. Given this, the data presented here also focused on resources as opposed to the environment as a whole.

### The Roles of Students and Instructors

The roles of students and instructors were, at first, difficult to interpret from the observational data. It appeared that they were inconsistent without strong patterns within or between settings. However, it became clear that this was because there were actually three different communities students and faculty were operating within, and roles in each differed. The first community was the classroom community, which included both lectures and labs. The second was the local research lab setting, where students worked within a lab under the direct supervision of a faculty scientist. The third was the larger community of practice; the community of chemists. Each was embedded within the other, so that talk about any one community might occur in any setting. This explained the inconsistency seen in faculty talk concerning roles. For example, an instructor might be talking about the larger community of practice, while in the local research lab. Roles in each setting will be described in more detail below.

#### Classroom Community

The student role in lectures and classroom labs has been fairly clearly defined from the discussion above. Although the content and activities students were exposed to were generally dictated by the instructors of the course, students were given much independence in completing their assignments and in how much work they chose to put into learning. The amount of independence varied with instructor, but especially in the lab settings, students tended to be scaffolded toward higher and higher levels of autonomy. By the time they got to the research setting they had the ability to conduct most basic or common lab practices on their

own, they understood the language associated with chemistry, they knew the types of equations they needed to use to obtain information and they could work unsupervised.

Students had what might be considered a dual role in learning to become. Their tasks were well structured and mostly dictated, and therefore it might seem as though they were simply passive learners. However, faculty consistently insisted that it was the student, not the instructor that dictated their success or failure in the field. The faculty provided students with the basic resources they would need to be successful, but they insisted that students be responsible for their own learning. In some cases, this meant going beyond what was provided for them by the instructor. Take the following exchange in the L5A course. F. Beta was talking about inductive effects in bonding when a student asked a question:

1. Student: Explains that he is having difficulty finding the material on inductive effects in his textbook and asks where he might find more information on this.
2. F. Beta: Um, yeah, this is, uh, treated in organic chemistry.
3. Student: It's what?
4. F. Beta: In organic, organic chemistry, it's treated better, so...
5. The student clarifies that this topic is not in the textbook.
6. F. Beta: Um, no I mean these things should have been covered sometime before.  
You have never seen inductive effects in...
7. The student says that he has, he was just looking for more information.
8. F. Beta: Yeah, well I, I would, this is an inorganic textbook, so I would rather go to an organic textbook to find more on inductive effects.

In this exchange, F. Beta assumed that students have learned about inductive effects before, in organic chemistry, and would therefore know where to find information about it. Although difficult to interpret from text alone, the video showed that he appeared confused by

the student's question. He was even more confused when the student was taken aback by the fact that he may have to look beyond his own textbook to find information about the topic. The tone of voice presented by the student was one of frustration and annoyance that this information would not be in their textbook. Implied was the idea that if he had to know this material, the instructor should have provided him with information on it. The student in this case, had not fully bought into his role of needing to be responsible for his own learning, even though F. Beta expected that to be the case.

#### Local Research Community

The roles of faculty and students in the local research community were not quite as equal. Here, students took on most of the responsibility for completing tasks in a timely manner. Faculty acted as guides to help students through these every-day laboratory tasks, but they did not and would not do the work for them. For example, the following discussion occurred in the RLC setting. A student was explaining his results from an experiment, but it did not work because he stopped the reaction part way through in order to go home for the night. The other students and F. Iota tell him that in this case he cannot stop the reaction before it has completed. However, the discussion continued about his work and it was clear that he had not completed a task he had been asked to do:

1. F. Iota: We won't know until we do, until we do the spectra. We've got to get the spectra done. We've been talking about this now for two and a half months. Two and a half months...
2. Student: Yeah.
3. F. Iota: ...of sticking the aluminum chloride into the NMR. I'm starting to get annoyed.
4. Student says that he will do it on the following Monday.

5. F. Iota: It was Monday of this week that you were going to run the solubility. It was Wednesday of this week that you were doing the spectra, and it was supposed to happen two months ago. How hard is it to stick some aluminum chloride in a solvent in the NMR spectra—spectrometer?
6. ...Long Silence
7. F. Delta. Ok. Monday.

In this discussion the student was assigned a task that he never completed. F. Iota suggested that it was not a particularly difficult task, and voiced frustration that it had not been done yet because the results from this test were important for the overall goals of the research group. However, the faculty member was not going to run the test himself, even if it was simple to do. The student was responsible for completing his own tasks, in a reasonable time. Something he did not, in this case, do.

Faculty also acted as learners in the local research setting, with students being held responsible to present new information they had gathered through their experiments. This was apparent in the execution of the lab meetings themselves, where students would talk about their findings while faculty asked questions or clarified methods. Instructors would then help students interpret their findings in respect to the larger literature base. These exchanges were generally problematic, with the faculty and students working cooperatively to develop an understanding of the research.

### Community of Practice

In the larger community of practice, students had an almost negligible role, with either faculty or some other authority dictating much of what happened. It was within this community that students would have learned about appealing to or deferring to authority, but because it was embedded within the classroom and local research lab communities, it was difficult for

students to separate it from their roles in those two settings. It made sense that students would be marginalized in this community. From an apprenticeship perspective, faculty scientists still had a peripheral role compared to other, more experienced scientists. If the faculty in charge of the lab must act peripherally, than students working under them would be even more peripheral. Conflict would occur when students would fail to defer to authority, believing they had some more significant role to play.

Faculty did not very often talk about themselves as being the authority in the classroom. The authority appealed to in classroom settings was generally an unknown or unidentified individual. The instructor rarely suggested that chemistry was a certain way because they personally dictated it as such, though it did happen. For example, in the L5A course, F. Beta mentioned on more than one occasion that the reason something worked a certain way was because he has told students this. The intent was not that F. Beta himself had developed this knowledge, but rather that someone else had already calculated the values and he was just relaying them to the students. As he said in one case, "How do I know? Because they've already been calculated." However, in another case, when questioned by a student about how they might know something his response was, "Because I've just told you."

This was not common practice by faculty in the classroom. Even when instructors clearly could have authority over something, they often deferred it to someone else, such as TAs. In the L2A course, F. Gamma had just explained to students that strong bases should not be stored for long periods of time because carbon dioxide, which is an acid, will leak in, decreasing the pH of the base. At this point a student stopped class and asked why they store them for so long in the lab. The following exchange then took place:

1. F. Gamma: Because we're bold and brash. We're adventurous. Now, actually, you know I'm kind of a stickler about this stuff, but one or two days, big deal.

2. The student responded by saying that they made the solution one week and then used it the next, indicating it was sitting for an entire week.
3. F. Gamma: Why would you do something silly like that?
4. Student replied that they were told to by the lab instructor.
5. F. Gamma: You were told to. I know, it's a bad thing, being told to do things.  
Sometimes it's baloney. Ok?

In this case, F. Gamma, who students would naturally presume to be supervising the lab, supported by the fact that during observations of the associated lab, F. Gamma visited the classroom and discussed with the TA what would be happening the next week, denied any control over what happened there and in fact suggested that what the TA told them was baloney. Decisions about the storage of base seemed to rest solely with the lab instructor.

Similarly, in the L3B course, the instructor mentioned early that he was pressed for time because he needed to train his TAs for the lab, one of which was brand new. Later, though, he told students that they might have to do pre-labs, though he was not sure what the teaching assistants would have them do with that. Again, although it appeared outwardly as though he should have authority over the labs, he deferred that authority to the TA, taking the onus of any assignments off of him.

In another situation, F. Delta in the L3A course was discussing the output of an NMR spectrum, using it as a problem-solving episode. Students were having trouble understanding something about the graphical output. F. Delta began to try to clarify what was happening, saying, "Ok, so from the integral, *this is just a guess, I may not be right*, I see there are three protons that give rise to this signal" (emphasis added). F. Delta was doing two things here. First, he was suggesting that the important information was held in the data. Second, he was simply attempting to interpret that data, but he may not always do it correctly. In other words, the



authority here was not the instructor, but rather the data. So, despite the fact that F. Delta knew what molecule this NMR output came from, he deferred his knowledge to that of the graphical output itself, and suggested that he was not the authority on what this molecule might be.

This was also seen by faculty in the lab setting as well. In what was the only time in any setting, an instructor explicitly explained the importance of deferring to authority, F. Iota, while introducing a trip to the library, said,

1. F. Iota: Well, fundamentally this is one of the training grounds for doing science, sort of, the way we intend science to be done in the modern era. And, that includes, making sure we have good references for what the literature says. Whether that's for literature values for measured, measured quantities. Whether that is literature comparison with experimental, experimental methods....The library is really important, because if you want to publish a number, if you want to have any confidence in a number, you need to be sure your experimental design is accurate, that you are precise enough and that your values are getting around reasonable expectations, based on what's known.

It was also common practice, especially during story-telling episodes, for instructors to tell students about the findings of other scientists and what these findings have contributed to the world of chemistry. Again, this served to show students that faculty were there to relay information to students and to give them some resources to learn from, but not that they themselves had all the answers. Stories of scientists, such as Arrhenius (Arrhenius acids), Einstein (relativity), Hess (Hess's Law), Debye (Debye-Huckel formula), Patterson (water chemistry), Olam (super acids), Werner (coordination complexes), Michaelis and Menten (nonallosteric enzymes), Charles and Boyle (gas behavior), and Avogadro (number and law) were told throughout the classroom setting.

