TEACHERS' INSTRUCTIONAL GOALS FOR SCIENCE PRACTICE: IDENTIFYING KNOWLEDGE GAPS USING CULTURAL-HISTORICAL ACTIVITY THEORY (CHAT)

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ABSTRACT

Teacher’s Instructional Goals for Science Practice: Identifying Knowledge Gaps Using Cultural-Historical Activity Theory (CHAT)

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In AP Biology, the course goal, with respect to scientific acts and reasoning, has recently shifted toward a reform goal of science practice, where the goal is for students to have a scientific perspective that views science as a practice of a community rather than a body of knowledge. Given this recent shift, this study is interested in the gaps that may exist between an individual teacher’s instructional goal and the goals of the AP Biology course. A Cultural-Historical Activity Theory (CHAT) methodology and perspective is used to analyze four teachers’ knowledge, practice, and learning. Teachers have content knowledge for teaching, a form of knowledge that is unique for teaching called specialized content knowledge. This specialized content knowledge (SCK) defines their instructional goals, the student outcomes they ultimately aim to achieve with their students. The study employs a cultural-historical continuum of scientific acts and reasoning, which represents the development of the AP Biology goal over time, to study gaps in their instructional goal. The study also analyzes the contradictions within their teaching practice and how teachers address those contradictions to shift their instructional practice and learn. The findings suggest that teachers have different interpretations of the AP Biology goals of science practice, placing their instructional goal at different points along the continuum. Based on the location of their instructional goal, different micro-communities of teachers exist along the continuum, comprised of teachers with a shared goal, language, and culture of their AP Biology teaching. The in-depth study of one teacher’s AP Biology teaching, using a CHAT perspective, provides a means for studying the mechanisms that connect SCK to

classroom actions and ultimately to instructional practice. CHAT also reveals the nature and importance of contradictions or cognitive dissonance in teacher learning and the types of support teachers need to recognize contradictions and to internalize and set their instructional goal, facilitating their learning. Without recognition of contradictions, some of these micro-communities are not aware that their instruction is not in line with the AP Biology goal of science practice. An in-depth look at teacher learning revealed the criticality of reflective practice and the need for an “expert” within a teacher’s community to facilitate = learning and develop SCK to incorporate science practice in classroom instruction.

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DEDICATION

To James, Zelle, and Cora

"Success is the result of perfection, hard work, learning from failure, loyalty, and persistence."

~ Colin Powell

Chapter 1: Introduction

One of the recent movements in science education reform calls for a new approach, a paradigm shift, that focuses away from science as knowledge to be acquired to one that promotes a scientific perspective, one that embraces the community and culture of scientists by engaging students in the language, tools and ways of science practice (Barab & Luehmann, 2002). The Advanced Placement© Program recently redesigned their AP science courses to include this goal of a scientific perspective through science practice. The *Next Generation Science Standards* (2013) have also embraced the goal of science practice, making this shift “one of the most significant challenges for the successful implementation of science education standards” (Bybee, 2011, p. 39).

The use of “science practice” is the most recent attempt to articulate the complex scientific acts and reasoning performed and used by scientists. ”Scientific acts and reasoning” is meant to capture the knowledge, processes, and behaviors associated with doing science. The terms for articulating scientific acts and reasoning have changed over time from the scientific method, to scientific inquiry, and now science practice (Duschl, 2008; Ford, 2015). Science practice is the most comprehensive yet, capturing all three domains of scientific work. The three domains of science practice - conceptual, social, and epistemic -are elaborated upon in Chapter 2. In this study science practice is defined as disciplinary, goal-directed activities (Ford, 2008) that encompass the “ways of knowing and doing that scientists use to study the natural world” (Krajcik & Blumenfeld, 2006, p. 323). This definition relies on the work of Duschl (2008) which has the perspective of science practice as the domain of disciplinary work. This disciplinary work emerges from the activity of the scientific community, which includes forms of specialized discourse, norms for participation, and contextual influence of social, political, and culture of the community (Stroupe, 2015). Given the shifting articulation of terms to describe the scientific acts and reasoning from scientific method to scientific inquiry and now to science practice, this study uses “scientific acts and reasoning” as a placeholder for the various terms that have evolved over time.

Bybee (2011) elaborates on the challenges of successfully implementing the science practices in that the practices should be thought of as both learning outcomes and instructional strategies, representing educational ends along with instructional means. To make science practice a learning outcome, teachers should develop the abilities described in the practices, and they should understand how science knowledge and products develop as a result of the practices (Bybee, 2011; Krajcik & Meritt, 2012). They should also create and use instructional practices that align with research in learning. This literature has identified authentic experiences based on the practice of scientists as being an appropriate experience and environment for students to gain the desired scientific perspective (Brown, Collins, & Duguid, 1989; Krajcik & Blumenfeld, 2006; Lave & Wegner, 1998). Students can no longer go through the acts of doing science only to validate canonical information. The instructional practices require strategies that emphasize science as a way of knowing and doing and embed content knowledge in rich authentic science experiences within a community (Barab & Luehmann, 2002; Driver et al., 1994). Instruction should also aim to build students’ epistemological beliefs as a learning outcome (Sandoval, 2005). There is growing support for the need for explicit instruction about nature of science or scientific epistemology and the components involved in scientific practice. This explicit instruction, along with the rich inquiry experiences is essential for students to gain a science perspective (Lederman, 2007; Sandoval, 2005; Schwartz, Lederman, and Crawford, 2004).

Teachers have a critical role in creating these engaging environments and facilitating students' learning in science by planning and guiding student interactions with each other and with the tools that characterize science. Teachers’ knowledge is one very important component that influences their abilities to design and implement such instruction. To provide appropriate explicit instruction, teachers should have a deep and highly structured content knowledge so they can use it flexibly and efficiently during instruction (Sternberg & Horvath, 1995; Talbert, McLaughlin, & Rowan, 1993). However, this focus on science practice goes beyond what science teachers have realized based on the scientific inquiry of the 1990s (Bybee, 2011). To implement science as a practice, the science education community should better understand where teachers’ subject matter knowledge of science practice lies with respect to the reform view of science practice and how to build efficiently their understanding toward this reform goal of science practice.

The demand of changing instruction to incorporate science practices as an outcome and a tool for engaging in more authentic inquiry experiences is now placed upon the teachers of the redesigned AP Biology course. Prior to the redesign, the AP Biology course was articulated as a long outline of content the students needed to know and memorize to be successful on the exam. This coverage of breadth of content encouraged traditional pedagogy of lectures and “cook book” labs (Wood, 2009). The scientific acts and reasoning were a theme in the AP Biology course, referred to as “Science as a Process.” This theme was described as “Science is a way of knowing. It can involve a discovery process called inductive reasoning or it can be a process of hypothesis testing” (College Board, 2007, p. 6). This “Science as a Process” theme was elaborated upon in a lab manual that contained 12 recommended laboratory exercises. These “cook book” type of labs were predictable and had students validate canonical information

(Drew, 2011). There was not a specified list or articulation of the processes and knowledge associated with the Science as a Process theme in the AP Biology course prior to the redesign.

The National Research Council (2002) criticized the AP science courses for not aligning to research on how people learn. The report claimed that students should spend more time going into greater depth on fewer topics and experience problem solving, controversies and the subtleties of scholarly investigation. This call to action stimulated the AP Program to embark on a redesign of the science courses that reduced the breadth of the courses and increased the depth by focusing on building students' conceptual understanding and engaging students in the critical thinking and practices of authentic science. The redesign of the AP Biology course created a curriculum framework to transparently articulate what the students must be able to know and do, particularly to focus on bigger concepts and stimulate more critical and analytic thinking (Drew, 2011).

The redesigned AP Biology course addressed the call for critical and analytical thinking and depth of student understanding by articulating seven science practices. In the creation of the science practices, the redesigned AP Biology course established a new broad goal for students:

> By the time they finish an AP course, competent AP students should not only have mastered content, procedural, and epistemological knowledge about the domain but also know how to recruit subsets of that knowledge to address a particular problems or situations. Further, students should be expected to demonstrate that they know in what contexts a particular piece of knowledge is relevant, and then be able to apply it appropriately using the language, tools, and representations that are part and parcel of the discipline. (National Science Foundation, 2010, p. 196)

This goal aligns with the reform goal of a scientific perspective, one that embraces the community and culture of scientists by engaging students in the language, tools and ways of science practice (Barab & Luehmann, 2002). In the redesigned AP Biology course, these seven science practices are integrated with the content knowledge to create learning objectives, which articulate how the content can be applied as well as learned. These learning objectives are the outcomes or the goal for the course. The present study concentrates on the science practice elements of this AP Biology goal. The science practices embedded in the learning objectives are a significant change for AP teachers. The College Board knew this was a big shift for teachers to adjust to the approach, so they invested substantial resources in creating professional development programs and online tools to assist teachers with the transition (Drew, 2011). Given the magnitude of the shift expected of teachers, one might ask what type of professional development would effectively support teachers in this reform movement.

The Problem

The problems this research attempts to address are in response to several recent reform movements, specifically the redesign of the AP Biology course. Many teachers lack the appropriate subject matter knowledge of science practice to build the type of engaging environments and provide explicit instruction for students to gain the desired scientific perspective. To build teachers' content knowledge for teaching science practice, science education researchers should understand where teachers' knowledge lies in comparison to the reform goal of science practice and how to transform their understanding toward the reform goal.

To address these problems, the goal of this research has three parts. One is to analyze four teachers' instructional goals with respect to scientific acts and reasoning against the science practice goal of the redesigned AP Biology course, which aligns with the reform goal of science practice. This study employs a Cultural-Historical Activity Theory (CHAT) methodology as a method and framework for analysis. CHAT provides a methodology to analyze AP Biology teachers' knowledge and learning situated in their practice and context. It also provides a theoretical perspective for analyzing teaching and learning as a goal-driven and interactive, contextualized process (Engestrom, 1987). To guide the gap analysis a cultural-historical perspective of the development of the AP Biology goal with respect to scientific acts and reasoning is used to frame the teachers' instructional goals in comparison to the AP goal.

A second goal is to specifically analyze one teacher's specialized content knowledge of scientific acts and reasoning. Specialized content knowledge is a part of teachers' content knowledge for teaching, and is considered an instrument to design authentic learning environments, provide explicit instruction, and make instructional decisions (Smith & Neale, 1989; Zembal-Saul, Blumenfeld, & Krajcik, 2000). Since knowledge is situated in teacher practice, the use of CHAT provides a way to understand the relationship between specialized content knowledge, a teacher's instruction, and student outcomes. The third goal is to use the unique analytical lens of CHAT to describe one teacher's instructional goal, practice, and learning. These descriptions are an attempt to better understand his AP Biology teaching and shifts in a teacher's AP Biology teaching with respect to scientific acts and reasoning as it progresses toward one of science as a practice. By studying a teacher's AP Biology teaching over time, contextual factors and indicators of transformation of his AP Biology teaching or teacher learning will emerge. These factors and indicators may provide better insight into the variables at play in moving teacher practice toward the reform view of science practice.

Overall, in order to achieve these goals, the study analyzes four teachers' AP Biology instructional goals and knowledge situated in their instructional practice. To identify gaps in teachers' instructional goals in comparison to the goals of the redesigned AP Biology course, this study analyzes four teachers' instructional practice using a comprehensive framework of science practice and a CHAT methodology. In order to better understand teachers' learning through their practice and their specialized content knowledge of scientific acts and reasoning, an in-depth analysis of one teacher's practice and shifts in practice is conducted using the CHAT methodology. Together these analyses aim to describe teachers' gaps in their instructional goals of science practice and development of teachers' practice toward the reform goal of science practice over time.

Background of the Problem

The literature that attempts to better define "teacher knowledge of science" is extensive, but it varies in the frameworks of science knowledge and measures of teacher knowledge. Studies use different measures for characterizing knowledge (e.g., subject matter knowledge, pedagogical content knowledge, college science course completion). In terms of linking teachers' understanding of science and classroom practice, the research is inconsistent and modest perhaps due to a lack of focus on aspects of teacher knowledge that impact student learning (e.g., Wilson, Shulman, Richert, 1987). More recent research focuses on teachers' subject matter knowledge (SMK) and the complex construct of teachers' pedagogical content knowledge (PCK). Both have demonstrated impact to student learning (Alonzo, Kobarg, & Seidel, 2012; Hill, Rowan, & Ball, 2005; Jin, et al, 2015; Park, Chang, Chen, & Young, 2011). PCK is difficult for teachers to articulate, often tacit in teachers' practice, and research has varying constructs for PCK, creating a complex phenomenon to consistently frame and study with respect to student performance. Alonzo et al. (2012) has thoroughly summarized the extent of research on teacher PCK. To better specify teachers' subject matter knowledge, which can be observed in their practice, and to avoid the complexity of PCK, this study explores teachers' content knowledge for teaching, more specifically specialized content knowledge (SCK) of science practice. According to a construct of mathematical knowledge for teaching established by Ball, Thames, and Phelps (2008), specialized content knowledge is a sub-category of SMK. It is differentiated from PCK in that it focuses purely on the content knowledge unique to teachers and does not integrate this knowledge with pedagogy, the curriculum, or the student (Ball, Thames, & Phelps, 2008). The construct describes knowledge associated with the acts of teaching not teachers. Specialized content knowledge is reflected in the appropriate instructional goals teachers establish for student learning and actualized in the classroom activity system as a tool to mediate student learning. Specialized content knowledge is the focus of this study because it is a form of knowledge that has demonstrated being predictive of student performance in the area of elementary mathematics (Hill, Rowan, & Ball, 2005) and science (Alonzo et al., 2012).

Few studies capture a framework of teachers' content knowledge for teaching scientific acts and reasoning or articulate the knowledge in a way that clearly connects this knowledge to teacher classroom practice. By analyzing teachers' content knowledge for teaching actualized in their instructional goal and their instructional practice, this study presents preliminary insight into the mechanisms that connect content knowledge for teaching scientific acts and reasoning to student learning. CHAT (Engestrom 1987, 1999) provides a unique lens for studying this relationship. Teacher's instructional goals are assumed to be their internalized model of what it means to act and reason scientifically, which informs their instructional activity. Teachers externalize this model in their actions and the tools they use to facilitate student learning and the goals and objects they set for student learning outcomes (Engestrom, 1987, 1999). Using the lens of CHAT, specialized content knowledge is considered a psychological tool, a form of knowledge unique to teachers that can guide student learning. McNicholl and Childs (2010) operationalize pedagogical content knowledge (PCK) as a psychological tool, which supports the use of specialized content knowledge (SCK) as a psychological tool in this study. There have been other recent studies to use CHAT methodology to study teachers' knowledge and learning (Forbes, 2009; Forbes, et al., 2009) and pre-service teachers' reflections (Barrie-Sezen, Tran, McDonald, & Kelly, 2014). This study analyzes the externalization of teacher's specialized content knowledge of scientific acts and reasoning as both the instructional goal and the psychological tools of their instructional activity.

To employ activity theory throughout this study, some terms or phrases are needed to represent some concepts seen through the lens of activity theory. The study assumes that teachers' instructional goals are not solely composed of scientific acts and reasoning. It focuses on the scientific acts and reasoning portion of the goal. Any reference to teachers' *instructional goals* is a proxy of their specialized content knowledge of scientific acts and reasoning as it is internalized and then mobilized in their practice. It is placed in italics.

The frameworks by which studies describe teachers' knowledge of science or the scientific acts and reasoning vary, such as the nature of science (Abd-el-Khalick and Boujaoude, 1997; Lederman, 1992, 2007); Anderson's (1987) structure, function, development; and Schwab's (1978) substantive and syntactic aspects of science knowledge. Most of the above studies separate and study independently the content of science, the processes or activities of science, and the habits of mind or the nature of science. A majority of subject matter knowledge (SMK) studies use the nature of science (NOS) as the focus for SMK (see Lederman, 1992; 2007 for a review of this literature). Using understanding of the NOS as an indicator of SMK is problematic because there is evidence that teachers' responses to survey instruments or open questions about NOS do not predict what they will communicate about NOS in their pedagogical practice (Brickhouse, 1990; Guerra-Ramos et al., 2010). NOS also only represents the epistemological aspects of science (Ford, 2015; Sandoval, 2005; Schoupe, 2015), leaving a large gap in teacher subject matter knowledge unexplored. By focusing on science practice as the framework, the integration of content and process are considered as well as the nature of science, habits of mind, and/or epistemological aspects of practice are incorporated into the construct under investigation.

Due to the lack of a comprehensive framework to describe and study teachers' knowledge of scientific acts and reasoning and to better capture teachers' knowledge of science practice in their classroom instruction, this research intends to examine teachers' *instructional goals* against a cultural-historical continuum of scientific acts and reasoning. The descriptions of scientific acts and reasoning employed in this continuum are based on a historical progression of attempts to articulate and describe the acts and reasoning of scientists and how each attempt manifests itself in school science, as presented in documents that have informed policy and research over time. These documents include *Teaching Scientific Inquiry: Recommendations for Research and Implementation* (Duschl & Grandy, 2008) as well as other national policy documents such as *Inquiry and the National Science Education Standards* (National Research Council, 2000) and *Taking Science to School* (National Research Council, 2007). Overall, the cultural-historical continuum captures the historical development of the reform goal of science practice. The continuum includes the shifts in philosophy and science education research that are the subject of science education reform from the scientific method, through science as inquiry, and into a discourse and model-based view of science as a practice. Using descriptions of historical articulations of scientific acts and reasoning, this study intends to characterize teachers’ *instructional goals* related to scientific acts and reasoning in comparison to the AP Biology goal of science practice. The comparison provides descriptions of the gaps teachers might have from the reform-oriented view of science practice.

Researchers struggle to analyze teachers’ knowledge because their knowledge structures are routinized and tacit (Richardson, 1996). Asking teachers to translate this tacit knowledge into the public sphere so that it can be analyzed is difficult. This tacit knowledge is situated in teachers’ instructional practice, and teachers struggle to articulate this knowledge (Berliner, 1986). This presents a problem for researchers. An alternate method for understanding teachers' knowledge structures requires researchers to analyze how they mobilize their knowledge through their instructional designing, planning, implementation, and their interactions within the community of science teaching. There has been a call to use cultural-historical activity theory (CHAT) in education research as a means to resolve some of these issues (Grossman, Smagorinsky, & Valencia, 1999; Forbes, et al., 2009). A situative perspective, specifically an activity system perspective (Engestrom, 1987), permits the researcher to examine the larger interactive system and go beyond just examining the individual. This perspective includes individuals interacting with each other as well as the physical context of teachers’ instruction and their instructional tools (Cobb & Bowers, 1999; Lave & Wegner, 1991). In a situated and social perspective, knowledge development is a contextualized act. CHAT provides a means for connecting an individual’s actions and the implicit knowledge related to those actions. It also provides a concrete framework that gives insight into collective activity as a site and evidence for learning, situating the activity within the greater social, historical, and cultural context (Engestrom, 1987, 1993; Grossman, Smagorinsky, & Valencia, 1999). The study intends to characterize teachers’ *instructional goals* of scientific acts and reasoning against a cultural-historical continuum and then use CHAT as a unique, sociocultural approach to analyze the transformation of AP Biology teaching activity toward the reform-oriented goal of science practice. Therefore, this study proposes to examine the following two research questions: 1) What are teachers’ *instructional goals* with respect to scientific acts and reasoning compared to the reform goal of science practice represented by the AP Biology program?; 2) What factors are involved in teacher learning as his/her central activity system transforms in the direction of the AP Biology course goal?

If the goals of reform are to incorporate more authentic learning experiences and explicit instruction of science practice in order to foster students’ scientific perspective, then the science education community should better understand teachers’ knowledge of science practice and how to develop this knowledge. The research identifies specialized content knowledge as a key conduit between science education’s reform goal of science practice and the science that is incorporated into individual classrooms by teachers, making it the focus of this research. The study aims to provide a situated description of the gaps of teachers’ *instructional goal*s when compared to the targeted AP Biology course goal and the factors involved in moving teacher practice toward the reform goal of science practice. The information gained by this study could be used to influence the development of teacher education programs, professional development and other forms of teacher support embedded in their practice.

Chapter 2: Review of the Literature

Reform Goal of Science Practice

The recent advances in science education aim for students to gain a scientific perspective, one that embraces the community and culture of scientists by engaging students in the language, tools, and ways of science practice (Barab & Luehmann, 2002). This advancement stems from research on how students learn science (e.g., National Research Council, 2005) and the ways of science. This research on learning as well as other advances in understanding science was synthesized in *Taking Science to School* (Duschl, Schweingruber, & Shouse, 2007). In 2008, the National Science Foundation (NSF) supported a collaboration of scientists, science educators, philosophers, and sociologists, which further elaborated on a model of science as a practice which is a significant shift away from science as a method and science as inquiry (Duschl & Grandy, 2008; Ford, 2015). This meeting and *Taking Science to School* initiated a focus in the science education community on science as a practice, which informed two national reform movements to adopt this approach, the redesign of the Advanced Placement© (AP) science courses (College Board, 2011) as well as *A Framework for K-12 Science Education* (NRC, 2012) which informed the *Next Generation Science Standards* (NGSS, 2013). These two reform movements have placed science as a practice at the forefront of science education reform.

Since this study aims to compare teachers' *instructional goals* against the AP Biology course goals with respect to science practice, a cultural-historical continuum is used to provide a cultural-historical activity theory (CHAT) perspective to the development of the AP Biology course goal. The continuum captures the historical development of the articulation of scientific acts and reasoning as it shifts from the scientific method to science as inquiry to discourse and model-based science practice represented in Table 2.1. Throughout this study, the cultural-historical continuum of the articulation of scientific acts and reasoning represented in Table 2.1 may be referred to as the continuum. These shifts could be considered historical phases as over time different attempts have been made to articulate what students must be able to know and do to reason and act scientifically. The continuum is based on the Duschl and Grandy (2008) report of the collaboration as well as several other key policy documents and research which captures the historical development and the articulation of each phase of the continuum. Since there is no universally accepted, canonical statement of what any phase of scientific acts and reasoning is (Woodcock, 2015), for the purposes of this study, the definition of scientific inquiry is based on the *National Science Education Standards (NSES)* (National Research Council, 1996) and the scientific method is based on a collection of research (e.g., Windschitl, 2004; Woodcock, 2015). The scientific models and discourse phase represents the recent articulation of science practice. This phase also represents the AP Biology course goal, which is the source of comparison for this study. Within the scientific models and discourse practice phase along the continuum, there is a greater focus on the epistemology of science. For the purpose of this research the broad epistemological themes of Sandoval (2005) were used to characterize epistemology as a part of teachers' *instructional goals*. Table 2.2 includes a brief description of each of these themes. The following paragraphs describe science practice and highlight how this articulation is different from earlier phases of scientific acts and reasoning.

Table 2.1. Cultural-historical Continuum of the Articulation of Scientific Acts and Reasoning (Duschl & Grandy, 2008). A complete continuum can be found in Appendix A.

	The Scientific Method	**Scientific Inquiry**	**Scientific Models and Discourse Practice**
Philosophical Progression	Experiment driven enterprise (logical positivism)	Theory driven enterprise (conceptual-change)	Explanatory model driven enterprise
Descriptions of School Science	• Hypothetico-deductive conception of science • Focuses on the final products or outcomes of science	• Focus on improvement and refinement of a theory • Science is described as acquiring data and then transforming that data first	• Emphasizes the role of models and data construction in the scientific process and demotes the role of theory

	• Oversimplifies observation • Linear process of discrete events, the parameters of each event are only considered after previous event is complete (Windschitl, 2004)	into evidence and then into explanations • Includes social domain, but with little explicit attention or analysis of its contribution • Focus on experimentation	• Involves complex set of discourse processes • Theories thought of as families of models, models' role between empirical evidence and theoretical explanations • Emphasis on discourse and dialogic strategies • Any and all of epistemology themes (see Table 2.2)
Processes of Scientific Acts and Reasoning	• Make observations • Formulate a hypothesis • Deduce consequences from the hypothesis • Make observations to test the consequences • Accept or reject the hypothesis based on observations	• Engage in scientifically oriented questions • Give priority to evidence to develop and evaluate explanations that address scientifically oriented questions • Formulate explanations from evidence to address scientifically oriented questions • Communicate and justify their proposed explanations (National Research Council, 2000)	• Posing, refining, evaluating questions • Comparing alternative theories/models with data • Providing explanations • Giving arguments for/against models and theories • Relating data to hypothesis/model/theory • Critiquing explanations, models, and data

Table 2.2. Broad Epistemological Themes (Sandoval, 2005).

Broad Epistemological Theme	**Description**
Scientific Knowledge is Constructed	Scientific knowledge is constructed by people and not discovered. Establishment of knowledge involves a dialectical relationship between observation and theory. Scientific knowledge is not accepted as "true" because people are persuaded of its value.
Diversity of Scientific Methods	There is a diversity of method used in science because disciplines of science are different as they explore different phenomenon. Scientific disciplines rely on standards of evaluation of methods and knowledge based on shared criteria.
Forms of Scientific Knowledge	There are different forms of scientific knowledge that varies in their predictive and explanatory power as well as their relationship to the natural world. Hypotheses, theories, models, and law vary in scope and purpose as forms of knowledge.
Scientific Knowledge Varies in Certainty	Some claims are more tentative than others (Osborne, et al, 2003) because it is either imperfect ability to comprehend the world, proximity to knowable truth, or construction of own reality.

For over the past 60 years science education has undergone some dynamic changes with attempts to conceptualize science, science learning, and science learning environments (DeBoer, 1991; Duschl & Osbourne, 2002; Grandy & Duschl, 2007). These attempts have fallen short of capturing “what gives science the power to achieve reliability and epistemic privilege” (Ford, 2015). The scientific method and science as inquiry conceptualizations present the scientists perspective and assume a common denominator of methods that describe scientific work. Both phases assume there is a shared, methodical process that results in knowledge making the domain-general skills distinct and unrelated from the knowledge it establishes (Ford, 2015). The scientific method attempts to define disjointed, ordered regularities of reasoning and action of scientists, where the hypothetico-deductive view of science dominates and primarily focuses on experimentation (Duschl, 2008; Grandy & Duschl, 2007). The epistemic or social nature of the acts and reasoning of the science community are missing from any description of the scientific method.

Scientific inquiry as described by the *Standards* attempted to rectify the narrow view of science acts and reasoning by creating a comprehensive description to include all possible features of doing science. They also tried to emphasize that doing inquiry requires “students to mesh these processes with scientific knowledge as they use critical thinking and reasoning to develop their understanding of science” (National Research Council, 2000, p. 18); however, the end goal of ‘understanding’ still emphasized declarative knowledge and a traditional process approach to inquiry. The statements included in the ‘understanding of science’ standard represented a central part of science focused on experimentation, theory building, the importance of evidence and the how and why science knowledge changes. However, these statements fell short of completely capturing science as a practice because they included a superficial view of the social domain of science inquiry missing specifically the roles of peers, collaboration, and critique in the process of knowledge construction.

Over time, scientific studies found that the work of scientists was substantially different from each other. The processes and knowledge of science were viewed as heavily interrelated and interacted in a way that resulted in unique practices that are appropriate for different contexts, which made it difficult to articulate generalities of scientific acts and reasoning (Ford, 2015). Based on these observations, reform movements in science education have landed on the term “practice” to capture the scientific and social acts and reasoning. The lists of science practices found in the *AP Biology Curriculum Framework* (College Board, 2011) and *A Framework for K-12 Science Education* (NRC, 2012) may appear similar to the list of scientific inquiry or the scientific method, but it is the use of the term “practice” that uniquely captures what matters most for students to learn about the reliability and epistemic privilege of science (Ford, 2015). Focus on practices includes scientific inquiry and goes beyond what science teachers have realized based on the 1990s (Bybee, 2011).

Practices are collective learnings that incorporate the activities, language, and tools -both implicit and explicit - that reflect the social relations and pursuit of an enterprise that are an inherent part of a community (Wegner, 1998). A practice elicits the idea of someone doing something, but the idea is beyond a simple action. It incorporates the historical, social, and epistemic dynamics that are critical to engaging in the core knowledge development and revision within the science community (Grandy & Duschl, 2007). Science through this perspective recognizes that consistent discourse within this community molds a person’s knowledge, skills, resources, motives, and attitudes (NRC, 2006). The situated component acknowledges the context dependency of knowledge development and scientific practice, and avoids a universalist, decontextualized, discrete list of science inquiry and nature of science items (Elby and Hammer, 2001; Osborne et al., 2003; Rudolph, 2000). Practicing science may exhibit regularities in reasoning and action, but these regularities are not descriptive or prescriptive rules (Ford, 2015). Ford (2015) captures how we can articulate what students need to know despite the situated nature of practice best: “Scientific practice is based not on rules, but on processes of perpetual evaluation and critique that support progress in explaining nature. Regularities are artifacts of these processes” (p. 1043).

For the purposes of this research, reform-oriented science practice is defined as disciplinary, goal-directed activities (Ford, 2008) that encompass the “ways of knowing and doing that scientists use to study the natural world” (Krajcik & Blumenfeld, 2006, p. 323), which emphasizes a more epistemological sensitive and social view of science. Emphasis is placed on argumentation, the value of evidence, and models as a source of reasoning and knowledge generation, helping to bring the epistemic aspects of science forward (Driver, Newton, & Osborne, 2000; Duschl, 2008; Grandy & Duschl, 2007; Osborne, 2007; Osborne et al, 2003). The reform goal of science practice expands the constructivist-based *Inquiry* standards to encompass a situated and sociocultural view of science and establishes the science community as a critical component of the science process (Grandy & Duschl, 2007), resulting in a more coherent view of science as a practice.

This reform-based goal of science practice incorporates three integrated domains: conceptual, epistemic, and social (Duschl, 2008). All three domains are critical to science learning and should be explicitly a part of instruction and visible in students’ thinking and science practice (Duschl, 2008). Historically, all three domains have not been incorporated into the goal of science practice. As previously mentioned, early attempts to capture the acts and reasoning of science do not explicitly include the epistemic or social domain, and instead focus on the performances of science[1] and the concepts of the discipline separately. The performances of science practice are not completed in the abstract. The reform-based goal of science practice integrates the discipline concepts with the cognitive or physical performances, which are considered the *conceptual domain* of science practice (Duschl, 2008). These cognitive or physical performances (see Table 2.1 for a list) integrated with the discipline concepts are referred to in this study as the "performances" of science practice such as comparing alternative models, making predictions, collecting and organizing data, or discussing theories or models (Grandy & Duschl, 2007). It is the integration of performances of science practice with language, symbols, and models that is important to the reform-based goal of science practice (Edelson, 1997; Fodor, 1998; Ford, 2008). The performances of science practice become a crucial contributor to deepening student understanding of content, and this entanglement of performances and concepts seems to be an inescapable aspect of the development of full scientific understanding (Krajcik et al., 2008).

The social and epistemic domains are domains that are embedded in science knowledge and practice and are critical to science learning and gaining a scientific perspective (Duschl, 2008). Having an epistemic understanding of science means understanding the ways in which scientific knowledge is generated, validated and refined through the actions of the science community, the motivation behind these actions, and scientists' active pursuit of evidence (Edelson, 1997; Grandy & Duschl, 2007; Osborne, 2007). An epistemic understanding incorporates the decisions and judgments involved in knowledge generation, the evaluation of knowledge statements, and knowing what counts as evidence or a well-supported argument

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[1] Duschl and Grandy (2008) and Ford (2008), which are the primary basis for this description of science practice use the term "activity" to describe the "processes" of science practice. To avoid confusion with the activity theory and activity system analysis of this study and the "process" emphasis of scientific inquiry, the author has chosen the term "performances" to substitute for the "activities" of science practice. Ford (2015) uses the term "performances" to refer to the activity of science that can be judged normatively as a part of science practice.

(Duschl, 2008). The epistemic domain also involves multiple forms of communication of evidence and explanations through representations, models, discussions, and evaluations. Student outcomes of the performances of science practice should incorporate evidence of this epistemic understanding to demonstrate a scientific perspective (Driver, Newton, & Osborne, 2000; Duschl, 2008; Grandy & Duschl, 2007; Osborne et al., 2003), which includes students knowing the purposes behind the performances of science in terms of knowledge generation and refinement.

The social domain incorporates the community of science, which impacts the “appropriateness” of the goal or performances of practice (Ford, 2008; Ford & Forman, 2006; NRC, 2006). In science, a performance is deemed inappropriate if it is not in accordance with those standards converged upon by the community (Ford, 2008). Participation within the science community or science practice requires knowing how to implement performances appropriately in order to improve upon the explanation of nature (Ford, 2015). It is this goal of appropriateness that captures the nature of science. Thus, practicing science appropriately promotes both an understanding of the performances of science and the nature of science. The goal of science as inquiry ignores the epistemic domain and minimizes the social domain to science practice (Grandy & Duschl, 2007).

Overtime, as the current goal of science practices developed, the epistemic and social domains, in particular, emerged and therefore, vary among the different phases in the cultural-historical progression of scientific acts and reasoning. The reform goal of science practice considers the conceptual domain, which is the performances of science practice, as well as the social and epistemic domains, which capture the nature of science. Considering all of these domains when describing the goals of science practice provides a comprehensive framework that is currently lacking in research which can be used to study teachers' specialized content knowledge of science practice.