The appeal to authority was certainly present, but the authority was rarely the instructor, except in practical matters, such as where to sit on exam day or whether or not a cheat sheet was allowed. Instead the authority was another scientist or even in several cases resources or knowledge from somewhere else, such as formulas, textbooks, stoichiometry, balanced equations, measurement tools, periodic tables, professional organizations, un-named scientists, laboratory specialists, the chemistry department or the activity series. Students were also sometimes allowed to be the authority, as shown through problem solving events when the students were asked to fill in information that was requested by the faculty, though students did not always choose to fill that role.

In the classroom settings, the authority figure was given a voice through the instructor, who knew how and where to find information about the topic and the scientists responsible for its development. In the research setting, students became responsible for being that voice. However, throughout all of the observations made there were only three occasions in which students were asked to explore original literature and in only one of those three were they given any access to the resources needed to find those sources. All three of these experiences took place in four or five thousand level courses. In one they were told only to find articles relating to a topic of their choice and write a review of them, an assignment that was confusing for some students. In the second they were given the initial articles they were to read, and it was not clear for some students if they were supposed to find more. In the third, students were taken on a trip to the library where they were instructed on how to use the resources therein to find the literature they needed. Only in the third setting was it made explicit what the importance of knowing how to find and use literature was, as well as having graded assignments around this task. Therefore, although appealing to authority was extremely important in the research lab

settings, and students were regularly exposed to this throughout their coursework, they were not taught how to become the voice of the scientists that came before.

This confusion was seen when observing the Teaching Assistants assigned to the lower level classroom labs. They consistently and regularly appealed to authority, but not surprisingly, the authority was the faculty in charge of the course, the laboratory technician, the stockroom manager or themselves, but never other scientists. While faculty rarely suggested that they were in control of the knowledge base, the TAs did. For example, in the CL1 lab, the TA was explaining to students about the kinds of reagents that could be used to test for three different biomolecules. In this case students were supposed to go through the introduction to this lab in what might be described as inquiry, where they obtain data first and then decide what biomolecule the reagent was testing for. The TA, however, early on in the explanation said, “Ok, so we do not know, *well, I know*, but you do not know what reagent A, B, and C is, but we’re going to find out what reagents A, B, and C are today” (Emphasis added). In this case, the TA was not ready to allow the students to construct this knowledge on their own, and instead made clear that although they may not know it yet, she already knew the answer. This suggested that even when at the stage of being able to teach others about chemistry, they themselves still view chemistry as something developed locally rather than globally or historically.

In the research lab settings, faculty not only required student to appeal to the authority of other scientists, but they also were more inclined to act as authority themselves. They dictated the overall pathways for student research and were hesitant to allow students to work independently. The work of the student in their lab was a reflection of their own work within the scientific community. In one case a student appeared to not recognize that he was marginalized within the greater research community, and still must defer to the faculty. In the

RLA meetings a female student was presenting her work in which she suggested that she was unable to get a reading from the IR using a certain sample. The following exchange took place:

1. The male graduate student tries to clarify the female presenters claim that she could not get a reading on the IR.
2. The female presenter confirmed this as being the case.
3. The male graduate student suggested that she was wrong.
4. The female presenter tried to explain, saying that it was not sensitive enough to get a reading.
5. The male graduate student again tells her she is wrong, and that given what she has told them, the test should be sensitive.
6. The female presenter explains again why it was not sensitive and showed him the IR output to verify her experience.
7. F. Alpha: I think the challenge you have is that you're functionalizing it with amino, and that's not a strong bond. So, you won't get much—
8. The male graduate student interrupts F. Alpha to tell the female presenter that she should be using sulfur instead.
9. The female presenter begins to respond to that comment, but is cut off by F. Alpha.
10. F. Alpha (to the male graduate student): Can you make that molecule?
11. The male graduate student responds uncertainly and appeared caught off guard by the question.
12. F. Alpha (to the male graduate student): You're an organic chemist, right?

In this discussion the male graduate student had challenged the female presenter by suggesting that data she collected was erroneous. F. Alpha allowed the two to converse back and forth, giving the presenter a chance to explain why she believed her output to be accurate.

Finally, F. Alpha intercedes as a way to explain why both were actually correct. The presenter probably had an accurate, negative output, but it was also possible for her to get a positive output, if she would use something other than an amino functionalized group. However, here the male graduate student cut F. Alpha off, and told the female presenter what she should do instead. At this point, the entire tone of the conversation changed. F. Alpha challenged the male graduate student, and asked him if he could make the molecule he suggested. From his expression and his response, he was not expecting this question, or he was surprised by the hostility in her voice. When he responded it was with much less certainty than his previous comments. F. Alpha still comes back at him with a sarcastic comment about him being an organic chemist. The conversation ended with F. Alpha using humor to defuse the situation, but the tension was apparent.

### Summary

The roles of students appeared to be dictated by the faculty, and were based in some part on the role of the faculty themselves. When faculty took on dominant roles, students tended to be forced into marginalized roles. In each community, faculty and students had different roles to play. Since these roles were defined by the faculty, they seemed to understand them and had clear expectations of what they thought students should do in each community. Students, however, did not always buy into or understand their roles and sometimes conflict would occur when they either under- or over-estimated their role in any one setting. Because of the conflict that would result when roles were not fulfilled, it seemed likely that understanding and buying into their roles was a significant part of students progressing through their apprenticeship.

## The Role of Tasks

As described previously the primary tasks students were engaged in were problem solving and lab experiments. Though they sat passively and listened in many cases, the goal of this was simply to gain basic knowledge or understanding. This was often tied in with the extrinsic motivators of doing well on exams or getting grades for homework. Ultimately, the goal appeared to be that students were able to apply their knowledge to solving problems and to actually doing commonly used experimental techniques. In both the lecture and the lab content was highly decontextualized. In fact, context was present very rarely in the classroom setting, and then generally only during story-telling episodes. The question was why decontextualization was so important and what happened when activities were contextualized.

The observations made of the research lab meetings suggested that individual students had highly specialized topics, even within the same lab setting. Faculty in the classroom understood that they had a very diverse population of students in terms of future needs. In the L1A lecture, the instructor made several remarks that singled out a certain group of students for which specific material might be important. For example, when she discussed colligative properties of solutions F. Alpha said, "Alright, so one of the things that we, that you experience a lot, and, and this is more relevant for the chemical engineers or mechanical engineers, boiling point elevation." The implication was that some material especially that which was quite specific, might only be useful for certain groups of students.

In the L3B course, the instructor, on the first day, made a point to ask students what their majors were, working through several, such as pre-med, PA and dietetics. He acknowledged, however, that those who might be majoring in botany would not get much information specific to them, because he did not know much about plants and the book did not cover this area. From the point of view of instructor, it did not make sense to present problems,

content or experiments within highly specific contexts because these may not be relevant to large numbers of students. Rather, presenting these as generalized rules, theories, laws or processes allowed them to fully benefit all students no matter what they might become in the future.

The following excerpt was from the CL1 course. As part of another research project, this particular lab section had students conduct different labs than other groups from the same course. As such, the TA was asked to ensure that they covered the context of the experiment, which was focused on understanding what types of biomolecules can be found in different foods. This excerpt was just a few seconds of the total time T. A. Zeta spent describing this lab, but it showed what happened when a TA used to teaching generalized labs was asked to now put them into context.

1. T.A. Zeta: Alright, so what's the big question that we're ask, asking ourselves today, is what groups of macromolecules are in foods. So, I've already just, just said that. Proteins, carbohydrates, lipids, fats. Um, chemical relevance. So, how is this relevant to us as chemists? Um, it's by using the knowledge of chemical properties and reactions we can identify macromolecules in food. So, the biological relevance is, each class of biological macromolecules has unique chemical properties. What's the real world value? How does it relate to us on a day-to-day basis? What do food labels really mean? So, if you look on the back of a soda can, or the back of a box of crackers, it tells you the content of you know, per serving, right? So, there's this amount of protein and this amount of carbohydrates and this total fat in grams and all that type of stuff, right? So, that's how we relate to, you know, what's in our food we eat every day.

The TA actually read these explanations about connections to biology, chemistry and everyday life straight from the lab handout. Presumably, the students would have already read this as part of their pre-lab, but the TA was unable to put this lab into any more context or tell any other story about this other than what was already given. The only part not read directly to students was that when she mentioned the can of soda or box of crackers, but even that was generalized.

This was one of the few times in which significant context was explicitly added to what would otherwise generally be a decontextualized discussion. It was not clear why faculty did not choose to put more context into the experiments or content talk. One instructor, F. Epsilon, actually contextualized much of his talk, but had such little student involvement in the class, that adding context appeared to have no real negative repercussions. However, it seemed that unless the faculty had a story to tell or were very comfortable with context, they did not add it in.

### The Role of Resources

Resources were defined as any materials that students and faculty had access to, which helped or hindered them in completing tasks. Based on the descriptions above resources were made available to students, were highly structured, and were dictated by the faculty. Power points were posted, notes were defined and given to students, as were methodologies and lab supplies. Although there were many resources available to students, access to those resources was often limited, either by the student themselves or by other member of the community.

Students were given almost complete control over the resources available to them in the lectures. They could choose to use the books, the power points, the pens or pencils, the chairs and desks, the notes or the periodic tables as they saw fit. However, those resources specifically provided by the instructor, which included things like notes or power point



presentations were designed to give all students equal access to them. They were posted online, made into handouts or neatly written on document cameras for easy recording. These were the only resources that were consistent across all students, who chose to attend the lecture. Because most other resources were left up to the students to manage, faculty seemed to take care that the resources they made available to students were highly structured and clear. The instructor did their part by providing those resources or suggesting those resources be used, but ultimately the student controlled how or even if they did so.

The resources provided by the faculty were always essentially useful, even if the students neglected to use them, or disagreed. In an L1B observation it was the first day of class, and the instructor was telling students to please sign up for the OWL problems. The following exchange occurred:

1. F. Beta: You already know that OWL is very friendly, if you make a mistake—
2. Students interrupt with dubious laughter
3. F. Beta (also laughing): Well, yeah, I—you need to, you need to learn about OWL.

Just like about a person. The more you learn about a person, the better you can communicate with the person, and the OWL. Once you know how it works, it shouldn't be that hard.

In this case, students immediately began to laugh at F. Beta's suggestion that OWL was a friendly resource. Though he recognized the students' thoughts on this, by joining along in laughter, he also suggested that it was, in fact, easy to use, and put the responsibility on the students, saying that they just needed to better familiarize themselves with how it worked.

In a second case, F. Gamma in the L2A course was talking to students about buffers, and suggested that they must know about this topic. He then asked a question:

1. F. Gamma: Is anyone using the CD-ROM that came with the textbook?

2. One student responded that he was.
3. F. Gamma: What's your impression?
4. The student responded that it was sometimes helpful.
5. F. Gamma: Sorry?
6. The student repeats again that it helped sometimes.
7. F. Gamma: It helps sometimes. How does it help?
8. The student replied that it walked them through the problems.
9. F. Gamma: Thank you D-. You made my day. I never had a son, but—um, yeah, it, they're very useful, ok?

In this case the instructor asked a student about resources, and although he was not fully enthusiastic about the CD-ROM, saying it was only sometimes helpful, the instructor took this comment and turned it into a full positive. Resources were meant to be used and taken advantage of.

There were some resources, however, that students did not have personal access to, but faculty still wanted to give them experience with. In the lectures, the faculty would often refer to real-world ideas, equipment or supplies used in research that students may or may not have any personal knowledge of or access to. Some things, such as snow or car engines could be talked about casually with basic expectations that all students had some knowledge of or experience with them. In order to give students experiences with resources beyond their access, however, instructors used story-telling. There was no feasible way in the lecture or lab that students would be able to directly experience and understand what would happen if protons were exposed to NMR, and so since those resources were not accessible to students, F. Delta told a story about it instead:

1. F. Delta: This was an experiment a graduate student experimented in the nineteen fifties, and they thought, um, well this is predicted by theory, by quantum mechanical theory. Um, let's put some of this into a magnet, shine some light on it, we'll record the spectrum, write a paper, go to a conference, and then move on with our lives. Right? Um, that's what, that's what they thought....So, each proton, in each chemical environment, gives a different signal in the NMR. And, from that data, from that information of where, where, um where the proton absorbs, what frequency of light the proton absorbs, we can tell something about what kind of goo is sitting around that proton of interest. Which was a surprise to this physics student, who, um, went on to win the Nobel Prize, but has completely revolutionized our world for structure determination.

As noted previously, storytelling was common in all settings, and it provided ways for students to experience chemistry in context and gave them theoretical access to resources that they otherwise would not have.

Most of the resources and supplies that students had access to were in the laboratory and as mentioned previously the labs were what might be referred to as cookbook. Students were given open access to glassware and other equipment as it was available, although supplies were not always in enough quantity to supply the lab. However, the question was why assignments were so highly structured, if resources were fairly abundant. One reason might be that there were financial limitations to allowing students to have more control over resources. However, the data collected in this study indicated a different reason for keeping labs more prescribed and it specifically had to do with access to resources versus availability of resources.

One example of this took place in the CL3 lab, taught by a teaching assistant. In this case, the TA changed the prescribed laboratory on his own. The reason for this was because it

took too long for students to complete it in the three hours allowed. To make up for this the TA decided to cut out the front end of the lab, which originally required students to synthesize two compounds via a series of reactions. Once this step had been completed they were supposed to analyze the mixture using both infrared spectroscopy (IR) and gas chromatography (GC).

Originally the TA suggested that the front end of the lab took three hours in the previous semester and total the entire lab would take six if done in full, indicating that the second part of the lab should also take approximately three hours.

The TA appeared to have had to make this decision on his own. One of the primary resources that seemed as though it should be available to TAs was a faculty member who was supervising the course. It was not clear if the faculty was involved in this decision, but the TA claimed it as his own idea to account for the problems with timing. In either case, a six hour lab scheduled during a three-hour period was out of place. Recall, though, that faculty did not tend to involve themselves in the working of the associated labs, and on several occasions it was clear that they were not even aware of what was being done in them. Therefore, in this case, outward appearance would suggest that despite faculty being a resource that was available, he or she was not accessible to the TA.

To cut down on the time of the lab the TA provided the starting material and products for the students and they needed only prepare them in mixtures for both the IR and the GC. This laboratory started at eight am, and the IR and GCs were required to be turned on and allowed to heat before using. However, the TA was not allowed to turn the GC on; only the laboratory technician could do this. Unfortunately she was in a meeting until nine am. In the meantime, students were allowed to run their samples through the IR, but this immediately became problematic. The IR was not producing the output the way the TA had wanted it, and with only

two salt plates available to run samples with, progress was slow. By 8:30 am a crowd of students had gathered in the room with the IR and GC and they were audibly frustrated.

The TA chose to turn on only one IR, and it became clear that he was not very familiar with how it was used, as he could not get the output right. Eventually he was forced to turn on the second IR, but had to ask a student what button to press to run a sample. Students also asked for more salt plates, and because TAs were not allowed to leave the lab unattended, he sent a student to go to the stock room to ask for them. However, everyone from the stockroom was in the same meeting at the lab tech and another student informed the TA that there was a large crowd gathered outside the stockroom and no one was helping them. Again, resources were available, but not accessible. The TA did not have enough training on the IR to understand how to troubleshoot it. The stockroom attendants were in a meeting and left no one to take care of the supplies, which in this case were too few to be effective.

By 9:20 only one group had successfully completed their IR, and in that case their output was upside down. Most groups did not care to wait any longer and simply printed out copies of this group's data for their own use. The lab tech arrived around this time to turn on the GCs, but turned on only two of them, though either three or four were available. Students had to wait for them to warm up before using them. Eventually, the lab tech brought in more salt plates for students to use. Unfortunately, this happened too late, and most of the student groups had given up trying to run their samples through either machine. By the time students left, just two hours into a three-hour lab, only two groups had successfully run their IR and four had run the GC. The other groups chose to simply take data from the groups that ran them. The TA expressed frustration that the groups took other people's data and suggested that there would be consequences for doing so.

What happened in this situation? First, this lab would not have taken the six hours originally estimated by the TA. Although the synthesis portion may have taken most of the original lab period, the GC/IR portion would have taken very little time had the machines already been warm and properly set up. Even had the lab tech been in a meeting until nine am, and unable to turn them on until then, the students would not yet be at this stage and so it would leave time for them to warm up without hindering student progress. Also, the extra time could have been used to make sure they were programmed properly for data output. In a normal lab setting student groups would all be finished at staggered times. Having only two machines turned on, or even having only one salt plate per machine, would probably not significantly hold up student groups. Therefore, the original design of this lab was quite suitable and *necessary* given the access to resources available to TAs and students.

The transition away from the originally designed lab failed not because there were limited resources available to students, but instead because the access to those resources was limited. If the TA had been allowed to turn the machines on himself, he could have had them set up prior to students needing to use them. Had he been properly trained in using the IR, he would have been able to troubleshoot the problems, or he could have assured they were set to display data properly. He might have also been able to have more than just two salt plates available as well. It appeared that part of the reason for having structured and defined labs was not because resources were not available for more open experiences, but because students, including the TA, were not allowed access to some of those resources. It must be clear to both students and TAs that although they were free to use the equipment and supplies made available to them, they had limited access to those controlled by other, more senior, personnel.

Note that problems with resources occurred in all three of the labs taught by TAs, but in neither of the upper division labs taught by faculty. In fact, in the CL5 course, the instructor

explicitly told students to just tell her what they would need to complete their project and she would get it for them. In a second case, the lab was in need of Pasteur pipettes. The instructor told a student to go get a box from the stock room. When he came back with a large box he tried to take only what he needed and wanted to return the rest, but F. Alpha insisted that they not return them, until the supply had been refilled.

The limited access students and TAs had to certain supplies and equipment might also, in part, explain why they were hesitant to use them in the research lab setting. Up until working in this setting, their access was always limited to what was explicitly made available by faculty or a staff member. Students were freely allowed to use supplies available within the lab classroom, but those brought in from the outside were dictated specifically by the TA. Even then, the TA did not always appear to have direct access to other supplies, or did not think to make use of the access they had. The following example took place in CL1, as students were gathering equipment they would need for that day's lab, which included ten test tubes per student group.