The goal of science practice has the appearance of being very systematic, as if there is a heuristic to be followed for each performance in any given situation. Yet the evidence that someone has achieved an understanding of science practice is much more fluid, manifested as the person having an implicit understanding of the performances of practice and the integration of the three domains. Ford (2008) refers to this as a "grasp of practice." This is an inherent kind of knowing; for every performance the person must know how to do it, in what other ways it could be done, the circumstances for its completion, and the overall goal for its use. It is this knowledge about the performances and domains of science practice that is the target of this study. For students to gain a "grasp of practice," teachers should know the how, when, why, and the appropriateness associated with an array of science practice performances in a myriad of problem contexts. It may require teaching patterns of performance in isolation in some circumstances as well as the interaction of the performances in other situations. Teachers should also explicitly teach about the domains of science practice. This knowledge is the specialized content knowledge of science practice.

Specialized Content Knowledge

In order to achieve the type of classroom instruction advocated by the reforms, teachers should have deep and highly structured content knowledge so they can use it flexibly and efficiently during instruction (Sternberg & Horvath, 1995; Talbert, McLaughlin, & Rowan, 1993). Deep content knowledge involves teachers knowing the structure and nature of their discipline, demonstrating fluency in science community discourse, and recognizing application of science content knowledge and processes of science practice to students' lives (Gess-

Newsome, 1999). This type of knowledge is needed in order to engage students in authentic experiences of the discipline and teach for understanding (Newmann, 1993; Talbert et al., 1993). The following paragraphs describe the construct for content knowledge for teaching or specialized content knowledge used in this study, which is based on the work of Ball, Thames, and Phelps (2008) and Hill, Rowan, and Ball (2005).

To better understand the deep content knowledge required for teaching, this study proposes to better understand teachers' specialized content knowledge of scientific acts and reasoning as it is internalized to establish the *instructional goals* of their central activity of AP Biology teaching. The study also aims to describe teachers' specialized content knowledge (SCK) as a psychological tool used to mediate student learning. There is not an agreed upon definition of SMK or PCK within science or across disciplines (Alonzo et al., 2012). I am applying a mathematical knowledge for teaching construct (Ball, Thames, & Phelps, 2008) to science practice because the construct is a practice-based theory that analyzed teachers' knowledge through their tasks or actions in the classroom. This practice-based approach aligns with the CHAT perspective of this study, which analyzes the teaching activity and the tools and actions associated with that activity. My interpretation and application of this construct in science is supported by the work of Alonzo et al. (2012) that compares Ball, Thames, and Phelps' (2008) content knowledge for teaching construct to her content knowledge sub-category of PCK in the science domain. The nature of the knowledge is the same, just organized under different constructs. Ball, Thames, and Phelps (2008) studied mathematics teaching, focusing on the procedures involved in doing math. This emphasis on math procedures is parallel to the specialized content knowledge of science practice, which also incorporates procedures, as well as knowledge of and strategy in using the performances of science practice as a part of a science community. The study explores in-depth the content knowledge for teaching or specialized content knowledge because this form of knowledge, no matter the greater construct, has demonstrated to be significantly related to student achievement in math (Hill, Rowan, & Ball, 2005) and early indications of a relationship in science (Alonzo et al., 2012).

The definition of specialized content knowledge for this study is based on descriptions of the knowledge needed to carry out the work of teaching, by focusing on the tasks or actions of teaching and not the teacher (Ball, Thames, & Phelps, 2008). Ball, Thames, and Phelps (2008) identified the fundamental differences between specialized content knowledge (SCK), and knowledge used by experts in the discipline, which they termed common content knowledge (CCK). Specialized content knowledge and common content knowledge are sub-categories of subject matter knowledge (SMK) and differentiated from PCK in that it focuses purely on the content knowledge unique to teachers and does not integrate this knowledge with pedagogy or the student (Ball, Thames, & Phelps, 2008). The distinction is first alluded to by Dewey (1902) "Every study or subject thus has two aspects: one for the scientist as a scientists; the other for the teacher as teacher. These two aspects are in no sense opposed or conflicting, but neither are they identical" (pp. 285-286). Specialized content knowledge is considered specialized because it is unique to teachers, where a more broadly defined CCK is used in a variety of setting by experts in fields other than teaching. SCK is also “pure” in that it is not interwoven with knowledge of students, pedagogy, or curriculum, which draws a clear distinction between specialized content knowledge and pedagogical content knowledge (Ball, Thames, & Phelps, 2008). SCK is knowledge about what teachers must know about a discipline in order to carry out teaching, knowledge that informs teachers’ choices and actions (Ball, Thames, & Phelps, 2008). For example with respect to science practice, CCK is knowing the canonical definition of models and the role of models in science practice. SCK is explaining the role of models as part of explicit instruction appropriate for the student population, and that an explanation to an AP level student is different from elementary level. In contrast PCK involves incorporating and building the role of models into lessons or laboratory exercises. Through their practice-based research, Ball, Thames, and Phelps (2008) also provided examples of mathematical specialized content knowledge mobilized in teacher actions. The examples shown in Figure 2.1 are a sample of those included in their study, and are included here because they are believed to be transferrable to teachers' specialized content knowledge of science practice.

- Interpreting student errors,
- Evaluating alternative algorithms or solutions to solving problems,
- Explaining a procedure or practice, which involves knowing how the procedure works, rationales for the procedure, knowing the steps and meaning of a procedure, knowing what and why steps are needed
- Knowing whether a method or procedure will work for a specific problem or context
- Explaining concepts, which is different from providing definitions and examples
- Representing the meaning of a concept or practice effectively
- Selecting appropriate representations, which involves knowing when and why features of a representation are appropriate for the concept
- Selecting examples for a concept
- Determining validity of an argument
- Assigning student work, listening to students talk, grading and commenting on student work

Figure 2.1. Samples of Specialized Content Knowledge in Tasks of Teacher Practice (Ball, Thames, & Phelps, 2008)

The following section further clarifies how this study is differentiating common content knowledge and specialized content knowledge. Scientists have a "grasp of practice," knowing when, how, and why to apply certain activities of science practice when approaching a problem (Ford, 2008). The declarative knowledge associated with the concepts and performances of science, as well as the procedural knowledge of the performances of science practice, are considered common content knowledge in that they are used by experts in the fields of science as well as teachers. Scientists' strategic knowledge is implicit in their actions because they are members of a community of practice that are guided by the rules of evidence with the common aim of knowledge construction. However, if a teacher is to develop in students this same sense of knowing when, how, and why to apply the components of science practice, s/he should be able to unpack the knowledge of scientists, create authentic experiences, and explicitly teach students the heuristics and reasoning associated with the actions that are implicit to and employed by scientists for certain problems and contexts. In order for this to happen, teachers should know and explicitly teach how the domains of science practice are integrated with each other and the performances of practice, and the overall dynamics among these in terms of the goal of science practice (Lederman, 2007; Sandoval, 2005; Schwartz, Lederman, and Crawford, 2004). Using the example provided earlier, a teacher should unpack the meta-knowledge associated with use of models and explain the relationship of models to theories. It is that unique knowledge of how to unpack and explain that is specific to the activity of teaching. The knowledge teachers need to explicitly guide and engage students in these practices is unique to a teacher and therefore considered specialized content knowledge (Ball, Thames, & Phelps, 2008).

Broad Theoretical Perspectives

The proposed research is framed by two broad theoretical perspectives. The reform goal of science practice and the analysis of teachers' *instructional goals* and transformation of AP Biology teaching are informed by a situative perspective. Cultural-historical activity theory (CHAT) provides a methodology to systematically analyze teaching and learning (Engestrom, 1987) as well as a theoretical perspective for analyzing AP Biology teaching as a goal-driven and interactive, contextualized process. Both perspectives influence the conceptual backing of the research, the overall research design, and the analysis of the findings.

Situative Perspective

A situative perspective integrates two research programs of human behavior: cognitive science, which analyzes individual activity and the information generated through activity, and interactional systems, which study groups of individuals engaged in joint action with materials and informational systems in their environments (Greeno, 2006). Explanations from a situative perspective break down the individual and environment barrier and consider both the participation of an individual in his/her environment and the individual structures of information that are used in this activity (Barab, Evans, & Baek, 2004; Greeno, 2006). From a situative perspective knowledge, more appropriately termed “knowledge about,” is an individual’s contextualized activity that is constructed through interaction of the individual with the environment (Barab, et al, 1999; Barab, Evans, & Baek, 2004; Brown, et al., 1989; Greeno, Smith, & Moore, 1992; Lave & Wenger, 1991).

There are three aspects of the proposed research that are based on a situative perspective. To determine teachers’ knowledge about or their “meaning” for science practice, the researcher intends to analyze four teachers’ actions, interactions, use of tools, and meaning making in the larger context of their classroom practice. Studying teachers’ actions and activity in their classroom context unveils their knowledge structures because their knowledge about science and science teaching is situated in their participation and practices in a community of science educators (Brown, et al., 1989; Greeno, Smith, & Moore, 1992; Lave & Wenger, 1991). Studying teachers’ actions and interactions with tools and other people provides insight into knowledge structures or how teachers’ knowledge about science practice functions in their discourse, choice of representations, language, and artifacts. A situative perspective supports this approach to studying teachers' knowledge in that the activity in which knowledge is deployed is not separable from or ancillary to cognition - learning and cognition are fundamentally situated and inextricably linked (e.g., Blumenfeld et al., 1998; Greeno, Smith, & Moore, 1992; Lave, 1988; Lave & Wenger, 1991).

Teacher learning can also be described through a situative perspective. How a person learns and the situation of the learning become a fundamental part of what is learned, supporting the effectiveness of teachers' active learning (Garet, Porter, Desimone, Byrd, & Yoon, 2001). The premise behind this study is that communities of teachers transform or shift based on the actions and tools created by the community members. This premise reflects a situative perspective which views learning as an enculturation into a community, to know how to participate in the discourse and practices of a particular community (Cobb, 1994; Lave & Wenger, 1991). Through the enculturation of new members entering the community, the community changes through the ideas, artifacts, and ways of thinking that its new members bring to the community discourse (Putnam & Borko, 2000). The context and situation of teacher learning is important, for example whether the learning takes place embedded in their instructional environment or outside of their environment, in a different space with different tools. Teacher learning is also social and distributed among its members (Putnam & Borko, 2000). All of these themes of a situative perspective support the approach and analysis of this study of teacher learning.

A situative perspective also supports the study's focus on teachers' specialized content knowledge (SCK) as a measure of their knowledge for teaching science practice. Specialized content knowledge is unique to science teaching in that it is shared among a community of science teachers and no one else (Ball, Thames, & Phelps, 2008). The actions and interactions influenced by SCK (e.g., selection of examples, representations, or explanations of processes or procedures) incorporate a teacher’s meaning of science practice that is uniquely contextualized in his/her classroom practice. Explaining teachers’ knowledge of science practice through SCK incorporates both their participation as a science teacher in a classroom community and the information structures that are used in the activity of teaching science practice with students, which is characteristic of a situated perspective. Specialized content knowledge from a situative perspective presents an ideal measure for capturing the variety of meanings teachers have of science practice as it is actualized in their classroom environment, connecting the continuum of scientific acts and reasoning to classroom activity. For this study a situative perspective guides the approach of analyzing a teacher’s activity in his science classroom context to reveal his specialized content knowledge, analyzing this teacher’s learning, and the selection of specialized content knowledge as the measure of teachers’ knowledge for teaching science practice.

Cultural Historical Activity Theory (CHAT)

From a situative perspective knowing and learning are action-relevant terms that involve interacting with things and other people within a certain context (Barab & Hay, 2001; Greeno, Moore, Smith, 2001). From this perspective learning is viewed as an activity, an activity of meaning making that is socially formulated, goal-directed, and tool-mediated. Activity theory is concerned with the activity of learning that occurs through conscious actions. It is not concerned with disembodied actions but is interested in actions that transform something (Barab, Evans, & Baek, 2004; Engestrom, 1987). According to the principles of activity theory, an activity is a coherent, stable, relatively long-term endeavor directed to an articulated or identifiable goal or object (Rochelle, 1998). Moreover, activity can only be adequately understood within its culturally and historically situated context. This study employs cultural historical activity theory (CHAT) as a methodology to describe teachers' *instructional goals* against the redesigned AP Biology course's science practice goals. CHAT is also applied to analyze an AP Biology teacher's learning activity as his AP biology teaching progresses toward the AP Biology goal of science practice. Each teacher's *instructional goal* directs his/her AP Biology teaching, the activity system of interest for this study. Since activity is best understood within a cultural and historical context, each teacher's *instructional goal* is situated within a cultural-historical continuum of scientific acts and reasoning.

CHAT is useful to study the interactions of a teacher with people, instruments, and the contextual features of the environment that shape a teacher's information structures, his/her teaching practice, and his/her *instructional goals*. The methodology provides a metric that parses data into appropriate grain sizes for analysis - an activity system, and provides an a priori set of relations among the entities of an activity system shown in Figure 2.2. A researcher must examine not only the kinds of activities that the teacher engages in, but also the goals, objects, rules or norms of the activity system (Engestrom, 1987, 1999; Nardi, 1996) to capture the contextualized nature of the activity. CHAT has been used in educational research to describe teachers' curriculum revisions (Forbes, 2009); teachers' pedagogical content knowledge (Forbes, Madeira, Davis & Slotta, 2009); contradictions in an astronomy course (Barab, Barnett, Yamagata-Lynch, Squire, & Keating, 2002); preservice teachers' reflections (Barrie, Tran, McDonald & Kelly, 2014); and new teacher's transition into teaching (Saka, Southerland, & Brooks, 2009). Overall the use of CHAT, and specifically the third generation definition of CHAT, makes it possible to incorporate the historical continuity of an activity (i.e., AP Biology teaching) and situated dependencies of the activity being analyzed (Engestrom, 1999). The following information describes the structure of an activity system and explains how this structure aids the analysis of teachers' learning.

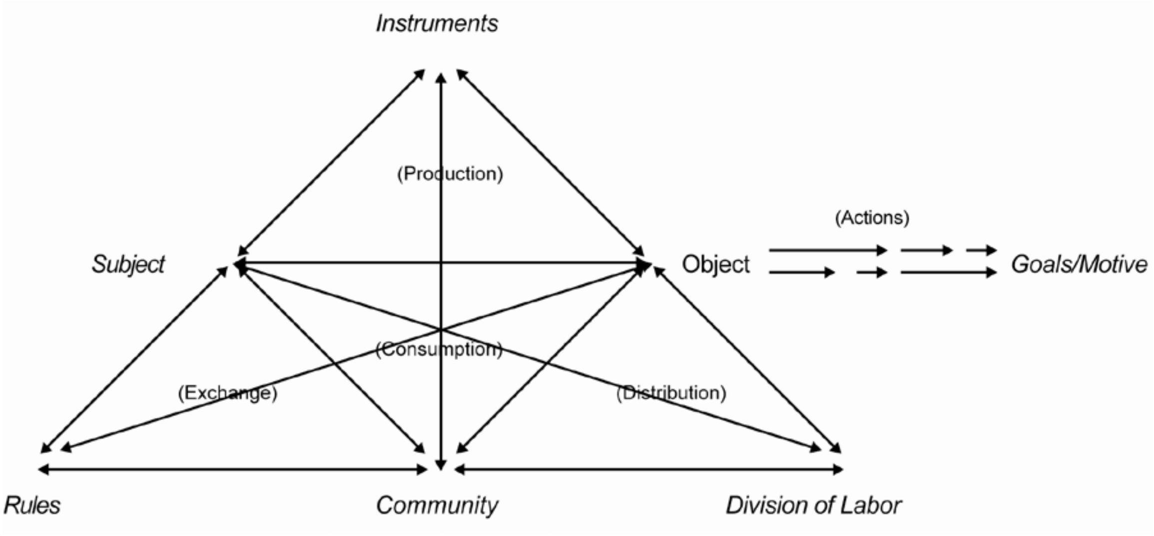

Figure 2.2. Cultural-Historical Activity Theory Model of Human Activity (Engestrom, 1987)

To use activity systems as a framework for analysis, third generation activity theory focuses on the activity system as modeled by Engestrom (1987), which builds on Vygotsky's triad of mediated activity. A mediated activity system describes the process of meaning making as a subject's active pursuit of an object mediated by tools or instruments (Vygotsky, 1978). Figure 2.2 is a depiction of the activity system model, which expands beyond the mediation triangle to include the contextual factors (lower portion of triangle). The triangle model incorporates mediated activity, the top triangle, and the contextualized nature of activity by including the community, rules, division of labor as the base of the triangle. In this study the activity triangle represents both the activity of AP Biology teaching, which is referred to as the *central activity system*, and the transformation of this *central activity* from the perspective of the subject (the teacher), which represents teacher learning activity. The differences between these two forms of activity are explained later in this section. This next section explains why the teacher is the subject of a central activity system of AP Biology teaching, where the outcome is student learning.