A student approached T. A. Zeta and said something to her:

1. T. A. Zeta: You don't have enough?
2. T. A. Zeta (to class): Ok, who has more than ten test tubes?
3. No one responded.
4. T. A. Zeta (to student) trying to figure out how many more test tubes they still needed.
5. T. A. Zeta (to class): So, everyone, every group give N- one test tube until he gets to at least nine. Ok. So give a test tube up. Cause he only has four.
6. T. A. Zeta (to student, N-): So, you need at least five people to give you test tubes.
7. T. A. Zeta (to student, later): Are you good now?

8. T. A. Zeta (to class): Alright, he's good now. Thank you for your generous, your generosity.

Despite the fact that the students were allowed to find their own resources for the lab, the first thing T. A. Zeta did was to accuse groups of taking more than they need. So, while on the outset it might appear as if they were given freedom over their surroundings, in reality, they were held to the expectation that they use resources only as they were instructed. After realizing that it was not the students that were at fault, but the laboratory supplies not being sufficient for the class, T. A. Zeta then made the decision to have other groups give up one of their ten test tubes, until N-'s group, also had nine. Therefore, again, it appeared that no one had full access to resources. The students must give up some of their glassware, making more work for them during the lab and the TA appeared to be either unable to use the stockroom supplies to get more or unwilling to try.

When the TAs were allowed access to resources, they often had go through either the faculty in charge of the lab or the stock room to get what was needed. The following was an example from CL2, where the TA was trying to figure out why students' solutions were already basic enough to turn a pH indicator blue, even before starting a titration.

1. T. A. Eta (to a group of students): I bet, I bet I know what happened. Because last week when I went to get calcium carbonate from the stockroom the guy came up to me with two bottles. One was, like, the ACS reagent, and the other was kind of a non-(inaudible). Sort of like, actually, I've got—(T. A. Eta walks over to his reagent cabinet and comes back with a bottle). It was in a bottle like this. And, he asked me if this was alright, or the reagent one. I said definitely the reagent one. Today T-, the main guy down there just gave me what I asked for already measured out. He didn't



ask me which one, and it was kind of in a pellet form, then what I got, because last week was really powdery. This week it was a lot more like a, a—

2. Student finishes for T. A. Eta, saying, “Pellet.”
3. T. A. Eta: --pellet, little tiny pellets. I bet he took it out of this bottle, which this is not going to be pure calcium, so I bet there’s a lot less calcium in the knowns that I prepared today.

In this situation, the TA had to prepare three solutions using calcium carbonate, but he was not given direct access to or control over his resources. When allowed that control, in the previous week, he made a choice that resulted in the lab turning out as he had anticipated it would. However, when that choice was made for him, by a stockroom manager, the result was unexpected. T. A. Eta had to spend almost ten minutes of lab trying to trouble shoot, and students became confused and several stopped working because they could no longer follow the lab protocol. Finally, students were instructed to simply skip the first part of the lab and move on to the second part, meaning they did not get to collect data they would need to do calculations later.

The two faculty instructors of labs had open access to equipment and supplies, and faculty were never a strong presence in the lab settings run by TAs. Any visits to labs by faculty were short and limited to brief discussions with TAs about how things were going. It was not clear if the faculty did not understand the limitations of access to resources for their TAs and students or if they understood this, but did not connect it to graduate student behavior in their research labs. Faculty expected students to take advantage of all of the equipment available to them, and became frustrated when they hesitated to do so. The following exchange took place in RL3. A student had been presenting the results of her current laboratory work, when the instructor stopped her to ask a variety of questions about what she had done.

1. F. Alpha: Ok. Have you been able to do SEM, or--?
2. Student: Responds non-verbally, indicating that she hasn't.
3. F. Alpha: No?
4. Student: Explains that she has saved other images similar to what she has in her power point.
5. F. Alpha: Images? Ok.
6. Student: Continues on, saying that she knows she needs to do the SEM (both the student and F. Alpha laugh while she's talking).
7. F. Alpha: Right.
8. Student continues to try to explain why it hasn't been done.
9. F. Alpha: Ok, so we need to get that.
10. Student again comments that she already has certain data she can use.
11. F. Alpha: Ok. The SEM might be better.
12. The student finally says ok.
13. F. Alpha: Yeah.
14. Student: Ok.
15. F. Alpha: Yeah.
16. Student then admits that she does not know how to use the SEM.
17. F. Alpha: I think, C-, have you used it?
18. C-: Yeah.
19. F. Alpha (back to student presenting): Ok, so C- can help you. Ok.
20. Student goes back to presenting.

The student was told, prior to this presentation, to do an SEM, but had not yet done it.

F. Alpha had to suggest it again, and the nervous laughter and quiet insistence on it being done

indicated that the student had avoided it too long. The student, on her part, continued to attempt to defend the pictures she had already taken through other means, and although not explicitly stated, it sounded as if it was a way to avoid doing the SEM altogether, though she admitted that it needed to be done. Eventually, the real reason for her hesitation was brought out, namely that she did not know how to use the machine. Immediately, F. Alpha singled out another graduate student who was familiar with the SEM and told the presenter that C- will help her, in what was the end statement in the discussion. Based on what was observed in the lab setting, it made sense that students would be apprehensive about using equipment or supplies that until this point they have had limited access to or control over. Faculty did not see these limitations and they quickly solved these problems so that work continued to get done.

## Conclusions

The roles of students and instructors appeared to be important in periods of conflict or stability. Student roles were ultimately dictated by faculty and they changed depending on the community. The led to problems with students misinterpreting their role, causing frustration for faculty. Tasks, however, appeared to be straightforward things, dictated by faculty and accomplished by students. Problems occurred when students failed to complete tasks, but this failure seemed to have more to do with a conflict in role recognition, or possibly in resource accessibility. It was difficult to draw any strong conclusions about resources, however, because many of the problems stemmed from limitations at the level of the stock room. It was possible that the institution studied here had a stock room that was highly protective of its resources and so problems observed in the lab settings were purely local.

## Other Findings

There were some trends in the data that appeared to be significant, but either no strong patterns were found, or there were not enough observations made to be able to draw any conclusions about them. These include: Individual Student Work and Questioning Strategies. Each of these is discussed in more detail below, and indicated possible areas for future research.

### Individual Student Work

Silence played a larger role in the lectures than originally expected, because based on literature (Lord, 2002) it was anticipated that faculty would speak almost ad nauseum. However, there were actually many opportunities for silence. The instructor would stop and think, they gave time for students to write down notes, and there was wait time after asking questions. Only one of the five faculty tended to simply talk or lecture without stopping to ask questions frequently or allowing for pauses in their lecture. The question was whether these pauses had some significance in encouraging students to work independently during lecture, or if there was some intent beyond simply transitioning to a new power point slide.

Other than the exams, however, it was almost never recommended by instructors that students work alone. Silences were not even meant to be silent, as it was almost always tolerated when students would begin to talk socially during long pauses, generally caused because of transitioning in equipment or distraction when writing something down. In fact, during wait times for questions, faculty would become frustrated when there was silence, often preferring students to talk so that they could share what they think they know with others.

In addition, faculty actively encouraged students to work together on everything from homework, to studying, to in-class discussions, to lab exercises. This cooperative encouragement was also dominant in the research labs as well. Students were often referred to another student who had more experience with a certain procedure or machine. Others were

asked to work separately, but together so that they could trade data on a similar but different project, each informing the other. There was no indication that students were scaffolded towards more or less independent work throughout their experiences, as they were consistently encourage to work cooperatively with other students.

### Questioning Strategies

Because apprenticeship emphasized scaffolding of knowledge, it was possible that faculty questioning strategies might provide insight into how they expected that knowledge to develop. All faculty questions in the classroom lectures and labs and research labs were therefore categorized along Bloom's Taxonomy to determine if questions fell into higher levels as students moved up through their coursework. However, findings from this suggested that the questions asked in higher level classes were not higher on Bloom's Taxonomy scale than those asked in lower level classes. Most questions posed by faculty were simple recall or comprehension in all settings. The only main difference was that faculty in research labs asked few to no rhetorical questions, something that was common in the other two settings.

These findings were consistent, however, with the rest of the data analysis described earlier. The goal of the classrooms lectures and labs was to provide students with a strong background of basic knowledge and skills. Comprehension was emphasized in all settings. Even in research settings, faculty took on the role of learner, and so questions still tended to be for basic clarification and recall. Other, more developed ideas, such as synthesis or evaluation, were discussed cooperatively in conversation, but not generally asked in the form of questions.

However, this was one area in which the researcher's limited understanding of chemistry outwardly hindered interpretation or analysis of faculty questions. Unfamiliarity with the content caused difficulties in categorizing questions. Therefore, there may have been more interesting patterns in this data that were not seen because of inexperience with the material.

## Conclusions

There were several key findings from the analysis of this data. First, there was no describable normal teaching of college science lectures or labs. Faculty were all different, and were consistent across settings. Some had high levels of student involvement, while others had almost none. Students, therefore, were exposed to a variety of faculty teaching approaches along with a variety of resources and experiences.

However, despite the differences in faculty, students received very consistent messages about learning. First, basic content and process skills were emphasized throughout all settings. Learning beyond these would take place once students reached the research setting and could work cooperatively with faculty and other students in smaller settings. Second, students needed to be able to appeal to authority. Faculty consistently did this themselves, but it was not done explicitly enough for students to pick up on it and to be able to do so on their own. Third, roles of students, as defined by faculty, were an important indicator of how they might move through the community of practice. Conflict was seen when students outwardly failed to conform to their expected roles. Finally, resources may also play a role in conflict, but because of the nature of the data, it was not possible to determine how significant this might be.

## CHAPTER V

### CONCLUSIONS AND IMPLICATIONS

#### Conclusions

The observations conducted through this study have been used to address two primary research objectives. The first was to describe the apprenticeship experience for students, especially in terms of legitimacy and peripheral work via LPP theory (Lave & Wenger, 1991), but also as a way of describing authenticity in terms of roles of participants, the environment and resources. The second was to determine how this new understanding of scientific apprenticeship might be used in science education. By observing the breadth of chemistry student training from introductory college lectures through laboratory experiences important conclusions about apprenticeship in science education were drawn.

#### A Description of Apprenticeship

This research began with the assumption that learning to become a scientist is an apprenticeship and therefore will reflect the legitimate and peripheral aspects of Lave and Wenger's (1991) theory. The observations made here indicate that students become legitimate members of the community through a combination of self-selection and faculty (old-timer) acceptance. However, even faculty acceptance appeared to be based on student initiative or drive. There were no direct conversations recorded to indicate that any one particular student would not, eventually, be able to continue in the program or were not particularly qualified for becoming a scientist. However, there were three incidences that indicated that although students might self select themselves into the community; they also influenced how faculty mediated their progress. First, F. Gamma let his class out early one day because he was having a particularly bad day. After the class, in an informal conversation, he explained that he had to let

one of his graduate students go because the student was not being productive in the lab. A second conversation took place in a lab research setting, in which a student faced conflict with both the faculty and the other students in the lab because of what appeared to be a poor attitude and lack of cooperation with others. Finally, there was the student in the RLB setting, who had consistently been productive and was given leeway by faculty in designing his own pathway for research. In each of these cases, individual students appeared to both self-select into the community, but also influenced how the faculty interacted with them.

The idea of being peripheral members of the community was easier to document. Students began taking courses which gave them the basic information they would need to be successful scientists. These courses were built around general content knowledge and process skills which were then directly applied in research settings. The labs, though not evenly scaffolded, did show a strong change in emphasis between 3000 level and 4000 level, with the shift in the upper division courses going toward more independent work on the part of students. These findings reflect those found in research by Ritchie and Rigano (1996), in which they suggested that before high school students were able to benefit from a research experience, they first had to master certain process tasks and laboratory skills. College students were taught those skills prior to entering the lab, so it was not necessary for them to learn them *in situ*.

The research settings afforded another set of scaffolds, but those were more difficult to interpret. Most students were given the same level and type of responsibilities in the lab setting, each contributing to a larger laboratory-wide interest. Some were allowed more integral involvement, generally based on experience, in which they were also given tasks of helping other students with their work. Ultimately, it appeared that the most freedom was given to students who had both been associated with the lab for a significant period of time and could be trusted to carry out their work with little supervision. Therefore scaffolding occurred around



more community of practice type activities such as developing research agendas and interpreting data.

Students were not taught in the early peripheral experiences about appealing to the research developed in the greater community. The idea of science as a community of researchers working together, or the social and historical aspects of science were discussed in lectures and in the two upper division labs, both taught by faculty, but they were rarely the main focus of assignments or lectures. Students, therefore, had difficulty when they were expected, in the research setting, to be able to regularly and knowledgeably refer back to and cite their sources. This was consistent with the study conducted by Kolikant et al. (2006), in which they found that students had very little experience engaging with scientific literature in college level science courses.

In the research lab, faculty dictated overall experimental questions, methodological agendas, interpretation of results, and public dissemination of data. However, these aspects of scientific activities were neither scaffolded, nor emphasized in the peripheral classroom experiences, leaving them to be scaffolded in the research setting itself. A study by Hunter et al. (2006) indicated that faculty believed students were not ready when they enter the research lab to be able to undertake such tasks as developing their own study questions. This was consistent with the findings of the observations of these chemistry settings, where faculty did not attempt to teach students these ideas until they were in the research setting.

The apprenticeship of scientists, in this case chemists, appeared to formally begin at the research laboratory level, with extensive scaffolding in classroom settings. There were several things students had to learn or understand before they could be successful in conducting research. First, was their role as students versus the role of their faculty mentors. Second, students must understand and be capable of completing the tasks that were assigned to them.

Finally, students must be aware of the resources made available to them, and understand how and when to use them.

### Roles of Faculty and Students

A discussion of the apparent roles of faculty and students during these observations led to some confusion, which was initially difficult to explain. This was, in part, because of scale. Specifically, this study was focused on looking at how the interactions between classroom communities and research lab communities inform the larger community of chemists. However, the roles of faculty and students in each of these individual settings changed, making interpretation difficult.

In classroom communities there was an apparent dominance by the faculty. However, faculty also required an almost equal, or even more heavily weighted, contribution from students. While faculty provided the content and resources for learning the material, the onus of actually learning was placed on the shoulders of students. Therefore, while classrooms appeared to be very teacher-centered, faculty talk suggested that students were responsible for utilizing the resources faculty gave them and taking advantage of the opportunities they were offered, such as office hours or extra study sessions.

The research lab settings, however, looked quite different. This setting was very student centered, with faculty playing the role as a guide in keeping progress, assessing results and insuring methodologies were appropriate. The faculty also became learners while the students attempted to teach them what they had found in their individual projects. Faculty encouraged students to talk about their data, they asked questions that helped them clarify what had happened and they encouraged students continued efforts to relate decontextualized content to their own specific projects. Students, on the other hand, took a major role in conducting these projects, developed the data and presented their findings to peers.

When dealing with aspects of the larger community, though, it was clear that the faculty were firmly in charge. If looking at this from a sociological perspective the reason for this could be because faculty were legitimate, though still peripheral in this community, meaning their students were possibly not even legitimate and certainly even more peripheral. This being the case, the work of their students was a direct reflection of the faculty in this community and therefore directly effected their own movement through. This reflected the findings of Traweek (1992), where she found that the quality of experiments conducted by researchers was an important aspect of accepting or rejecting knowledge for other researchers and also led to credibility. As such, faculty ultimately had control over the large-scale design of research projects, the overarching questions of interest, and the next steps in experimentation, including what controls should be done and whose methods to take on. They were also concerned with output that would go into the community, including publications and presentations. At the same time they were concerned about what information was coming from this community, and whether it overlapped their own interests. Students had almost no say in this aspect of research and faculty did not tend to ask them their opinions on it.

The problem was that, while faculty seemed to move seamlessly between these different communities, students did not. Expectations that faculty had for students changed depending, not necessarily on the setting, but on the community that talk centered around. Therefore, faculty could be in the classroom, but be talking about the larger community of practice. Some students had a difficult time understanding what was expected of them in any one setting because talk about roles was inconsistent. When the actions of students failed to meet the expectations of faculty, conflicts arose.

In the classroom setting, students tended to underestimate their role, believing they had much less responsibility than they did. Although faculty made many statements to suggest

to students that they had control over their own learning, students sometimes spoke in ways that suggested they believed faculty had complete control. They may not recognize the need to use the resources made available to them, or may not appreciate the resources in the same way faculty did. On at least two occasions in the classroom setting a student relied on the faculty to provide them what they needed to know to succeed, and became frustrated when faculty expected them to go beyond those resources. Faculty also became frustrated when students failed to take responsibility for their own learning, or put low levels of effort into assignments.

In research lab settings, students underestimating their role was a problem because they took on a large range of tasks. Because faculty tended to control resources in the classroom setting, students in the research lab might have been hesitant to utilize certain pieces of equipment, or did not understand that they must work on their own time. Conflict arose when students failed to take ownership of the tasks they had been given, when they had not progressed in their abilities, still struggled with simple tasks, or when they were continually unable to complete tasks. Faculty, for their part, failed to realize that the limitations students faced in classroom settings were reflected in the research lab. Students were limited in access to resources, especially laboratory equipment. It made some sense that they were hesitant to use those same resources in the research lab, without feeling as though they must first defer to the authority of the faculty member.

However, the most fundamental problem was that students did not recognize that there was a larger community of chemistry, and they were unable to identify their role within in. This led some students to over-estimate their role. For those students who were highly confident, and took on a role in the laboratory setting as being an independent worker, conflict arose when they tried to extend this to issues relating to the larger community. Faculty were securely in control of aspects dealing with larger research agendas, and they balked at student attempts to

dictate this on their own. Faculty became frustrated when students failed to recognize that they were not doing their work independently, but rather within a framework of already established ideas, methods, theories and laws.

As some students progressed through these communities, it appeared that they were able to adjust to their roles, recognizing or learning their responsibilities along the way. Several examples of successful interactions were seen in each setting, where students were able to adjust to their roles and faculty expectations. Other students seemed to struggle and problems were observed in each setting with different students, each a result of students not understanding their appropriate role within the community and faculty expecting behavior that was not present. In at least one case, conflict led to a student not continuing in their research lab. It was not clear if this student continued on in another lab, or simply left the community altogether.

Because of the complex interactions between students and faculty observed in this research, a model of roles was developed for the sake of clarity (Fig. 7). In the model, each community is represented by concentric circles, which is reflective of the patterns of movement through a community of practice from peripheral toward more central, as described by Lave and Wenger (1991). Students begin along the outer edge, in the classroom community, but as the other two are embedded within, it demonstrates the possibility that a student or a faculty member could simultaneously belong to two or even all three communities at one time. Each concentric circle is divided into left and right halves, with the left half representing the roles and expectations of the faculty and the right half representing the same, but of the students.