Most CHAT-based research analyzes the general activity of schooling where students are the subject of the activity system. Similar to the research presented in Forbes, et al. (2009) and Forbes (2009), in this study, activity systems are reconfigured and used to describe teachers as the subject with the object being student learning for the *central activity* or a teacher's own learning activity. For this study the teacher is the subject because s/he is the agent of the activity and in control of the teaching activity as well as his/her own learning activity. This reconfigured activity system as a unit of analysis focuses on a teacher's central activity of AP Biology teaching through a coherent instructional module in the classroom. This means the boundaries of a representative central activity system are defined by the object of the teaching activity. The central activity system aims toward a high-level goal (student's scientific perspective which incorporates scientific acts and reasoning), where a teacher (subject) within the classroom community (community) works toward a student learning outcome or result (object) which is connected to the broader system goal (student's scientific perspective). The teacher uses instruments to facilitate achievement of the object, which includes content knowledge, strategies, symbols, examples, representations, and tools. The context of the activity is captured by the bottom of the triangle which includes the community in which and for which the activity takes place (e.g., the school, other teachers, students, etc.) and the division of labor and rules within that community. These components of the activity system are interacting toward the goal, which constitutes the central system activity, and the system triangle illustrates the dynamic interactions of the components within the system using double arrows.

To gain more comprehensive insight into teachers' activity and their instrument facilitated actions, there are hierarchical levels within an activity system that differentiate the immediate actions of the teacher, the automatic operations, and the overall, object-driven activity (Leont'ev, 1978). The three levels - activity, action, and operations - are the fundamental principle of analysis for activity theory according to Leont'ev (1978) and referred to as the cultural levels of behavior, conscious, and automatic levels respectively. These levels permit further analysis of the dynamics between an activity, the conscious actions, and the automatic, unconscious operations that are dependent on the activity's environmental context. For example, when an action is first performed, it requires conscious effort and planning toward the object (student learning outcome) of the action. With enough practice and internalization, actions become operations, requiring less conscious effort. For data analysis the levels provide another degree of description of the activity system, which provides additional insight into teachers' actions toward their *instructional goals*, learning activity, and the environmental factors of these activity systems.

Activity consists of a chain or series of actions directed consciously to transform the object into the goal through the use of tools. Analysis of the central activity systems of this study centers on teachers' series of conscious actions that are a part of their AP Biology teaching (central activity) as they use physical and psychological tools to transform student learning outcomes (object) into the ultimate goal of a scientific perspective (Engestrom, 1999; Nardi, 1996). This study is interested in these conscious actions and the psychological tools associated with science practice (i.e., examples, representations, explanations of the components of science practice). The actions leverage specialized content knowledge - teacher's explanations of processes, selection of examples and representations (see Figure 2.1 for a full list) – as psychological tools to facilitate student learning. These actions, among others, were described and isolated by Ball, Thames, and Phelps (2008) as tasks that actualize specialized content knowledge mobilized in teachers' classroom practice. The AP Biology goal of science practice is new to teachers of this study, so there exists contradictions with their already operationalized knowledge and practice. As they attempt to use this new information in their instructional practice, study observations focused on their conscious actions directed at addressing the contradictions and implementing science practice into their AP Biology teaching. CHAT provides a lens for studying these conscious actions in the greater context of the teaching activity, relating the tool of specialized content knowledge to the object of student learning outcomes and the rules or language of the classroom community.

Central activity versus learning activity. There exists a network of activity systems. Each component of an activity system (e.g., object, instrument, subject) was "produced" by another activity. The central activity is the targeted unit of analysis. It is nested by the activities that produce the components of the central activity system. The central activity system is the work of AP Biology teaching, which has an object of student outcomes of concepts and practices of AP Biology. Learning activity is "production of objectively, societally new activity structures (including new objects, instruments, etc.)" (Engestrom, 1987, p. 98). The learning activity of this study is a teacher (subject), as representative of a greater community (AP Biology teacher community), learning through his/her engagement in the activity of AP Biology teaching. The subject is learning through the activity of his/her work – learning is embedded in his/her practice. The learning activity is the transformation of the central activity system (see Figure 2.3). In the learning activity the subject attempts to resolve a conflict between the current form of the central activity and a future, more advanced form of the central activity. To completely resolve the conflict is to transform the central activity so new activity structures exist as the future form of the central activity. This process of transformation of the central activity is only possible if there is an awareness of the contradictions of the central activity system. The object of learning activity is the progress of the central activity system, the subject's conscious attempt to advance their central activity (see Table 2.3 for further elaboration of each component of the central activity and learning activity of this study).

Since the teacher is learning[2] through his/her work (central activity), s/he is acting on this contradiction by creating tools and establishing objects for student learning as a part of his/her instructional practice. This type of learning is different from a teacher that is given instruments to mediate his/her learning in a different community and context removed from the classroom, like a professional development session. Each individual within the greater community is transforming their central activity. Each individual subject's actions, new artifacts, and new objects eventually permeate the greater community through the social interaction of the community; therefore, transforming the community as a whole. Engestrom (1999) promotes this movement of study from individual actions to analysis of the broader community context and back to the individual actions. This movement illuminates the contradictions and the community-individual relationship as the community's central activity transforms.

Table 2.3. Components of Central Activity System and Teacher Learning Activity (Engestrom, 1987)

Component of Activity System	**Description**	**Central Activity of Study**	**Learning Activity of Study**
Activity System	The unit of analysis	AP Biology teaching	Transformation of AP Biology teaching
Subject	Individual or group of the activity oriented to transform some object	Teacher	Teacher
Object	Cognitive object, outward goal, concrete purpose, objectified motive	Student learning outcome	Progress of the central activity system, AP

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[2] From this point forward I refer to "learning activity" as "learning" to simplify explanations and descriptions that require the use of both learning activity and central activity.

	of the activity; connected to the broader system goal/motive		Biology teaching
Goals/motive	Motivation or goal that orients the activity within the community	Student scientific perspective	Resolve the conflict between current and future form of AP Biology teaching
Instruments	Technical tools directed toward object or psychological tools directed toward activity	Classroom lessons, specialized content knowledge, labs, articles	Creation of new tools and new objects of central activity; reflective practice
Actions conscious	Actions individual is aware of, example is use of tools to facilitate student meaning making toward object	Actions directed at student learning of AP Biology	Actions directed at transformation of own AP Biology teaching
Community	Group of individuals who are a part of the activity taking place includes shared space and experiences	Local district/school community includes students	AP Biology community (micro-community)
Rules	Norms of the community of the activity, rules of engagement or language	Language, cultural norms for classroom participation	Language, cultural norms of being an AP Biology teacher
Division of Labor	Specialization and stratification of roles and responsibilities distributed throughout the community (horizontally and vertically)	Between student and teacher and among students in learning	Between student and teacher and among other teachers in micro-community (AP community)

Psychological tools. In Vygotsky's mediation triangle, the instruments play a critical role in mediating the interaction of the active subject and the object of cognition. The use of instruments broadens the psychological operations beyond the immediate stimulus (object) response action, changing the object toward the overall goal of the activity system; therefore, leading to expansion or learning. Without the instruments, it is a simple stimulus response that is operational and not conscious so no learning occurs (Engestrom, 1987). There are two types of mediating instruments: technical tools and psychological tools. Technical tools (worksheets, lab equipment, etc.) mediate the object for the subject. Psychological tools are different in that they can also mediate an object resulting in control of an act (behavior) by the subject or someone else's act or behavior (Vygotsky, 1978). As Engestrom (1987) suggests, "the essence of psychological tools is that they are originally instruments for co-operative, communicative and self-conscious shaping and controlling of the procedures of using and making technical tools" (p. 18), thus supporting the essential relationship between them. According to Vygotsky (1981), psychological tools can be language, systems for performing procedures, symbols, diagrams, or writing techniques. For CHAT activity systems the subject is oriented to transform some object using a cultural–historically constructed tool (technical or psychological) (Engstrom 1987, 1994; Rochelle, 1998). Using a CHAT perspective, the psychological tools can be principles, frameworks, or ideas about something (learning, teaching, science), and often reflect the internalized thinking patterns or practices of the community (Engestrom 1987, 1994; Grossman, Smagorinsky, & Valencia, 1999). McNicholl and Childs (2010) site Wartofsky's (1979) definition of psychological tools as secondary artifacts that represents the technical tools (primary artefacts) and include recipes, beliefs and norms which preserve and transmit current ways of acting and thinking with the primary tool. Through this definition, McNicholl and Childs (2010) operationalize pedagogical content knowledge (PCK) as a psychological tool, which supports the use of specialized content knowledge (SCK) as a psychological tool in this study.

For the purpose of this study, the CHAT definition of psychological tools is interpreted to include SCK as a psychological tool that mediates student learning. Specialized content knowledge of scientific acts and reasoning includes the accepted explanations, symbols, representations, procedures, principles, and practices of the science community used for teaching (central activity system) (Ball, Thames, and Phelps, 2008). Engestrom's (1994) book, *Training for Change: New Approach to Instruction and Learning in Working Life*, is dedicated to the application of activity theory for student learning. In this book he emphasizes the importance of the subject matter knowledge for teaching. For students to consciously construct their understanding or “deep-level learning,” teachers must set objectives (objects) that clarify the explanatory models and modes of discourse in which student performance is to be based. Teachers must also select technical tools and experiences that will cause a cognitive conflict (the role of contradictions or conflict in learning from an activity theory perspective is elaborated on in the next section) for students, motiving their learning activity. To set clear objects and select appropriate tools, teachers must have a command of the subject matter knowledge of these models and discourse practices of the community of practice in which students are on the periphery of entering. Teacher’s explanations, selection of representations or examples, and recognition of appropriate models and practices for the discipline is their specialized content knowledge, which is used as a psychological tool for teaching.

It is important to note that although tools are present whenever subjects are engaged in a certain central activity, tools are also constructed through the activity (Bannon & Bødker, 1991). In this way, mediating action involves subject, object, and tools that are constantly transformed through the central activity. Thus, in the act of teaching, teachers use their specialized content knowledge, but this knowledge can be transformed through the activity of teaching as they create new objects and use different tools in an attempt to resolve their own cognitive conflict and learn. In this study, a teacher’s use of specialized content knowledge to facilitate student meaning making is analyzed as a metric of teacher learning.

Contradictions. Contradictions are important to learning because they motivate the overall transformation of the central activity system. The goal of learning is to overcome the contradiction or fill the gap so there is continued development of the community to establish new, more culturally-advanced and articulated forms of activity (Engestrom, 1987; Saka et al., 2009). Contradictions can be tensions or conflicts that arise within activity systems or among systems due to tensions among the components of the activity system. In learning activity the subject attempts to resolve a contradiction. These discordances within the system motivate actions within the system and lead to the evolution of the system. The evolution or expansion of an activity system depends on a cascade of contradictions: “The resolution of one contradiction often leads to another and so on until a new state of equilibrium is reached within the activity” (Forbes, et al., 2009, p. 34).

Engestrom (1987) outlines four types of contradictions experienced in series by the subject of the central activity system as it transforms. The first type of contradiction is *within* a component or node of the activity system model (i.e., subject, object, etc.). It arises due to an issue identified by a participant in the central activity system. For example, in science teaching, the teacher (subject) may wrestle with his/her role as facilitator or transmitter of information. This discordance is called a ‘need state’ which the teacher must grapple with in order to make decisions about and consider competing alternatives when engaging in science teaching practice (Engestrom, 1987). Although this need state is ill defined, it initiates and motivates the transformation of the central activity system.

As the activity system continues to develop there are also tensions between the different components or nodes of the system, a secondary contradiction. This contradiction is better defined and as the subject attempts to overcome this form of contradiction; new artifacts are formed and lead to new forms of the activity. An example for science teaching activity may be tension between the curriculum tools available to meet certain student learning outcomes (object). The learning outcome may be for students to construct a model based on data and information available about an ecosystem. The curricular materials provided expect students to use the model to learn about ecosystems. To resolve this conflict, the teacher must adapt the curricular materials to facilitate an outcome of student constructing a model.

The third type of contradiction exists between the object and goals of a current form of the central activity and the object and goal of a more culturally advanced form of activity. For example, this type of contradiction would exist between common practices in a classroom and more reform-oriented practices in a classroom. As some individuals within a community engage in the more reform-oriented practices, this conflict creates tension between those who adhere to the established practices and those who seek to appropriate the new practices. This contradiction might also be on the individual level as individuals within the community resist the object and goals of the future form of the activity system. The resistance is intentional, which is different from a contradiction that is ill defined or unconscious to the subject (Forbes, 2009).

The fourth type of contradiction exists between the central activity of a system and the neighboring activities of adjacent systems, the activity systems that "produced" the component of the central activity system. There are adjacent activity systems that create the tools/instruments used by the central activity system. For example, there is an activity system that produces the textbooks (tool) used by AP teachers and students. This type of contradiction, for example, may exist between the science teachers (subject) and the pre-service program that trains and prepares individuals to be science teachers (subject-producing activity).

As a whole, any of these contradictions can be a source of tension that the subject attempts to overcome in order to transform the activity of the system. This discordance in the system is not a sign of dysfunction, but an opportunity for intervention and improvement. Identification of these contradictions or series of contradictions provides a means for documenting the transformation of the system through the generation of shifting objects and new tools and artifacts as the subject attempts to close the gap. However, improvement and gap closure (learning) cannot occur unless the subject is aware of the contradiction by undergoing some reflective event. Engestrom (1994) differentiates a contradiction with a motive, in that any contradiction can become a motive for learning if it is noticed, faced, and experienced by the learner. Leont’ev (1981) sees this reflective event as the core to learning:

> It [conscious motives] requires a certain special activity, some special act. This is an act of reflecting the relation of the motive of a given, concrete activity to the motive of a wider activity, that realizes a broader, more general life relation that includes the given, concrete activity. (p. 238)

Leont’ev (1981) is describing the reflective event that makes a conflict for activity conscious as the subject becomes aware of discordance between his/her existing form of the central activity system and some future form of the central activity where the contradiction does not exist, a new form of the central activity system. This new future form becomes the goal of the central activity and closing the gap becomes the motive for transforming the activity system. For this study the future form of AP Biology teaching is the future activity system that is directed to teachers’ *instructional goals* for student learning. Their *instructional goals* reflect, from their perspective, the greater redesigned AP Biology goal. The process of resolving this contradiction is called learning or what Engestrom (1987) calls learning as expanding.

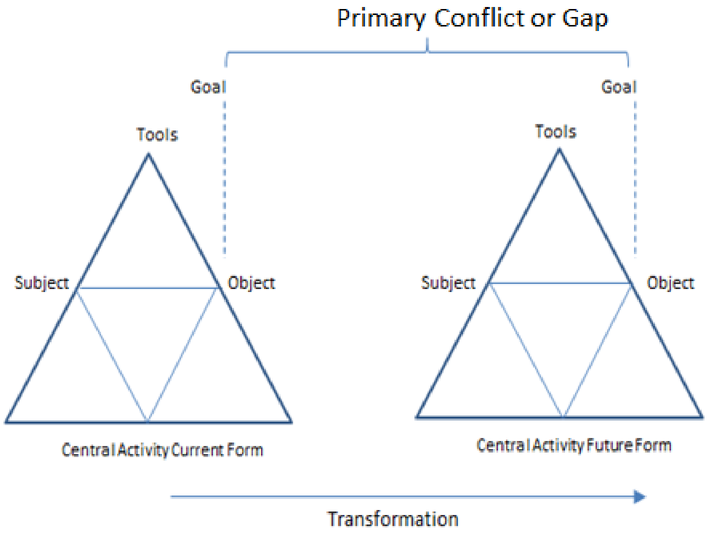

Figure 2.3. Learning Activity as Transformation of Central Activity System

Learning as expanding. The goal of learning from an activity theory perspective is the continued development of the community to establish new, more culturally-advanced and articulated forms of activity (Saka et al., 2009) and for the individual (subject), movement toward central membership of the community (Lave & Wegner, 1991). Engestrom (1999) terms the transformation *expansive learning*, where each expansion of the central activity is a snapshot or phase of the overall evolution of a system in which the activity progresses. For teacher learning through their practice, learning or transformation of their activity system is evidenced by teacher engagement in more advanced forms of teaching practice (Forbes, 2009). Engestrom (1994) recommends the use of an “expansive cycle” model to observe individual’s (subject) transformation through repeated cycles of the long-term development process.