Each community has a brief description of the apparent roles of either the faculty or the students. In the upper part of the model roles and expectations of faculty and students match, leading to what might be called “Stable” interactions between them. In the lower portion,

though, the expectations of faculty and those of students do not match, which leads to conflict. The lower, conflict, portion was smaller than that of the upper, stable, portion because there is very little conflict outwardly observed in relation to what appears to be stable interactions. In addition, a note is added on either side of the model indicating that while faculty appear to easily transition between each setting, students have a more difficult time doing so.

Because this model was developed purely from observations and recording of faculty talk, each section of the model will need to be studied independently, using other forms of data to either confirm or modify it in its current form. For example, it was not clear that conflict was not happening much more often than what was outwardly witnessed through discussion. Conflict resolution was often in the form of faculty informing students of what they must do to set things right. Since students did not ever seem inclined to argue with these demands, the conclusion drawn based on observation only was that the conflict was resolved and the relationship returned to being stable. However, conversations with both faculty and students might reveal that the conflict was still there, just not verbally expressed again. This may significantly increase the portion of the model given over to the conflict side of each community. It is also possible that this line may shift per community, with fewer conflicts in one setting than another.

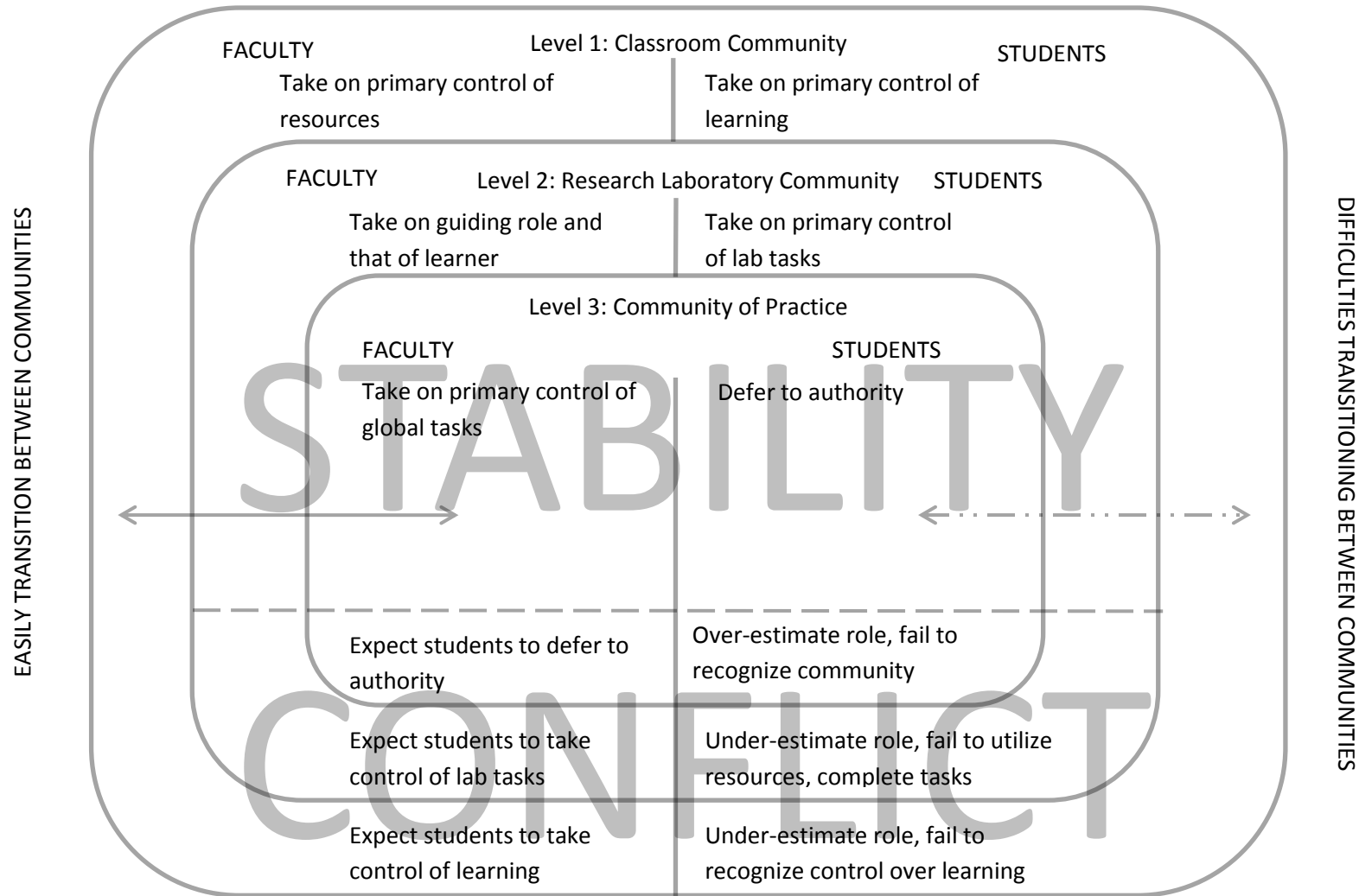


Figure 7. Model of expected roles of faculty and Students.

## Tasks Assigned to Students in Each Setting

Related to the roles students and faculty take on were the tasks assigned to each and the resources available. Throughout the observations, tasks tended to be consistent, if not completely clearly defined, which was reflected in confusion over student roles. In classroom settings faculty assigned students tasks, generally passive note-taking or taking exams, but also tasks that required outside work in the form of problem solving, laboratory write-ups or small projects. Other than sometimes not recognizing that they needed to put more effort in or supply their own resources for successful completion of these tasks, students tended to accept tasks and completed them if given the proper extrinsic motivators. In classroom labs, students were given very specific tasks to do, but were left to complete these tasks in their own time, and sometimes in their own way, depending on resources. Students also seemed to accept this, though some sought out shortcuts to limit the time they must spend on tedious or onerous tasks. Faculty became frustrated when students attempted to do this, but there were few outward conflicts associated with it.

In the research settings, again, students were assigned tasks by faculty and they tended to accept those tasks and complete them, though not always in the time frame expected. Rarely were students allowed to define their own tasks, though older, reliable or more experienced students were given that opportunity on occasion. Conflict, again, only occurred when students failed to complete tasks on time, but this was generally not because the task itself was a problem, but rather because of the resources being limited or difficult to acquire, or because students underestimated their role in completing their assigned tasks.

For the larger community of practice, however, there was very little discussion about task allocation. There was some talk of finding literature values, and again, faculty assigned this task to students and students accepted the task, as they did most other assignments. There was



also some limited talk about students presenting information they had gathered in some professional setting. Students were expected to attend any events involving their colleagues that were local. They also appeared to be expected to write their own presentations, though it was also clear that the faculty had some ultimate control over this. These discussions were extremely rare, however, and so no strong conclusions could be made.

In general, tasks were given to students by faculty in all settings. Students readily and willingly complied with most tasks assigned to them and rarely did conflict break out that was not attributable more to unclear roles or resources rather than ill-defined tasks. On the one occasion when there was confusion and conflict over task assignments the problem appeared to be that the requirements of the task were not made explicit to students. However, since observations were not made of the actual classroom discussion regarding the assignment itself, there was no way to draw further conclusions about this.

#### Roles of Resources Available to Students

As noted when discussing roles and expectations, problems arose when students misinterpreted their own position within any given community of practice. Any reform, therefore, might rely on ensuring that students were better able to recognize their own responsibilities and limitations within each setting. However, when considering resources, conflict could often be attributed to discrepancies between faculty expectations of resource use and students' use of those resources. In this case, it was faculty who failed to recognize the limitations placed on students in terms of resources.

Faculty freely gave away resources for students to use in all settings. It was up to the student to use these resources effectively toward their own learning. The problem was that it appeared that students had more control over resources than they actually did. In the classroom setting, resources were things like office hours, books and their associated resources, power

point presentations, and study guides. Faculty spent time dealing with resources, whether it was through preparing study guides or power points, or from actually holding extra study sessions on top of their own office hours. They expected students to take advantage of the resources available to them. What they failed to see though, was that though they offered these resources, they spent almost no time teaching students how to best use them. In fact, there were so many resources available, it was not at all clear which were the most critical for students to take advantage of or if they did take advantage, the best approach for ensuring success. In this case, students had many resources to choose from, but had no reasonable expectations to be able to identify the most productive use of their time.

In classroom lab settings the problem was different. Here, students and TAs both had plenty of resources. In addition, TAs appeared to have authority in the classroom. Faculty consistently used talk that suggested the TAs were the ultimate decision makers of what happened in the lab setting. This, however, was not the case. Here, resources were controlled by the department stock room, the stock room manager and the laboratory coordinator, and it did not appear that equipment allocations could easily be overridden by students or teaching assistants, though they could by faculty. In each of the three lab sessions observed in which TAs were the instructor of record, students faced restrictions on equipment or resources that limited their ability to conduct, complete or draw adequate conclusions about the lab they were working on. The problem was that because faculty did not face the same equipment restrictions when they taught labs, and because they were rarely involved in the operations of the lower level labs, there was no apparent understanding on their part that these significant limitations existed.