Each expansive cycle contains the processes of internalization and externalization. The cycle is initiated with the process of internalization, which is “socializing novices to become competent members of the activity as it is routinely carried out” (Engestrom, 1999, p. 33). Internalization is the appropriation of the practices, rules, and language of a community’s culture (future form of the central activity) initially by the individual’s interactions with other members and tools of the community, but eventually through the critical practice of self-reflection. There is also externalization, the creation of new artifacts in response to contradictions within the central activity system that reflect the internalized model of the future form of the central activity system. Saka et al. (2009) best summarizes Engestrom (1999) with respect to the coordination of internalization, externalization, and contradictions in the system:

> While the disruptions and contradictions of the activity become more challenging, internalization, increasingly take the form of critical self-reflection and externalization as a search for possible solutions increases. Externalization reaches its peak only when a new model for the activity is designed and implemented. When the externalization is completed, internalization becomes the dominant form of learning and development. (p. 1001)

Together the two processes spurred by the goal of the central activity and the contradictions within the central activity system create a process of learning that connects the object of the system to the goal of the activity (Saka et al., 2009). These processes together make transforming the community and the goal of activity possible. By incorporating these two processes, it is important to recognize that the central activity system is evolving, and therefore, the object of the system should not be viewed as an ultimate goal, but milestones in the course of activity (Dewey, 1922 in Engestrom, 1999) toward a goal. The transformation of a central activity system is learning and the process of development functions as a conduit between object and the goal of the activity system (Saka et al., 2009).

From a CHAT perspective of the expansive cycle, internalization provides a mechanism that connects specialized content knowledge to classroom practice and changes in both knowledge and practice. Teachers set *instructional goals* to guide their central activity system based on their internalization of the reform-based canonical definitions and concepts accepted and articulated by the greater science education community. For this study it would be based on their interpretation of the goals of the AP Biology course. To establish *instructional goals*, teachers interpret the canonical articulations/definitions and determine what is appropriate for their level of students (not individual students) and how they would break down the canonical information so it is digestible for students. This is specialized content knowledge, the knowledge reflected in the instructional goal and externalized in the classroom activity system as a tool to mediate student learning. Teachers' internalized model is externalized in their *instructional goals*, and ultimately the activity system is considered specialized content knowledge. This study is using teachers' *instructional goals* and the central activity system guided by this goal as a proxy to better understand and observe teachers' specialized content knowledge.

Zone of proximal development. At the collective or community level of the central activity system, the expansive cycle described above could be seen as similar to the phases of Vygotsky's (1978) Zone of Proximal Development at the individual level. At the beginning of an expansive cycle, a reflective event occurs in which individuals or communities recognize a contradiction between the current central activity system and the future form of the central activity system. The reflective event and initial internalization of the future form of the activity system occurs at the social level, "where shared cognition emerges through interaction between and among individuals" (Vygotsky, 1978, p. 57). Through continued individual actions of externalization to resolve the conflicts, the learning activity turns inward (psychologically inside the subject) as the individual internalizes additional conflicts until the future form of the central activity system is reached.

This future form of the central activity system must be within reach, within the zone of proximal development, for the learning activity to take place (Engestrom, 1987). The initial awareness of the future form and conflict is facilitated socially as a collective goal of the community and requires more skilled members of the community to facilitate the initial phases of the expansion of the activity system. However, the expansive cycle (learning activity) does not have a pre-determined course, single-dimension, or even direction (Engestrom, 1999). The contradiction and future form of the activity system are identified through careful consideration and reflection of the central activity and expansion of this activity: “It requires reflective analysis of the existing activity structure – one must learn to know and understand what one wants to transcend. …it requires reflective appropriation (internalization) of existing culturally advanced models and tools that offer ways out of the internal contradictions” (Engestrom, 1999, p. 33). The critical aspect of learning activity is the more skilled members of the community who facilitate the initial reflective event and the social appropriation of the advanced form of the central activity. Without the reflective event and identification of the future form the community does not address contradictions that exist and the central activity is non-expansive (Engestrom, 1999).

In summary, for this study the cultural-historical continuum of scientific acts and reasoning situates the description of the expansive cycle of this case into a cultural-historical context (CHAT). The continuum itself represents past, current, and future articulations of what is means to do science that oriented and served as a goal of the various forms of AP Biology teaching (central activity) over time. This historical framework can provide the relative position of teachers’ *instructional goals*, and therefore, their content knowledge for teaching compared to the reform-oriented goal of science practice. This does not dictate a direct path or prescribe progression for community transformation of the activity system. The “direction” of progression is made within each community’s expansive cycle. Within each individual phase of its evolution, the internal contradiction is identified which sets the “path” for the expansion. The “path’s” future form of the activity system is the goal for the activity system, and the motive is to close that gap and reach the goal. As each individual's actions aim to resolve this conflict and create new objects and new instruments (externalize the goal of the future activity system) the community moves toward the goal. When the externalization is dominant, the goal is "reached," and a new model for the central activity is designed.

Another way of thinking about this evolution from the more global community perspective is the community recognizes a gap in their goal and each individual within the community takes action to fill that gap, creating new instruments shared among the community, which mediate their understanding and move them toward the goal of the future activity system, filling the gap. Once the gap is "filled" a new gap is recognized and internalized and another expansive cycle begins. Not every teacher within the community performs the same actions or creates the same new instruments, but it is the collective of the individual actions within the community that evolves the community toward the future form of the activity system and the individual (subject), toward central membership of the community (Lave & Wegner, 1991). Within this newly designed activity system, which became the current activity system, a "new" conflict is identified becoming the new goal for the community which is internalized and another expansive cycle begins.

The following example ties together the cultural-historical continuum of scientific acts and reasoning and teacher learning, which is also represented in Figure 2.4. The representation grossly exaggerates the degree of transformation from scientific method to scientific inquiry. Progress along the continuum is most likely gradual, not like punctuated equilibrium of biological evolution. The example includes a representative teacher of the AP Biology community whose *instructional goal* of scientific acts and reasoning is within the scientific method portion of the continuum as the subject. Upon awareness of a contradiction, each member of the community internalizes the future form of the activity system, so this internalization incorporates his interpretation of the future form that will resolve the conflict (Engestrom, 1987). The future form is set within the individual's zone of proximal development (ZPD) depending on their context. His future form of the activity system is likely not exactly in line with the reform-oriented goal of science practice because it is not immediately "within his sight" or within the expertise of the members of the community the individual socializes with as he internalizes the practices and culture of this future form of the activity. His future, more culturally advanced form of science practice may be with some aspect of scientific inquiry or idea of social aspects of scientific acts and reasoning. His actions are motivated toward resolving the conflict and achieving a new form of the central activity oriented toward the more advanced goal.

Each individual within a community is attempting to internalize a model of scientific acts and reasoning that is within his zone of proximal development and externalize this model and move the community toward this new goal. Through a series of expansive cycles, a community may progress from a scientific method view of science practice to a scientific inquiry view, but the path is not predetermined and the progression is unique to the community. Explained through a simple analogy, teachers are not aware of the full map in front of them with the ultimate goal being the AP Biology course goal. They have in their sight a milestone along their path, and the next milestone is revealed once they achieve the first milestone, but only if a reflective event brings this milestone within their sight.

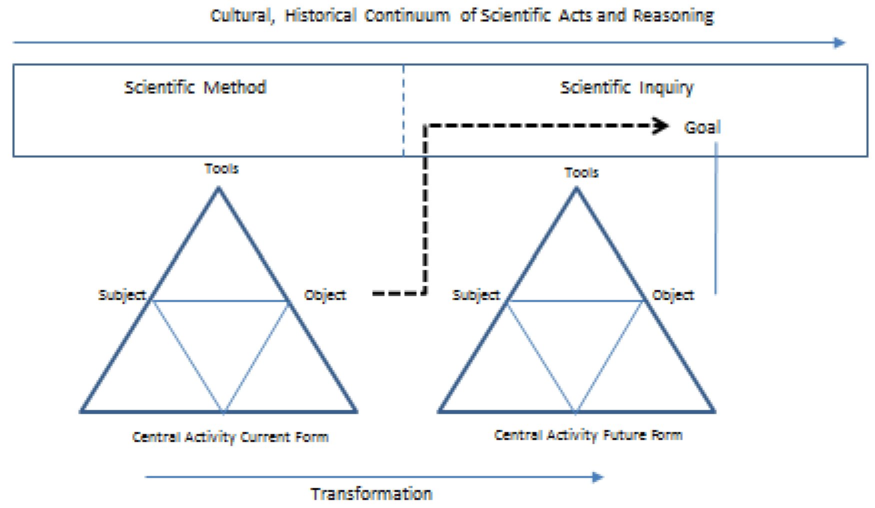

Figure 2.4. Expansive Learning of AP Biology Teaching Against Cultural-Historical Continuum of Scientific Acts and Reasoning

Based on the theoretical frameworks described in this chapter, the following section provides a brief synopsis of the aims of this study. In general, teachers have content knowledge of the domain that is unique for teaching. This specialized content knowledge defines their *instructional goals*, the student outcomes they ultimately aim to achieve with their students. In AP Biology, the course goal with respect to scientific acts and reasoning has recently shifted toward a reform goal of science practice, where the goal (student outcome) is for students to have a scientific perspective that views science as a practice. Given this recent shift, this study is interested in the gaps that may exist between individual teacher's *instructional goal* and the goals of the AP Biology course. To study gaps in their *instructional goal*, the study is using a cultural-historical continuum of scientific acts and reasoning which represents the development of the AP Biology goal over time. The study analyzes four teacher's instructional practice and goal, placing each teacher along this continuum, which provides insight into their gaps from the AP Biology goal. The study is also interested in analyzing the contradictions within their central activity system and how teachers address those contradictions, shifting their instructional practice and learn. To analyze teachers' learning through their practice and their specialized content knowledge of scientific acts and reasoning, an in-depth analysis of one teacher's practice and shifts in practice is conducted using the CHAT methodology. Together these analyses aim to describe teachers' gaps in their *instructional goals* of science practice and development of teachers' practice toward the reform goal of science practice over time.

Questions & Purpose

Many studies have attempted to characterize the subject matter knowledge teachers need to teach science with many focusing on the content and not the performances or practice of science. For those that do consider teachers' understanding of the performances of science, few of these studies use a comprehensive framework of science practice that includes the conceptual, social, and epistemic domains of science practice. Additionally, no study to date has established a cultural-historical continuum of scientific acts and reasoning that can be used to gauge and compare teachers' *instructional goals* (proxy for content knowledge for teaching) against the science practice goals of recent reform movements like the AP Biology program. Few studies attempt to analyze teacher practice and learning using a CHAT methodology. Unlike other approaches the CHAT methodology provides insight into the psychological tools, particularly specialized content knowledge, that teachers use to facilitate student meaning making; and therefore, connecting teacher content knowledge to their classroom actions and ultimately their practice. The CHAT methodology also situates teachers' knowledge of scientific acts and reasoning and their learning in their professional acts of teaching and uses the cultural-historical continuum as a framework that identifies gaps in teachers' *instructional goals*. More studies are needed that explore teachers' knowledge for teaching and the transformation of this knowledge, if the research community's expectation is to include science practice as an indicator of student gains of a scientific perspective. Using a situative perspective to explore teachers' knowledge for teaching as enacted in their instructional practice provides opportunities to address the gaps in the research. As such, this study pursues the following questions:

> 1) What are teachers' instructional goals with respect to scientific acts and reasoning compared to the reform goal of science practice represented by the AP Biology program?
>
> 2) What does a teacher's learning activity look like as s/he progresses toward the reform-view of science practice?
>
>> 2.a) Can specialized content knowledge of science practice be used as a metric of teacher learning activity?

Guided by these questions, the study intends to address these existing gaps in the literature and inform future efforts in teacher preparation and professional development programs that prepare teachers to lead students towards a deep and meaningful understanding of science practice.

Chapter 3: Methodology

This study is designed to be a multiple-case study (Yin, 1994) that explores teachers' *instructional goals* using a cultural-historical continuum of scientific acts and reasoning as a basis for analysis. The case studies include a description of four teachers' *instructional goals* compared to the AP Biology goal of science practice. The study also includes an extended description of one case's transformation of his central activity system over time. Using a multiple-case study approach reveals the variation among the different cases and permits the study to have a small level of replication when analyzing the cases' central activity systems relative to the AP Biology goal of science practice. Cultural-historical activity theory (CHAT) is the methodology used to analyze the central activity system of AP Biology teaching and the contextualized nature of the activity and actions as one teacher attempts to transform his central activity system. Each participant's unit of analysis is his/her central activity system, which provides insight into each teacher's *instructional goal*. Using CHAT situates each teacher's knowledge for teaching in his/her instructional goal and classroom practice by connecting his/her specialized content knowledge, used as a psychological tool, to his/her actions that facilitate student learning. Using CHAT methodology to study teachers' instruction over time also provides an opportunity to document and observe any shifts in specialized content knowledge or other components of the central activity system, which would serve as a metric for the transformation of the central activity system.

Population

The four case study subjects were members of a larger population (n=40) of in-service, secondary AP Biology teachers who were participating in an AP Biology online professional development and assessment program pilot – *AP Insight*. Due to the partnership between the

College Board and the pilot districts, each teacher was required to partake in the pilot and was compensated for his/her participation in the pilot. The teacher population came from three pilot, partner districts that varied in size and demographics and were located in two different states. The teachers varied in years of teaching experience as well as experience teaching AP Biology (see Table 3.1). The four cases for this study use pseudonyms to protect their identity. AP teachers were the focus of the study because the College Board launched a new AP Biology course in the 2012-2013 school-year that emphasized the reform goal of science practice as a core part of the course and exam. The teachers participating in this pilot were implementing the changes to the course and exam during the 2011–2012 school-year, one year prior to the national launch. The AP program is the closest thing the United States has to a national curriculum and exam, which benefits teacher content knowledge research (Baxter & Lederman, 1999). AP Biology teachers are also ideal for the study because they have the common exam and course objectives to meet, but there is no set or required curriculum. At the time of this study, the publishing market lacked a textbook specifically written for the redesigned course. Each teacher needed to modify and adapt their current district textbook to meet the redesigned course objectives. Since AP teachers typically design, plan/sequence, and implement their own courses, there are many decision points that can be monitored and analyzed. Since there is no common or shared curriculum, these cases also avoid teachers' narrow focus on adaptation of an assigned curriculum to meet their goals for student learning.

Table 3.1. Participant's Teaching Experience and AP Biology Teaching Experience

Participant Pseudonyms	Years Teaching	Years Teaching AP Biology
Ajay	3	1
Kyle	14	1

Melissa	8	8
Mark	26	14

AP Biology Instructional Context

Based on the research field's conception of science practice, the redesigned AP science courses included seven science practices that represent this shift to science as a practice. Although written as a discrete list (see Appendix B), each practice had embedded within it processes, procedures, and ways of thinking that further defined the practice. When designing the course, the intent was to represent practices where students should be expected to "demonstrate that they know in what contexts a particular piece of knowledge is relevant, and then be able to apply it appropriately using the language, tools, and representations that are part and parcel of the discipline" (National Science Foundation, 2010, p. 196). The *AP Biology Curriculum Framework* described a practice as "a way to coordinate knowledge and skills in order to accomplish a goal or task" (College Board, 2011, p. 1). This definition of science practice taken from Smith, Wiser, Anderson, Krajcik, and Coppola (2005) emphasized the role of the wider social environment as a part of the process and recognizes that consistent discourse within this community molds a person's knowledge, skills, resources, motives, and attitudes (National Research Council, 2006). Based on this definition of practice and the design goal of the course, the science practices of the AP Biology course were meant to incorporate the social and epistemological domains of practice, although the language was not explicit within the *AP Biology Curriculum Framework*, a document that articulates the content, practices, and learning objectives for the course. This goal of science practice was in line with the reform goal which promotes a scientific perspective, one that embraces the community and culture of scientists by engaging students in the language, tools and ways of science practice (Barab & Luehmann, 2002).

The science practice of mathematical modeling was a key part of the study's analysis so this section clearly defines the intent and definition of the reform goal of mathematical models. The terms and language used in the *AP Biology Curriculum Framework* aligned with the terms used in the *Next Generation Science Standards (NGSS),* which also represented the latest evolution of science practice within the science education community. Both programs emphasized the importance of models in science practice. Historically, prior to NGSS "models" were not foregrounded in science education standards. The term was incorporated into nature of science in NSES (1996). The *Next Generation Science Standards* (NGSS Lead States, 2013) defined models as physical entities, mathematical representations, analogies and computer simulations that contain,

> approximations and assumptions that limit the range of validity and predictive power…models are used to represent a system (or parts of a system) under study, to aid in the development of questions and explanations, to generate data that can be used to make predication, and to communicate ideas to others. (p. 6)

The *AP Biology Curriculum Framework* included mathematical models with representations in "Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems" (College Board, 2011, p. 81). Within the *AP Biology Curriculum Framework*'s description of models, it mentioned having students create, refine, describe, and use models to illustrate, predict, and address scientific questions (College Board, 2011). The AP Biology course goal for mathematical modeling was elaborated upon in a supplementary publication *AP Biology Quantitative Skills: A Guide for Teachers* (College Board, 2012). The AP Biology course defined mathematical modeling as the "process of creating mathematical or computer-based representations of the structure and interactions of complex biological systems” (p. 84). The resource outlined the components of mathematical modeling and process for approaching mathematical modeling with students, which started with identifying variables, assumptions, and simplifications or limitations of the modeling. Students were also expected to have the meta-modeling knowledge such as the accuracy of models and “false” nature of models. This description provided the metric to compare the cases’ *instructional goals* associated with mathematical models.