These issues compounded in the research lab setting. Though students were well-trained in using basic laboratory equipment that they regularly had access to in classroom labs,

they were hesitant to use other resources that were often restricted in those same settings. Large detectors, such as NMRs, were especially troublesome and it was no surprise that even TAs were restricted in their use of these machines during classroom labs. While faculty expected students to use resources freely, students hesitated, expressing either concern that they did not have adequate training, or voiced concern about resource access and availability. Their concerns were well founded, considering the restrictions placed on them during classroom work. Faculty, however, appeared to not recognize these limitations, causing frustration when resources were not used in the research setting.

In this case, the problem lay not with students, but rather with faculty and the limitations placed on resources by other members of the community. There was no reasonable way to expect students to feel comfortable using equipment in the research lab when they were formally told, even as teaching assistants, that they did not have access to that same equipment in the classroom lab. Because faculty appeared to have full access to all resources available, they had no reasonable understanding of the limitations placed on students in these settings. In addition, they failed to recognize the importance of training students in using the resources and supplies available to them, expecting them somehow on their own to be able to easily recognize the most productive way to use what they have.

Note that here also, as with the roles of tasks, students' access to resources was mostly limited within the classroom and research lab communities as delineated above by the discussion on the roles of students and faculty. There were very few discussions about resources that involved the larger community other than articles or books as reference. Again, though, students were expected to understand how to use those resources effectively, it was not at all clear that they were given any formal training on how to approach this. The only other area that related to the larger community of chemists was some discussion of presentations at local or

national events, but these discussions were limited and so no conclusions could be drawn on their impact to this study.

## Implications

### Thoughts on Apprenticeship

To begin, the first question of this research was how learning to become a scientist, in this case a chemist, was reflective of Lave and Wenger's theory of Legitimate Peripheral Participation. Though they tracked several career fields in their research, formal scientific education was not one they had investigated, and there was no direct source found in which researchers have attempted to study the process of learning to become a scientist on a broad scale. This research indicated one very important difference between other types of apprenticeship settings, and the standard approach to becoming a scientist, that of an extensive classroom learning component. While other apprenticeships had some classroom experiences, e.g. butchers, those experiences were not as intensive and time heavy as what was observed here.

In fact, the classroom environment acted as a community of practice in itself, with very different expectations on both faculty and students than what was seen in other settings. In addition, the research setting that students were involved in before becoming part of the larger community of science was also not necessarily similar to what they would be doing once becoming chemists themselves. Legitimacy had to be granted not just one time, but up to three times and how peripheral a student was fluctuated depending on the community. Success in the classroom community did not necessarily equate to success in the research community and vice versa.

Therefore, while the overall process of learning to become looked like apprenticeship, with students starting at a peripheral point while slowly making progress toward becoming a scientist, the infusion of three communities into one apprenticeship process made this pathway much more complex. Therefore, claims that apprenticeship formally begins when students begin their lab work is not completely accurate. It was clear that the coursework students had to undergo was integral to success in the research setting. However, it was also not clear that students leaving the lab had reached the same level of understanding of what it meant to be a member of the community of chemists as the faculty in charge. In other words, there was very little scaffolding occurring, especially in the research labs, where experienced students appeared to be treated no differently in terms of task or resource allocation as newer students. It was possible that this was simply an artifact of limited observations, but this was one area that merits more study.

#### Thoughts on Reform

The second question was how these findings might inform the reform efforts currently used in K-16 settings based on apprenticeship learning theory. First, it took a very long time for faculty to feel students were ready to do research on their own. There was only one instance in which a graduate student was allowed to make his own decisions about his immediate research agenda, and even that was approved by the faculty. Therefore, the technique of having students immersed in the science, such as the class design used by Roth and Bowen (1995), does not seem to be an appropriate alternative to learning. Student were not ready for the responsibility of developing their own questions, designing their own methodologies or developing their own research agendas, at any level of formal schooling, according to faculty. Not only that, but students who entered the research lab believing they were capable of doing their own research

were actively discouraged from doing so, sometimes to the point of causing actual conflict between themselves and the faculty in charge of the lab.

However, the sample observed here has inherent bias. Only laboratory research groups in which the faculty insisted on meeting with their core set of students on a weekly or bi-weekly basis were observed. The fact that faculty wanted this oversight, might naturally indicate that these particular scientists were more hands-on or had a micro-managing personality, which might reflect their desire to be in charge of student work. Faculty who did not hold formal meeting with their research group, may not have shown the same tendencies as these faculty. It would be of interest to observe the one-on-one interactions of other faculty with students to see if they had the same inclinations to discourage students from working too far ahead on their own.

However, even if it was only a subpopulation of faculty who tended to prefer students to learn how to do these things with direct oversight, the implementation of labs and activities at the K-16 level that specifically teach students how to design and implement research projects is somewhat problematic. The reform literature specifically attempts to make changes to the tasks that students are assigned, taking the responsibility away from teachers and giving it to students (Nicaise et al., 2000). According to the observation made in this study, it was the role of tasks that actually caused the least amount of conflict in learning to become. Students were comfortable with accepting tasks from faculty and faculty tended to prefer to be the person assigning those tasks. It appeared that faculty only allowed students to become responsible for dictating tasks only after they had demonstrated that they could complete tasks efficiently, understood the implications of them, and could be relied upon to help others with their tasks.

So, if reform efforts should avoid placing too much responsibility on students for developing tasks, where should it focus? Results from this study indicated that what does seem

to cause conflict is that students were unable to recognize that they were a part of a larger community of science. This was most often seen in their failure to refer back to the literature when discussing their own work within the classroom or research setting. Rather than focusing on changing the tasks, it might be more appropriate to focus on garnering a sense of a larger community with students. Doing this would actually be counter to having students create their own questions, design their own methodologies or plan their own projects. In the research settings, all of these things were dictated not by the individual, but by the norms and standards of the community. Teaching students about their role within a greater community of practice seems not only more practical, but also is more in line with the expectations of in research lab settings.

The implications of this study are that the language students deal with in the classroom setting, does not always prepare them for the language they encounter in the research setting. Most specifically, they are not accustomed to recognizing that scientific research is embedded into a community of practice and that they are learning to become a member of that broader community. Science educators interested in developing scientific literacy by introducing students to the broader community of science and their research, support reform that involves the use of Adapted Primary Literature (APL; Norris & Phillips, 2003; Phillips & Norris, 2009).

#### Adapted Primary Literature

The basic theory associated with APL rests in the understanding that scientific literacy is currently misinterpreted and incompletely defined. Norris and Phillips (2003) provide an argument for why this is the case. They believe that the term “literacy” is often defined in two ways. The first is *fundamental* and refers to the basic ability to read and write. The second, *derived* sense of the word refers to being knowledgeable, learned and educated (in science). The claim is that often science education relies on the derived definition to judge literacy, but takes

for granted the fundamental aspect of it, assuming that if students are able to read and write then they are scientifically literate. However, the problem with this is that simply being able to read and write generally does not imply that a student is able to read and write scientifically. Rather than being a simple function or tool of science, reading and writing are necessary constituents of science.

The problem is that reading science has been highly neglected in educational practice because it is believed to be a passive experience for students. It is generally assumed that good readers are able to analyze, summarize and criticize texts as an extension of knowing words, locating information and recalling content of those texts. However, this is not the case. Part of the problem lies in interpretation of text. The same text can be interpreted in multiple ways, and part of that interpretation rests on how the reader views themselves relative to it. For example, a reader who takes a dominant stance to the text might automatically allow their own personal views to override any of the information provided. Contrast that with a deferential stance, in which readers assume everything written in the text is truth. In science, however, the goal is to have readers take on a critical stance, in which they negotiate between the text and their own background knowledge and beliefs in order to interpret what is recorded. The ability to read and write goes beyond being able to interpret words and locate information, and insists that readers also understand that text can be critically evaluated and judged.

Taking this much broader view, when faculty ignore reading and writing in the classroom, they implicitly encourage the simplistic idea that understanding science text relies basically on being a good reader. So, what are the implications of this from an educational perspective? First, by failing to focus on the more critical aspects of reading and writing science, a view of science as facts, laws and theories that are isolated from each other with little to no interconnectedness is perpetuated. The result is that although students might be able to read



science they have no way of interpreting it in respect to the broader community. The metacognitive ability to see their role within the practice of research is not developed enough for students to be critical thinkers. In addition, the view of science as a boring recitation of facts is inconsistent with the high levels of interconnectedness found in literature and fails to properly portray the socially and culturally dependent nature of science and the tentativity of scientific knowledge (Norris & Phillips, 2003).

Although reading and writing of scientific literature is generally ignored in science education it is possible that this causes no detriment to students because instructors still talk about scientists, their research and the implications of it. However, Norris and Phillips (2003) also sought to explain why oral talk is not the same as text. They suggest that talk includes communication that is not inherent in text, including non-verbal clues that provide students with a framework within which to interpret the information. Text has its own inherent structure, but students have to, on their own, learn how to interpret the unexpressed intentions found evident through speech. Research has found that talk is useful to share, clarify or give out knowledge, but text is important for organizing and consolidating ideas. Therefore, though teachers may talk about science, scientists and research, this talk comes already interpreted by the instructor and serves the purpose of only adding on information. It most likely is not incorporated into the students' frameworks as needing to be situated within an understanding of community.

How does this idea of reading and writing relate to APL? The recommendation is that in order to teach students to be scientifically literate, they must read and write scientific literature. Phillips and Norris (2009) make this argument explicit. They state that scientists spend as much as a quarter of their time reading and writing scientific literature, and if that is expanded to communicating in any form their ideas, that percentage jumps to almost 60%. Science

education, in general, emphasizes the hands-on portion of scientific inquiry, but given that over half of a scientist's time is taken up with reading, writing, and disseminating findings, the importance of the minds-on portion of inquiry must be acknowledged.

The problem, according to Phillips and Norris (2009), is that the language inherent in science education is not reflective of the language inherent in authentic scientific inquiry. Scientific papers and research tend to be formatted quite consistently, and in general they focus on forming an argument, including justification and evidence for claims. Science education texts tend to present science as truth, fact-based and lack any form of argumentation. The goals of reading these textbooks are generally to introduce students to terminology, rather to, as scientific literature is meant to do, stimulate creativity, through critical analysis of the text.

However, the talk in classrooms observed in this research appears to do just what it is meant to do; that is to teach students the foundational knowledge they need to move onto laboratory work. But, Phillips and Norris (2009) point out that when not exposed to primary literature, students do a poor job of explaining it when they did read it, tend to lack an ability to be critical and often take what they read as fact. The findings in this study support this, as even graduate students rarely justify their findings via scientific research and appear surprised or unprepared when asked to do so. The best way to address this, according to Phillips and Norris (2009) is to implement the use of adapted primary literature in science education. This is literature that keeps the general argumentative form of authentic scientific research papers, but adjusts the readability to any appropriate educational level (K-16).

However, while the suggestion exists that APL improves students' abilities to think critically about science and be better able to form arguments and justify their own work, this is not in itself sufficient to recommend change. There have, though, been several studies that have shown that APL has made significant impacts on students. One such study examined the effects

of a journal club on several factors, including students' ability to read, write and understand scientific research and the benefits of the program on their graduate studies (Kozeracki, Carey, Colicelli, & Levis-Fitzgerald, 2006). Though this study has several severe limitations (e.g. self-reported data, rather than actual measurements of understanding) it does indicate that exposing third and fourth year undergraduates to primary literature has several benefits. Some students claim that it broadened their knowledge base outside of their own research areas, allowed them to read research articles quickly, increased their confidence in criticizing research and improved their excitement toward science. Relative to this research, the findings of Kozeracki et al. (2006) suggest that exposure to primary literature improves students' transitions into graduate studies. It is not clear, though, if it does so through addressing the conflicts about role found in this study.

If APL is able to make improvements in students' abilities to recognize a larger community of practice then the next question is how it can be implemented into the classroom. There are several trade journal articles that provide simple ideas for using APL in the college classroom. Janick-Buckner (1997) points out that a primary issue with students reading scientific literature is that they are generally unfamiliar with it. Often there is technical terminology that students have a difficult time processing and they do not understand how to read articles to get the information out that they need. To combat this problem, students are given guides in which they are provided information on how to read and evaluate the articles. A similar approach is taken by Scott and Simmons (2006) in an upper level crop science course. The problem with these articles, though, is that they are implemented in an upper level college course with few students and for which the entire course is created around using primary literature as their main source of topic information. This is not necessary a practical approach for lower level, large lecture classes, and unfortunately the literature here is scarce.

Theoretically, APL provides an interesting approach to increasing student awareness of theirs' and others' roles in the community of science and improving their experiences once they move onto graduate research. Practically, however, there is much less evidence to suggest how this could be done effectively and what the outcomes of these methods might be.

#### Limitations

There were two areas in which the findings of this study should not overstep the data collected. The first dealt with making assumptions about pedagogies, especially inquiry versus direct teaching or "good" versus "bad" teaching. The second dealt with the findings on resources.

#### Pedagogy and science education

Educators might question the purposeful and explicit lack of reference in this report to what has often been considered best practice pedagogy in science education. However, the intent with this project was not to judge faculty teaching against an ideal of guided inquiry. Rather, the goal was to look at what exists in its current form to see how it does or does not contribute to students learning to become scientists.

Science education cannot be considered the same community of practice as science. Judging one on the foundational work of another would be inappropriate and misleading. There is no way scientists should be expected to naturally teach in such a way as would be appropriate to science educators, especially given the fact that those educators spend years learning and refining their trade.

Had the quality of teaching been judged during observations, very little of what is considered best practice educationally would have been seen. Inquiry was absent in most cases and teacher driven pedagogy was predominant. This research suggests that given what they

expect students to know, faculty may see no reason for teaching via inquiry, since direct lectures are effective in teaching content and cookbook labs are effective in teaching basic process skills.

The major issue found in this research is not that students need to know how to design or conduct their own experiments, but rather that they do not understand the role they play in the larger communities of practice. From an educational perspective, of course, inquiry would actually solve this problem. The methods of inquiry draw on real data, consider historical developments, and use strong foundational evidence to predict what will happen in new situations, all of which would force students to consider science as a larger community of practice, rather than as a set of known facts to be learned. Using inquiry would ideally provide students the very thing they are missing in their current pathway to learning to become and may, in fact, reduce conflict over time.

#### Interpreting the Role of Resources

The second area where clarification seems necessary is that there is a problem with not only student roles, but also with resource allocations. This is an area where inquiry teaching might greatly improve what was observed in this study. Students would be given control over their resources in such a setting and they would have the expectation of using them as required.

However, one of the major problems with resource allocation appears to be administrative, rather than educational. In other words, limitations of resources seem to come from somewhere beyond the teaching assistant, faculty and students directly associated in the course. Many of these issues were beyond their control. Awareness that the problem exists was important, but recommendations are limited to this institution and the direct administration of those resources. The data does not allow interpretation beyond this.

## Future Research

This project was vast, including very large amounts of data that provided some evidence to the apprenticeship of scientists, in this case chemists. Though it was possible to describe the process of learning to become, raised awareness of areas where conflicts may arise and provided some general beginnings of possible solutions to those conflicts, it still raised more questions. There are two major areas where future research is important. One deals with simply refining and extending the results of this study. The other heads toward the application of practical suggestions for improvement.

## Refining Research Findings

There are several limitations to this research, all of which could be and perhaps should be extended through more research. First, this study was focused primarily on the sub-discipline of chemistry at a single research university. Extensions could be made in two directions. One would be to see if the same trends were happening in other disciplines, such as biology, earth science and physics. Another is to extend the observations to other universities within a single discipline to consider the larger role of institution on these findings. This might be particularly helpful in parsing out the actual role that resource limitations are playing in student/faculty conflict.

Also, a model was created that defines student and faculty roles in each of the major communities of practice observed here: classrooms, research labs and chemistry. Each component of that model was based on the data collected from this study, but can be studied individually using more invasive methods. For example, conflict appeared to occur in the research lab community when students underestimated their roles, especially regarding resources. These conflicts also appeared to be resolved by faculty explicitly defining those roles for students. Without further data, though, it was impossible to tell if that conflict was actually

caused by a confusion in roles. Even if it was, however it was also unclear if it was actually resolved on either the part of the faculty member or the student or what the future implications of that conflict might be for either.

#### Empirical Work on Practical Applications

One specific recommendation, which might be useful to address conflicts associated with the roles students play, was the use of APL. Assuming that the model created by these observations was sound, at least to begin with, the use of APL in the classroom could be studied to consider the role it might play in resolving conflict. If it does not, there are two possibilities. One is that the approach was not sufficient to reconcile student understanding of their roles in each community of practice. The other was that, in fact, there was not a real conflict here. Either way, it would be useful to know if APL might be able to make strides toward mediating students' conceptions of where they fit into the community.

Of course inquiry is often a focus in science education, as mentioned above. This research suggested that perhaps the focus on the usefulness of inquiry could be extended and somewhat refined. Many of the assumed benefits students gain from inquiry were actually not expected by faculty until learners were well into their laboratory research experience. It is possible that the benefit of inquiry does not, in fact, come from being equally able to teach content along with teaching students how to design and implement their own experimental research. Rather, based on this study, it may come from the fact that when teaching inquiry we tend to provide a more global context to the material, giving students real data to work with, and familiarizing them with the roles of scientists who collected that data. It may be that teaching about the nature of science and history and philosophy of science associated with inquiry would be the actual benefit, beyond simple knowledge acquisition, of inquiry teaching.

This is something to be seriously considered, especially if the same types of conflicts arise in other settings.



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## Appendix

### HSIRB Approval Letter for Research


# WESTERN MICHIGAN UNIVERSITY



Human Subjects Institutional Review Board

Date: July 30, 2010

To: Reneé Schwartz, Principal Investigator  
Marcia Feters, Co-Principal Investigator  
Susan Stapleton, Co-Principal Investigator  
Brandy Skjold, Student Investigator for dissertation

From: Amy Naugle, Ph.D., Chair 

Re: HSIRB Project Number: 10-07-15

This letter will serve as confirmation that your research project titled "Language Use by University-level Chemistry Instructors: Descriptions and Analysis of Authentic Science in Classrooms" has been **approved** under the **expedited** category of review by the Human Subjects Institutional Review Board. The conditions and duration of this approval are specified in the Policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note that you may **only** conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: July 30, 2011