Figure 3.1 contains a condensed list of AP science practices; the full list can be found in Appendix B. These practices were integrated with the targeted concepts of the course to establish the course learning objectives. This integration of concepts and practices was designed to give teachers clear information about how students are expected to demonstrate understanding and abilities on the AP Exam and in the classroom. Along with transparency, the integrated learning objectives were also meant to emphasize the importance of the use of knowledge in meaningful ways, rather than just “knowing” (Lehrer & Schauble, 2006). The example learning objective below is as it appears in the *AP Biology Curriculum Framework* along with the corresponding science practice that is listed as being integrated into the learning objective (College Board, 2011).

> LO 1.1 The student is able to apply mathematical methods to data from a real or simulated population to predict what will happen to the population. [See SP 2.2]
> Science practice 2.2 The student can apply mathematical routines to quantities that describe natural phenomenon. (p. 3)

For the purposes of exam creation, measurement, and clarity for the teachers, at the end of the learning objective at least one science practice identifier was listed. However, the learning objective itself involved many different science practices such as data analysis and making predictions. So, by design, each learning objective incorporated multiple science practices representing the integrated and sophisticated way in which the practices are interrelated and meant to be achieved by students. I have unique insight into the intent and use of the science practices and design of learning objectives throughout the AP Biology redesigned course because I led the development of the science practices and designed the structure and intent of the AP Biology course, specifically the learning objectives within the redesign science courses.

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.
Science Practice 2: The student can use mathematics appropriately.
Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.
Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question.
Science Practice 5: The student can perform data analysis and evaluation of evidence.
Science Practice 6: The student can work with scientific explanations and theories.
Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

Figure 3.1. Condensed List of AP Biology Science Practices (College Board, 2011, pgs. 97 – 102)

Selection of Case Study Sample

The selection of case study participants was targeted and not random. Given the dispersal of the population of teachers in two different states, the study selected cases from a single district to facilitate data collection and ensure a consistent district context across the cases. The case studies intended to be representatively different in order to gather evidence of the variation of instructional goals of scientific acts and reasoning. Purposely selecting teachers that vary in their *instructional goal* may provide insight into different points along the cultural-historical continuum and different insights into the cases as they vary from the AP Biology goal of science practice. Prior to the start of the pilot, the population of teachers was given a short questionnaire that probes for the following selection criteria: research experience, orientation toward science teaching, and their goals for students learning science. Windschitl (2004) found previous research experience within a science lab or field influenced the authentic inquiry in teachers' classrooms. Teachers' orientation toward science includes their beliefs about science, how knowledge is established in science, and science teaching and learning and impacts their science instruction (Harwood, Hansen, and Lotter, 2005; Woodbury and Gess-Newsome, 2002). Questions about teachers' goals for students learning science give insight into teachers' expectations with respects to developing student's scientific perspective and where these expectations might be positioned along the continuum. Based on the responses to the initial questionnaire, four teachers were selected and approached for participation in the full study.

Case Study Profiles

Prior to providing a description of each teacher who participated in the case study, a description of the district context in which all of these teachers taught is included. All four teachers taught AP Biology at a high school within a large, urban school district in the southeast part of the United States. At the time of the study, each teacher participated in the College Board pilot (described previously) and the same professional development events that introduced the redesigned AP Biology course as well as the College Board's online professional development and assessment system they were piloting. The teachers participated in the district-wide Professional Learning Community (PLC), which provided time every Monday to work with the school or department community. For AP Biology the district adopted the Mader (2009) *Biology* 10th Edition textbook. This was the first year the district used this textbook, so experienced AP Biology teachers were switching from a Campbell textbook (various editions used throughout the district) to the Mader text. The district also has a common *AP Biology Curriculum Guide* and a district-wide mid-term exam. This exam contributed to the teacher's professional evaluation. Both the *Curriculum Guide* and the exam dictated a sequence of instruction that may not align with the philosophy of all of the teachers. Even though the district had these accountability measures, each teacher participating in the case study identified students' performing well on the

AP Exam as being their primary goal for student learning. Therefore, achieving the science practice goals of the course was important to their *instructional goal*.

Ajay. Of all of the cases Ajay had the least teaching experience, and the case study occurred during his first year of teaching AP Biology. He was an East Indian male teaching at a high school with a total population of approximately 2,100 students that was diverse student population (73% Hispanic, 11% Caucasian, 7% African-American, 5% multi-national, 3% Asian, and 0.1% Indian). He had a master's degree in biochemistry. Like Mark he also taught regular and honors levels of biology. His master's degree involved limited experience in a research or laboratory facility. His instructional goals and comments about the new AP Biology course were often in reference to how much of the curriculum he wanted to have completed by a certain date. During an interview he even said, "I'm all about time." (p. 3, post-study interview). When he reflected on his instructional goals for student learning, Ajay wanted students to critically evaluate, investigate and explore topics as an approach to all science classes or other subjects. He would like for them to question their actions, thinking, and observations.

Kyle. A veteran high school science teacher for 14 years; however, the case study took place during Kyle's first year teaching AP Biology. He was a Caucasian male teaching at a large high school with a total population of approximately 2,400 students that was diverse (33% Caucasian, 31% African-American, 25% Hispanic, 6% multi-national, 4% Asian, and 0.3% Indian). He taught a Genetics and a Zoology course along with AP Biology giving him three different courses. He also gave up his planning period in order to teach an additional section for additional pay. His highest degree was a bachelor's of science in biology. Kyle had some experience in a research facility. He twice participated in a local university's teacher research program where he worked in a laboratory for a total of 12 weeks. In the pre-pilot questionnaire

Kyle stated that his goal for students was to learn to do science and realize the relevance and application of science to the real-world. Throughout the study, during interviews and in classroom observations, Kyle reiterated this goal. Kyle embraced the new AP Biology course saying even though he has the goal of helping students pass the exam, the course helps him deliver on his goal of students understanding genuine science.

Mark. With the most experience of all of the case studies, Mark had 26 years of teaching experience and a self-reported 14 years of teaching AP Biology. He was a Caucasian male teaching at a high school with a total population of approximately 1,800 students that was diverse student population (42% Hispanic, 29% African-American, 20% Caucasian, 6% multi-national, 3% Asian, and 0.4% Indian). Mark taught the full vertical progression of biology offered at his school including regular, honors, and AP levels. Similar to Kyle, he participated in a six week summer teacher research program at a local university almost 10 years ago as well as a National Institutes of Health sponsored program. His explicitly stated goal for students focused on science literacy: students learn how to read and have an opinion about commonplace articles, newspapers, and magazines and know what they're talking about and impact on their lives. Mark also had an implicit goal to build his students' confidence and independence which he often referred to in interviews, but did not officially state as an instructional goal.

Melissa. Melissa was an experienced teacher and AP teacher that taught both AP Chemistry and AP Biology. She was a Caucasian female teaching at a district magnet school with a total population of approximately 2,000 students that had a diverse student population (50% African-American, 26% Hispanic, 13% Caucasian, 6% Asian, 4% multi-national, and 0.4% Indian). As required by the magnet school, students applied and were accepted into one of three specialized programs. She had taught for 8 years total, teaching AP Biology for the duration. She had extensive laboratory experience from her years as a doctoral student in a biology field where she studied Alzheimer's using transgenic mice models. Melissa was also a lead teacher within the district. She was one of three teachers who created the district-wide AP Biology Curriculum Guide. She stated that her goal for her students involved developing an understanding of science as a foundation of life, getting students to think and reason for themselves and being able to apply scientific principles to all aspects of their academic lives. With the shifts in the AP Biology course her goal for students focused at times more on their gaining a conceptual understanding. She believed the science practices helped "round out" student understanding as she shifted away from a lot of detail. Melissa felt the new AP Biology course was changing her teaching because she was trying to frame each lesson by the science practices and aimed to include science practice in all lessons.

Researcher's Role

As previously mentioned, the teachers were participating in an *AP Insight* pilot. As the primary designer of the *AP Insight* program, I had the opportunity to work with the participants as a part of the pilot. I led the professional development the teachers participated in for the pilot. To these teachers I was their "expert" on the redesign of the AP Biology course as well as *AP Insight*. In that role and as the researcher of this study, I found myself immersed in the study and became a part of the study in terms of the social support and socialization of the AP Biology goals for the teachers. For example, scheduling an interview immediately after instruction forced the teachers to reflect on their instruction, which may not have been a regular part of their practice. The nature of my questions focused on science practice, alerting them to issues or contradictions. As the researcher, I was careful to not provide definitions of science practice or the performance of science practice, but the wording of my questions forced some of the teachers to notice nuances of my language such as the use of science practice instead of inquiry.

As their primary point of contact with the *AP Insight* program and redesign AP Biology course, my role at the College Board could have played a role in their perception of my expertise. As I worked with them over the course of the year, my relationship with each case was slightly different. Some maintained their view of me and my role and expertise as a College Board person who led the professional learning and *AP Insight* work. Two of the cases grew to see me as a researcher and as an expert colleague. They engaged in deeper discussions about their teaching and demonstrated more concern with my documentation of my findings of their teaching. For example, Mark repeatedly asked for "off the record" discussions so he could check in with me on how he was doing with his instruction and whether he was completing his journals correctly. He was also more concerned with getting his reflections "right". Based on these different perspectives, my role as "expert" within the study could have varying impacts on their reflective responses during the interviews. For all of the cases, I was their touch point for the AP Biology course. Each teacher asked me questions about the AP Biology course, how to interpret learning objectives or the course's enduring understandings, and of course the exam.

Data Collection

Teachers' central activity systems were analyzed based on qualitative data collected over a six month period. Data collection events included one pre- and one post-study interview, four classroom instruction observations, four pre- and post-classroom instruction interviews, and dual journal entries for each case. Table 3.2 provides an overview of each of the sources of data along with a description and purpose of the data. The next section orients each data source to the question of the research.

Table 3.2. Overview of Data Sources

Data Source	Description	Ajay	Kyle	Melissa	Mark
Pre-Study Interview	Semi-structured interview that occurred in the fall at the beginning of the study.	1	1	1	1
Post-Planning Interview	Interview that occurred prior to instruction. Includes open-ended section to allow teacher to describe intent for lesson as well as semi-structured section.	3	4	3	4
Post-Implementation Interview	Semi-structured interview that occurred after instruction.	4	4	4	4
Post-Study Interview	Semi-structured interview that occurred at the end of the study in the spring.	1	1	1	1
Classroom Observation	Observation of students and teacher in the classroom during instruction.	4	4	4	4
Instruction Artifacts	Includes lesson hand-outs, Power Point slides, laboratory exercises, equipment, articles, diagrams, graphs, notes written on the board.	5	9	7	10
Student Work Artifacts	Includes completed worksheets, lab papers, poster projects, entrance or exit cards.	0	28	26	24
Dual Journal	Journal that includes reflection on their own understanding of scientific acts and	1	3	5	17

	reasoning and their instruction related to scientific acts and reasoning (Windschitl, 2004).	

Research Question 1 is about teachers' instructional goals with respect to scientific acts and reasoning compared to the reform goal of science practice represented by the AP Biology program. The unit of analysis is the central activity system (AP Biology teaching), which is oriented toward the teacher's instructional goal. Each teacher's specialized content knowledge for teaching is situated within this central activity system and in particular for this study reflected on his/her *instructional goal*. Qualitative data to address this question was collected through pre- and post-study interviews, the classroom instruction observations, the pre- and post-classroom instruction interviews, and dual journal entries. The data illuminates each teacher's knowledge for teaching explicitly through discussion and their reflections and implicitly in-action through observation. Each participant was interviewed at the beginning of the study (Appendix C) and once again at the end of the study (Appendix D). These interviews were semi-structured, in-depth interviews, using a protocol informed by the school-based description statements from the cultural-historical continuum of scientific acts and reasoning (Appendix A) as well as questions about goals for their course and student learning. These interviews specifically probed their internalized model of "science practice" and how they interpreted the term and the performances within the practices. Through teacher interviews about their plans for instruction prior to the delivery of classroom instruction as well as the actual instruction, I documented each teacher's decisions for the instruction plan as well as his/her reflection of his/her implementation after the instruction. This data provided information on teachers' content knowledge for teaching that is situated in their classroom instruction and intent or goals for instruction.

To address Research Questions 2 concerning teachers' learning activity and the sub-question regarding specialized content knowledge as a metric of teacher learning, qualitative data was gathered through interviews following teachers' planning, through observations, and interviews after of classroom instruction. The unit of analysis for teacher learning is the transformation of the central activity system (AP Biology teaching) over time. AP Biology teaching activity data will be chunked into example central activity systems by the researcher, one activity system being the enactment of a coherent instructional sequence with a common student learning outcome or object. There were four instruction observations. An observation may include multiple instructional events for students. For example, there may be an Entrance Card, followed by notes via a lecture, and then a laboratory exercise. Since each of these experiences was directed at the same student learning outcome, but used a different tool and possibly a different division of labor among the students and teacher to facilitate students toward the learning outcome, the series of experiences are a part of the one example central activity system being studied.

Interviews conducted prior to the implementation of the instructional plan (Appendix E) were informed by the interview portion of the Lesson Preparation Method that was evaluated by Valk & Boekman (1999). The initial stage of the interview was open-ended, allowing the teacher to report on the intended lesson. The second stage of the interview used a general protocol that probed the teacher's learning objectives, motives for the lesson, and evidence of student outcomes. These questions were guided by the components of an activity triangle (Figure 2.1), which helped identify the teacher's intent of actions within the central activity as well as the representative central activity being observed. These questions also elicited evidence of each teacher’s decisions regarding the intended instruction, which provided some insight into his/her specialized content knowledge used as a tool to make the decisions.

Post-observation interviews (Appendix F) were semi-structured and allowed the researcher to ask standardized questions, stimulating reflection on evidence of student attainment of student outcome (object), success of the use of different tools, and follow-up on clarification of any observations and teacher or student actions. The specific questions for both interviews were contextualized by the science practice components planned and enacted within the lesson. All interviews were recorded, and observations were recorded and transcribed.

It was important throughout data collection to capture two essential elements of an activity system in order to get a sense of knowing in and from practice (i.e., teacher knowledge), the activity or process of doing, and representations that results from and used during activity (Engestrom, 1987; Forbes et al., 2009). Therefore, the teacher’s lesson plan and artifacts or tools used during instruction and samples of student work were collected for each classroom observation as evidence of the object (i.e., student outcome) produced through activity mediated by tools (Engestrom, 1987). With attention to these elements, all observations and interviews captured interactions with peers (when possible), students, tools, language, and representations so activity theory (Engestrom, 1987) could be used for analysis.

To triangulate the data, the teachers were asked to keep a “dual journal,”(Appendix G) one part of which chronicled their reflections on their content knowledge of scientific acts and reasoning, while the other part included a reflection about their implementation of scientific acts and reasoning in the classroom (Windschitl, 2004). Data triangulation also occurred through the multiple observations of the central activity system for each case. The central activity of AP Biology teaching is the unit of analysis, and the data spans four representations of this central activity system for each teacher. All of these data points facilitated the triangulation of the data across the observations, interviews, and journals.

Data Analysis

In order to address the first question regarding the comparison of teachers' *instructional goals* to the AP Biology course goal, interviews, journals, and teacher enactment observation transcripts were analyzed using a constant comparative method of coding process (Strauss & Corbin, 1990). This method of coding and recoding is best for trying to build a theory from empirical data (Creswell, 2007). The "theory" for the case study research would be a characterization of a phase within the continuum of scientific acts and reasoning for each teacher's *instructional goal* in comparison to the AP Biology goal of science practice. First, all data was coded for each component of the activity theory model; each category of codes is a node from the triangle model (subject, object, goal, instrument, etc. (Table 3.3)). The transcripts from the classroom observations and both the pre- and post-interviews were sectioned into examples of activities based on the object of the activity system. Each activity identified was assigned a unique identifier.

The activity system components situate the evidence of each teacher's *instructional goal* with respect to scientific acts and reasoning in the activity system, and therefore, represent teachers' content knowledge actualized in their *instructional goals*. The use of activity theory triangle model provides a consistent lens for analyzing the variation of teachers' instruction, ensuring data analysis focuses on the similar frames (central activity system) of instructional practice.

Table 3.3. Central Activity System Codes

Code	Activity Theory Node	Description
S	Subject	Individual or group of the activity

		oriented to transform some object
O	Object	Cognitive object, outward goal, concrete purpose, objectified motive of the activity; connected to the broader system goal/motive
G	Goals/motive	Motivation or goal that orients the activity within the community
I	Instruments	Technical tools directed toward object or psychological tools directed toward activity
A	Actions conscious	Actions individual is aware of that facilitate meaning making toward object
AI	Action directed by technical instrument	Action that used a technical instrument
AP	Action directed by psychological instrument	Action directed by psychological instrument
C	Community	Group of individuals who are a part of the activity taking place
R	Rules	Norms of the community of the activity
DL	Division of Labor	Distribution of roles within the community for particular activity

Second, all data was analyzed and coded if it related to some aspect of scientific acts and reasoning, whether it be within the content, social, or epistemological domain. The coding scheme for scientific acts and reasoning was left general to “science practice” since the resulting depiction of scientific acts and reasoning was unknown and intended to emerge from the data. Then, analytical induction was used to sort the data into categories of attributes of the different phases of the cultural-historical continuum. Data were sorted into evidence of epistemic domain, social domain, or conceptual domain of science practice. All of the sorted categories for each case study were analyzed against the cultural-historical scientific acts and reasoning continuum (see Table 2.1) to further refine and define each teacher’s instructional goal against the AP Biology goal, which is within the scientific models and discourse practice phase of the continuum. This approach combined the data of implicit knowledge embedded in instructional practice with explicit knowledge presented in teachers’ reflections and discussions about their instructional practice. The continuum could be used to guide the analysis of patterns; however, how teachers incorporated scientific acts and reasoning into their classroom was expected to vary. The resulting descriptions and evidence of the *instructional goal* emerged from the data and connected to specific phases within the cultural-historical continuum of scientific acts and reasoning. The continuum served as a guideline, but allowed for refinement through iterations as data was coded and recoded as evidence of scientific acts and reasoning emerged. The evidence gained from this analysis helped characterize each teacher’s *instructional goal* against the AP Biology course goal. If the AP Biology course goal was considered to be the origin of a measure, then each teacher’s position along the continuum provided a sense of the magnitude of the gaps of his/her *instructional goal.*

To address research question two involving a teacher’s transformation of the central activity and the role of specialized content knowledge as a metric of this transformation, coding of specialized content knowledge was used in combination with the activity theory component described above. Within each central activity system, there existed many teacher conscious actions. The specialized content knowledge construct (Table 3.4) was used to help identify some of the actions within the activity system as the target of analysis. The construct was created by adapting the tasks from Ball, Thames, and Phelps’ (2008) tasks of specialized content knowledge for teaching mathematics to the scientific acts and reasoning within the science domain. Other conscious actions not included in the construct of specialized content knowledge were also identified. Once the conscious actions of the teacher (subject) were coded within each representative central activity for each case study, rich descriptive accounts of the central activity in terms of actions, tools, object, and community context were created. After each representative central activity was described, patterns and changes across the representations were identified and described to provide a descriptive snapshot of a teacher's learning in terms of shifts or lack of shifts in object, tools, and student artifacts.

Table 3.4. Specialized Content Knowledge Coding Scheme/Construct

Specialized Content Knowledge	Code
Unpacking the nature of knowledge in the discipline	NK
Explaining a procedure or components of science practice	EP
Explaining concepts, which is different from providing definitions and examples	EC
Representing the meaning of a concept or practice	RM
Selecting representations	SR
Making and using representations	MUR
Selecting examples	SE
Not applicable to SCK	N/A

Reliability. For each phase of analysis, the initial coding categories were identified by the primary investigator. A second coder conducted a blind-coding exercise with a subset of the interview and observation transcripts. Agreements, agreements with arbitration, and disagreements were tabulated and inter-coder agreement established using methods suggested by Miles and Huberman (1994). Agreement meant the two coders had identical codes for the section of the transcript. Agreements with arbitration meant the two coders discussed the coding and, through the process, came to a common understanding of how the codes were being used and interpreted. For example, the second coder used the code "S" to represent parts of the subject-producing activity system, which the primary coder did not include. Once this discrepancy was discussed, as the coding verification continued, the primary coder could identify and agree with the other “S” codes that were a part of the subject-producing activity system. Disagreement meant the two coders could not agree on the codes given, and arbitration did not lead to agreement. Of the 60 codes analyzed, the two coders agreed on 21 (35% agreement) and agreed with arbitration on 39 (65% arbitrated agreement). There were no disagreements in the coding verification.

As a result of the coding verification exercise, two additional codes were developed as sub-codes for “conscious actions” to connect actions to particular parts of the activity system. All actions are directed toward the object of the activity system, but some involved other aspects of the activity system, mainly instruments. The two coders decided to add codes to distinguish between actions facilitated by technical instruments compared to actions facilitated by psychological instruments. I was adding notes of the connections of actions to other parts of the activity system throughout the initial coding. After conferring with the secondary coder, the notes became formalized into actual codes in order to complete the verification exercise.

In summary, this case study of four AP Biology teachers used qualitative data and a CHAT methodology to analyze the teachers’ instructional goals in comparison to the cultural-historical continuum and the AP Biology course goal. The sample of teachers who were a part of the case study was a part of a larger population of teachers who were in their first year of implementing the redesigned AP Biology course. The study collected data of each teacher’s AP Biology teaching at four instances over a period of a year. The data was coded using a CHAT model as well as a construct of specialized content knowledge. Aspects of scientific acts and reasoning were also identified throughout the data. Using the CHAT coding as well as the scientific acts and reasoning codes, each teacher’s instructional goal was placed along the continuum and comparisons were made to the AP Biology course goal. Using the CHAT codes and specialized content knowledge codes, one teacher’s central activity system was analyzed over time to identify evidence of transformation of the central activity system, in particular any shifts in specialized content knowledge.

Chapter 4: Findings

In this chapter qualitative findings from the four CHAT-based case studies are presented. The purpose of this research is to compare four teachers' *instructional goals* with the AP Biology course goal with respect to scientific acts and reasoning. The study also uses CHAT to describe in-depth one teacher's learning as he transforms his AP Biology teaching (central activity system). In this first section of findings, research question #1 is addressed, "What are teachers' *instructional goals* with respect to scientific acts and reasoning compared to the reform goal of science practice represented by the AP Biology program?" To address this question, qualitative data is presented which situates each teacher's *instructional goal* along a cultural-historical continuum and in comparison to the AP Biology goal. In the second section of findings research questions #2 and #2.a are addressed, "What does a teacher's learning activity look like as s/he progresses toward the reform-view of science practice?", and "Can specialized content knowledge of science practice be used as a metric of teacher learning activity?" The qualitative data addresses these questions by describing in more detail one case of teacher learning. The use of CHAT-based methodology for these questions permits an in-depth description of the contradiction that motivates teacher learning as well as the context, tools, objects, and actions that describe teachers' meaning making.

This first section of findings includes a description of each teacher's existing central activity system as evidenced by the observations of and interviews about his/her teaching activity. The descriptions also include any evidence of a contradiction within the existing activity system that would result in the establishment of a future form of the central activity system. In activity theory the central activity is directed by the goal of the activity. This future form of the central activity system represents the *instructional goal*. To better describe the *instructional goal*, each case's explicit discussion of his/her *instructional goal* and teaching activity through interviews and reflections are analyzed. Teacher reflections and interviews are also analyzed to identify teacher's awareness and motivation toward the contradiction. To provide greater depth and evidence of conscious contradictions revealed through teacher practice, the components of an activity system (objects, tools, rules/language) are analyzed and described. The resulting *instructional goal* for each case is an amalgamation of a future form activity and the existing activity system. If a conflict is not conscious, then a future form of the activity system does not exist for the subject, and there lacks a motivation to transform the activity system. The current form of the activity system persists, and the activity system does not transform. For example, evidentiary explanation is a performance of science practice that is a part of the reform goal. If a teacher recognizes this contradiction in his/her own instructional practice, then he/she interprets what the goal is and creates a future form or *instructional goal* for constructing explanations from evidence. If a teacher does not have a conflict with his/her current practice, then a future form is not recognized and evidentiary explanations are not a part of the instructional goal. Evidence of aspects of science practice missing from a teacher's existing central activity serves as an indicator that the aspect is also missing from the *instructional goal*.

Each description situates the teacher's *instructional goal* within a phase of the cultural-historical continuum of scientific acts and reasoning (Table 2.1 and Appendix A). The descriptions highlight the conceptual, epistemic, and social domains of science practice, in particular each case's definition and use of models as a key indicator of placement along the continuum. Even though the following descriptions attempt to parse out and discretely separate the different domains of science practice as a way to categorize each teacher's *instructional goal*, I understand that some of these distinctions are arbitrary and that knowledge exists in highly integrated networks that cannot always be neatly and easily separated.

Table 4.1. Cultural-historical Continuum of the Articulation of Scientific Acts and Reasoning (Duschl & Grandy, 2008). A complete continuum can be found in Appendix A.

	The Scientific Method	**Scientific Inquiry**	**Scientific Models and Discourse Practice**
Philosophical Progression	Experiment driven enterprise (logical positivism)	Theory driven enterprise (conceptual-change)	Explanatory model driven enterprise
Descriptions of School Science	Hypothetico-deductive conception of science Focuses on the final products or outcomes of science Oversimplies observation Linear process of discrete events, the parameters of each event are only considered after previous event is complete (Windschitl, 2004)	Focus on improvement and refinement of a theory Science is described as acquiring data and then transforming that data first into evidence and then into explanations Includes social domain, but with little explicit attention or analysis of its contribution Focus on experimentation	Emphasizes the role of models and data construction in the scientific process and demotes the role of theory Involves complex set of discourse processes Theories thought of as families of models, models' role between empirical evidence and theoretical explanations Emphasis on discourse and dialogic strategies Any and all of epistemology themes (see Table 2.2)
Processes of Science Practice	Make observations Formulate a hypothesis Deduce consequences from the hypothesis Make observations to test the consequences Accept or reject the hypothesis based on observations	Engage in scientifically oriented questions Give priority to evidence to develop and evaluate explanations that address scientifically oriented questions Formulate explanations from evidence to address scientifically oriented questions Communicate and justify their proposed explanations (National Research Council, 2000)	Posing, refining, evaluating questions Comparing alternative theories/models with data Providing explanations Giving arguments for/against models and theories Relating data to hypothesis/model/theory Critiquing explanations, models, and data

Micro-Communities along the Continuum

The cultural-historical continuum represents past, present, and future expansive cycles of the articulation of scientific acts and reasoning as the reform-goal of science practice developed. Although each teacher is motivated to implement the AP Biology goal, as a member of the greater AP Biology teacher community, their interpretation of what it means to practice science is guided by their specialized content knowledge of scientific acts and reasoning. These findings suggest that the teachers have different interpretations placing their *instructional goal* at different points along the continuum, away from the AP Biology goal. Since each case's goal is oriented toward a need or motive as defined by the members of the community (Forbes, Madeira, Davis, & Slotta, 2008) and given the spectrum of goals that exist, it is reasonable to think that the broader AP Biology community of teachers consists of many different micro-communities. The boundaries of each micro-community for this study are not drawn based on geographical location but based on the goal, language, and culture of the central activity system - AP Biology teaching. Each micro-community defines the goal of their activity system based on a common motive – to build student's scientific perspective. What differentiates the micro-communities is their interpretation and specialized content knowledge of the scientific acts and reasoning that structure their *instructional goal*. Each micro-community is at different points along the continuum as demonstrated by evidence of differences in their instructional goal that guides their AP Biology teaching (central activity system). Based on the findings, the four cases for this study represent three different micro-communities of AP Biology teachers. The descriptions of each case will begin with the two cases that are closer to the scientific method phase of the continuum, and two cases that are at different points within the scientific inquiry phase of the continuum. Presenting cases in this order helps to see each case against the historical continuum in temporal order and the gaps that exist against the AP Biology, reform-oriented goal.

The Scientific Method Micro-Community

Ajay. Ajay's awareness of a contradiction related to scientific acts and reasoning and the AP Biology course goal was limited based on the analysis of data gathered for this study. The following description of Ajay's *instructional goal* is related primarily to his existing central activity system. Ajay's depiction of scientific acts and reasoning, during interviews and in the classroom, placed his *instructional goal* in the scientific method phase of the continuum. When he discussed scientific acts and reasoning, Ajay focused on experimentation and theory building in a linear, superficial way, and his descriptions lacked references to dialogic practices. Descriptions of the work of scientists he used during his teaching activity focus on making observations, doing experiments and then analyzing data in a linear, step-wise way. He described knowledge construction or theory building as moving from testing a hypothesis, to proving a hypothesis, and then to sharing results with other scientists, “I think new ideas and knowledge is [sic] gained from like experimentation and testing different ideas and sharing the results” (p.3, pre-study). He described other scientists having the role of repeating, extending the experiment, and then sharing their results, which will either prove the original hypothesis right or wrong. Collaboration is important from a validation and contradiction of hypothesis stand point, but the dialogue among scientists was missing from his descriptions and the observed central activity system.

Models and their role in science have significantly evolved over time and serve as a key indicator of instructional goal placement along the continuum. Ajay’s understanding and use of models was limited to representations for instruction. During interviews and observations he did not provide sufficient evidence to indicate he understood the role of models in the scientific enterprise, which placed him on the scientific method end of the continuum. During the pre-study interview Ajay was asked about models he has used in the classroom and his response was, “I don’t…I’m not really sure what you mean by model exactly” (p 9, pre-study interview). After some additional discussions about models, his take-away was a definition of models as physical tools for learning. Even though discussions with the researcher alerted him to a contradiction with “models”, he did not appear to internalize models and consciously work to incorporate them into his instructional goal. Throughout the year Ajay frequently used models as an instrument to facilitate student learning, but never referred to them as models during instruction or in his interviews. When probed about his use of models he responded he has not used models in class because it is his first year teaching, and he is "trying to do what he knows" (p. 5, post-observation 2).

During instruction and reflections Ajay focused on the end products of science, a characteristic of the scientific method end of the continuum. When students do a laboratory exercise, he reflected that his primary concern was whether it worked or not. His evaluation of their laboratory results was based on the correctness of their results, not the practices they experienced or performed. This attention to the end product of science ignored the process by which the answers were established. His central activity system object appeared to separate the scientific acts and reasoning from the content to be learned. He frequently used data in his lessons as a means for students to apply their knowledge of evolution, diffusion, or feedback mechanisms. Another frequent central activity object was for students to learn the concepts and then apply them to data analysis and drawing conclusions from data. He believed, “once they have a clear idea of the concepts, then you can allow them to apply some aspects of the concepts” (p. 5 pre-study interview). From this point of view, the explanations of natural phenomenon of science and the practices of science were separate entities. From an activity theory perspective, Ajay saw scientific acts and reasoning as instruments to apply knowledge, not to construct the knowledge. Scientific acts and reasoning were also not objects or outcomes for student learning.

This separation of content and scientific acts and reasoning in Ajay’s observed central activity provided evidence of a gap in his *instructional goal* with respect to the epistemic domain of science practice. Based on interviews and his classroom activity, he viewed knowledge as being discovered and then applied to the real-world. His specialized content knowledge of the epistemic domain appeared simplified. To him science was tentative, and different forms of knowledge vary in their certainty, but there was limited association of the types of knowledge and their predictive and explanatory power. During a discussion about "truths" associated with science, he reflected that laws are absolute truth, but theories cannot be taken as definitive truth, "theories are not like absolute truth, but laws are absolute truth. So a lot of laws are used as a foundation to develop theories" (p 3, pre-study interview). Even though the evidence identified this as a limitation to Ajay's *instructional goal,* it was not a conscious gap that Ajay was aware of or attempting to resolve in his instruction.

The basis for Ajay's *instructional goal* was different from the other cases. Even though it was his first year of teaching AP Biology, he was still attempting to internalize the AP Biology course goal to establish his own *instructional goal*. His instruction and interview data described an *instructional goal* that was situated in the scientific method phase of the continuum. However, he also had a competing goal of time, which acted as a greater contradiction that guided his instruction. Ajay had the goal of completing the curriculum by February, but after the first observation for this study, he realized that he needed to slow his approach down a little bit and "just worry about them really learning it" (p. 8, post-observation 1). He had initially set the goal of February because when he took the class as a student he finished the course early, so the teacher had more time to review with students prior to the exam. His contradiction did not appear to be with the *instructional goal* of science practice within his existing central activity system and a future form. His contradiction was with the pacing of his course and student learning. As a first year teacher with little teaching experience, he was setting goals based on his experience as a student rather than his experience as a teacher.

In summary, Ajay's *instructional goal* with respect to science practice focused on experimentation and the linear process of theory building with little understanding of model's place in the theory building endeavor. He also separated the end product of science from scientific acts and reasoning. He frequently emphasized the concepts over the process, which placed him at the scientific method end of the continuum. His *instructional goal* as interpreted through observations appeared to not include the social and epistemic domains of science practice, which were included in the AP Biology course goal. There was insufficient evidence to indicate Ajay recognized the contradictions of his *instructional goal* when compared to the AP *instructional goal*. As he was missing the reflective event and awareness of this gap, there was no evolution of his central activity system across the observations and interviews. Ajay's internalized model of the AP Biology course goal did not seem to be in conflict with his existing central activity system. His *instructional goal* appeared to be based more on his current activity system goals rather than a more advanced form of the current activity. As previously mentioned, his primary contradiction and goal was based on pacing of instruction, which could be a reason for no evidence of central activity progression in terms of science practice, based on the data collected in this study.

Mark. Mark's *instructional goal* was also placed within the scientific method phase of the continuum. Both his interviews and his actions in the classroom focused on experimentation, protocols, and an oversimplified, step-like process as scientists work from hypothesis to build theories. In each of his classroom observations his central activity object centered on experiments – students collecting data, controlling variables, testing hypothesis, and writing lab reports. Each experiment had the goal of finding answers to the lab's question, which was a characteristic of scientific method in the continuum. Early in the discussions he defined science practice as "doing experiments, putting science in to practice, actually doing it, a series of steps to try to find an answer to something" (p. 7, pre-study interview). The instruments he selected to facilitate student learning toward the object were "cook book" labs, labs that have a known answer. His actions with students targeted the lab protocols and ensuring they achieved the right answer to the question. The science practices of any lesson were always in the background to the "answers" or concepts of science being studied. Like Ajay, he also placed emphasis on the end product of science.

Like Ajay, Mark's instructional goal primarily consisted of his existing central activity system. He demonstrated a primary contradiction with the use of models, which he wrestled with, but this study did not observe advancement or additional clarity on the extent of this contradiction. The following description is predominantly based on Mark's current central activity system. Mark had a limited idea of models and their role in science, never using the term during observations of instruction. He saw organisms as models of another group of organisms, as laboratory specimens, or as aspects of an activity being used to study the actual living organisms, such as a particular flower being dissected representing angiosperms. During his interviews and journal entries, he discussed the physical models of the cell membrane and cell size and structure he used in his classroom to help students visualize structures to facilitate learning and show students phenomena. He also mentioned mathematical models that were a part of his course content, (e.g., Hardy Weinberg, Gibbs Free Energy, and Chi Square analysis). Based on evidence from this study his conception of models included physical models for learning and mathematical models, but he did not refer to models as a form of knowledge. Mark also did not show evidence of understanding the role of models in science practice or exactly how mathematical equations were considered models. Both of these observations related to models placed Mark in the scientific method phase of the continuum for understanding scientific acts and reasoning.

For Mark, models and their explicit use in instruction did appear to be a conscious conflict in his AP Biology teaching (central activity system). When he reflected on a lesson where students used germinating peas to study cellular respiration, he stated,

> From my standpoint they were engaged in SP 1 [the indicator of Science Practice 1 in the AP Biology Curriculum Framework], but [they] didn't realize it because I don't specifically use the term 'model' and only implicitly make the connection between what we are doing as a lab activity and its direct correlation to living organisms. (journal entry 10/22/2012)

This journal entry along with responses in his interviews revealed his belief that his students were not aware of their engagement in the science practices of modeling because he did not bring their attention to models and model's relationship with the natural world. So his conflict was with whether the explicit use of models as an instrument to facilitate student learning was required. He also demonstrated gaps in his own understanding of models. Despite this awareness Mark was not observed explicitly teaching or demonstrating his own metamodeling knowledge or fully integrating models with other science practices in his central activity. He did continue to wrestle with the concept of a model and meta-modeling knowledge in his journal entries as well as through interview discussions throughout the study.

Within the continuum's scientific method phase, the conceptual domain of science practice dominates with little, if any, reference to the social or epistemic domains of science practice. During observed instruction, Mark's central activity objects concentrated on the skills associated with experimentation and the end product or answer with little attention to the epistemic domain of science. His descriptions of knowledge construction included simplified processes of experimentation and observing nature, which aligned more with a process of discovery rather than construction. He often referred to scientists or students “finding answers” to their questions as a part of scientific practice, as in knowledge is discovered rather than constructed. To Mark, experiments were refined or extended by adding to someone else’s experiment, adding another variable, and reading other people’s work to generate questions. To him, all knowledge is temporary until someone finds something that contradicts it, “it really takes one experiment to change people’s ways of thinking now” (p. 3 pre-study interview). Based on his interviews, he did not see different forms of knowledge as having different levels of certainty. In his discussions and classroom observations, he had a strong sense of experiments and knowledge being right or wrong. When discussing the construction of knowledge he saw “constructing knowledge as a right and wrong phenomenon, new ideas need to contradict an established idea” (p. 4, pre-study interview). His students were very concerned during labs about getting the right answer, in which he often replied that sometimes [labs] just don’t work out or “you get what you get, this is science”. This short exchange with students was the primary way in which he referred to “nature of science” with his students, in that science involves getting errors and not always working out. Using an activity theory lens, Mark’s *instructional goal* had gaps in the epistemic domain, so central activity objects and student perception of success of these objects were about getting the right answer whereas wrong answers were due to errors. The process for getting the answers did not appear important.

His *instructional goal* included little attention to the dialogic processes of science, which constitute the social domain of science practice. At one point he mentioned religion as a social characteristic of science that influences students’ learning, but did not see science as social, “I think there are social pressures on some of the things we teach, but I don't know it's really social on its own, but it's influenced still by things like religion" (p. 4, pre-study interview). When prompted, he mentioned the collaborative aspects of knowledge construction in science. He stated that scientists build off of each other's experiments, but his response did not emphasize the community establishment of knowledge or the complex discourse methods that build scientific explanations. In the observed classroom, reflections, or interview discussions, he did not provide a space for collaboration and scientific discourse among students demonstrating a gap between his *instructional goal* and the AP Biology goal.

Overall, Mark's *instructional goal* focused on experimentation and protocols and a hands-on definition of science engagement, which demonstrated a simplified view of scientific acts and reasoning that doesn't include a social domain. There was insufficient evidence to determine that he interpreted different forms of knowledge as having different levels of certainty, which indicated an unsophisticated understanding of the epistemic domain of science practice. The inclusion of models as an aspect of science practice within the *AP Biology Curriculum Framework* alerted Mark to a conflict that models should be a part of explicit instruction. He did not demonstrate action to address this conflict in the observed classroom instruction, but reflected in his journals and discussed his continued struggle with models and meta-modeling concepts during interviews. His conception of models, his experiment/theory orientation, and his gaps in the epistemic and social domains of practice placed his instructional goal in the scientific method phase of the continuum. Overall, Mark had other contradictions within his central activity system that were not directly in relation to scientific acts and reasoning. A large proportion of Mark's goal appeared to be his existing activity system in combination with his evolving goal related to models.

Based on analysis of the instructional goals and central activity system components described above both Mark and Ajay are a part of the same micro-community. Their central activity of AP Biology teaching was oriented toward an *instructional goal* of student scientific perspective that was shaped by the scientific method articulation of scientific acts and reasoning. Either Mark or Ajay could be a representative of their AP Biology micro-community. Based on this analysis they had a limited idea of the social domain that contributed to the establishment of knowledge in science. They both appeared to have a simple, discovery-based goal of the epistemology of science. Their *instructional goal* included science as a linear, experiment and theory driven enterprise placed them in line historically with the scientific method goal of scientific acts and reasoning.

Another key indicator that Ajay and Mark were within the same micro-community was their language with respect to the terms of models and science practice. In Engestrom's (1987) activity model, language or common terminology shared by the community would be a part of the rules for participating within an activity system. The term "model" was not a part of the initial vocabulary of either their classroom communities, from teacher or student perspective. Based on the interviews and observations, Ajay and Mark had limited understanding of models as a form of knowledge; models do not appear to fit into their descriptions of scientific knowledge construction or models as embodiments of theory. Additionally, the terms "science practice" alone was also unclear and caused confusion with how Ajay and Mark defined scientific inquiry, science practice, and the greater scientific enterprise during interviews. The AP Biology course's use of "science practice" and incorporation of science practice into every learning outcome introduced a new term that was not a part of their central activity system. Once they were aware of this contradiction, both Mark and Ajay internalized the term into their mental model differently. Mark equated the science practices of the AP Biology course to be the steps and processes of the scientific method, and scientific inquiry was the more global enterprise term. However, Ajay associated science practice as all-encompassing, beyond experiments to include writing papers and posters, and scientific inquiry is the experiments in the laboratory. Both of them appeared to be confused about how to organize this new term into their current schema of what it means to do science.

Scientific Inquiry Micro-Community

Melissa. Melissa's *instructional goal* was within the scientific inquiry phase of the cultural-historical continuum. When describing science practice, she often focused on experiments. At one point she mentioned other forms of scientific investigations (e.g., survey). However, during interviews and instruction she referred to the scientific acts and reasoning associated with experimentation: designing experiments, collecting data, and using the data to draw conclusions. For her, the quintessential part of science was the process of finding answers to questions and asking questions to form explanations or theories. However, this process of knowledge construction seemed to be linear in nature. She described questions as leading to experiments or theories, and data were how an idea eventually became theory. In her interviews, she emphasized the importance of evidence as a guide to experiments and writing conclusions and explanations. This was different from Ajay and Mark, who both focused on experimentation and conclusions. While Melissa's focus was still on experiments, she gave equal attention in her instruction to data as evidence and to the purpose of data collection to form explanations and theories.

Even though her idea of knowledge construction appeared linear, moving from questions to theories, there was evidence to support that she did see the interdependence of science practices. In particular she said that at the beginning of an experiment the background knowledge, evidence, and question were all important to giving direction to an experiment. In response to a question about whether she would isolate and teach students a science practice, she described an activity where she had the students document all of the science practices they applied in an experiment over a period of time:

> And it kind of helped open their eyes to, okay we did we used like four science practices, and it was a very simple experiment that we did. I'm not sure about isolating just one, I think because they work so well together. It's kind of collaborative with the science practices. (p. 15, pre-study interview)

After each activity, the students compared their documentation of science practice as a way to gain a common understanding of each practice. In the end, the students realized that in a single laboratory exercise they were using data analysis, refining representations, and making predictions. Melissa's inclusion of the integrated nature of the science practice as a part of her instructional goal generated an object for her central activity system. This object facilitated students' actions, and they achieved the object and gained a similar perspective of integrated science practices.

As previously mentioned, models are considered a key indicator of placement of goals along the continuum. Melissa did not appear to include models as a part of her instructional goal, but included models as instruments for mediating learning in the central activity system. Melissa's use of models was different from the AP Biology goal that included models as a means for learning and a learning outcome or a form of knowledge that was a part of science practice (Bybee, 2011; College Board, 2011). Based on observations and interviews, she understood models to be physical representations of abstract concepts like images and other hands-on/physical manipulatives. She attempted to differentiate models from representations by saying that representations were more abstract and models were more specific because they "could actually show you what it is you're supposed to be seeing" (p.18, pre-study interview). Throughout the investigation, she did not refer to models as tools for expressing scientific theories and did not have students use them to construct explanations or predictions. Like Ajay and Mark, when observed she did not use the term *models* with her students, but students engaged in the use of models to mediate learning. For example, Melissa frequently used videos or simulations to demonstrate concepts such as artificial selection and the immune system. At one point students created skits to model the immune system. In each of these examples, students were not made aware of the model they were using or the role of models in science practice, so meta-modeling knowledge was not a part of Melissa's *instructional goal*. However, Melissa admitted seeing the value in having students know this meta-knowledge of models. After the skit of immune system lesson, I asked if she spent time discussing with students the purpose or nature of models in relationship to natural phenomenon. She stated that she never really thought about it before, but she could understand why it would be valuable for students to know this type of information (post-observation 4).

Along with Melissa's holistic and integrated view of the science practices within experimentation, she did see that the goal of scientific practice was to expand knowledge. Despite saying this, other evidence within the study showed she had a very limited and simplified understanding of the epistemic domain of science practice. Based on observations and interviews, she viewed knowledge as being discovered and not constructed. Even though she described the process of knowledge establishment by scientists as collaborative, she depicted the process as proving and disproving theories based on data and experimentation. Evidence supports that she recognized outcomes of practices are dependent on the content of study, but there was insufficient evidence to determine if this was a consistent part of her internalized understanding of the epistemology of science. When prompted about whether evidence of the same science practice would look the same under different activities or content, she responded, “I think there are still differences even if you’re using the same science practice, there are still differences in how you’re using it and how you’re applying that” (p 16, pre-study interview).

Other evidence of how the epistemology of science was captured in her instructional goals is her descriptions of certain practices that involve the social and subjective aspects of practice. When attempting to describe the various science practices, she struggled with competing explanations and admitted that she gave little thought to the practices associated with competing explanations or the subjective link between data and evidence. These practices were included in the AP Biology course goals, which provided evidence of an unconscious gap in Melissa’s instructional goal and the AP Biology goal. There is insufficient evidence to indicate whether this interview could be considered a reflective event and whether this gap in understanding competing explanations and data versus evidence became a conscious conflict that motivated Melissa’s own learning activity.

Her placement on the continuum within scientific inquiry was also due to her varying degrees of including the social domain of science practice in her *instructional goal*. Her *instructional goal* appeared to reflect the contextual factors and subjective nature of science practice, but the inclusion of the complex discourse practices involved in knowledge construction appeared limited. When reflecting on her own experiences of being a laboratory scientist, she had a firm understanding of the collaborative and often competitive aspects of practicing science. She described the importance of sharing with the public findings, both right and wrong, and the bias that exists among scientists based on funding sources. When discussing the nature of discourse and collaboration among scientists, she remarked that “[money] created really big divides in the science community as far as whom you’re allowed to work with” (p 3, pre-study interview). This demonstrated that she grasped the contextual factors that impact community interactions. When discussing knowledge construction in science, her description of collaboration included the advantage of adding other people to the process to provide alternative, subjective lenses. She mentioned involving as many people as possible in all aspects of the process from how the experiment is going to be completed to gathering different opinions when considering evidence because “a lot of times we see it one way and then you talk to somebody and then you realize you could have something different and found different options” (p 5, pre-study interview).

Despite her inclusion of the subjective nature of scientific collaboration, there is insufficient evidence to indicate that the complex nature of discursive practice of community interactions were a part of her *instructional goal* for student outcomes. During interviews, she placed value on the discussions in her classroom to provide her feedback on student understanding and increase student engagement. However, in the observed central activity system, she did not include science discourse practices as an object of student learning. Therefore, her actions and technical tools used in the classroom did not result in the student outcome of discourse practices reflected in the science community. Similar to models, discourse in the classroom was an instrument for mediating student learning, where class discussions were often a part of a teacher lecture, but science community discourse was not the goal or intended student outcome.

As previously stated, the AP Biology instructional goal included science practices as a learning outcome as well as a tool for student learning (Bybee, 2011). The AP Biology’s depiction of science practice consistently included critique and evaluation across all of the science practices (see Appendix B for a comprehensive list of the AP Biology Science Practices). This was a defining component of the reform goal of science practice, in that it represented community involvement in the appropriateness of practices as well as the role of discourse to establish knowledge (Ford, 2015). In her observed central activity system, Melissa did not have an object that involved student critique or evaluation of their own or others work, or any information, data, model, or explanation provided to students. One lesson involved groups of students creating a skit to represent different parts of the immune response, but the object of that central activity system was focused on the content, not the interactions within and among the groups or eventual critique. There were opportunities to build student collaborative practices, but the evidence indicated that the social domain of science practice was not a key part of Melissa's *instructional goal*. The collaborative student outcomes were not realized in the activity. Her inclusion of the social domain of science practice was significantly more advanced than Mark or Ajay's, but an unconscious gap existed with the AP Biology goal, which placed her clearly within the scientific inquiry phase of the continuum.

Overall, Melissa was comfortable with the experimentation or inquiry facets of science practice that are a part of her *instructional goal*. She confidently spoke about experimentation, evidence, and data collection, and even the competitive nature of science practice. When it came to discussing or incorporating science practice performances such as models, discourse, or competing explanations as outcomes, she stated that she was not as familiar or gave little thought to these things. Even though she had laboratory experience, her understanding of the epistemic and social domains of science practice were very simple and did not reflect the complex discourse practices associated with a community of scientists engaging in knowledge construction. Her existing central activity system did not include these performances of science practice. There was insufficient evidence to indicate that there was a conflict within her existing practice, and therefore, these performances are not a part of her *instructional goal* for her AP Biology teaching.

Kyle. Kyle's *instructional goal*, unlike the other cases, consisted of both his existing central activity system and a future form of the activity system related to mathematical practices. During this study he demonstrated several secondary contradictions that demonstrated his progress as he wrestled with gaps in his existing central activity and his instructional goal. Of the four teacher case studies, Kyle's *instructional goal* was closest to the continuum phase of models and discourse; however, I would still position his goal within the scientific inquiry phase of the continuum for this study. Even though Melissa and Kyle were both within the scientific inquiry phase of the continuum, I would not place them within the same micro-community. Kyle's *instructional goal* and practice were closer to the AP Biology goal than Melissa's. The following description of Kyle's *instructional goal* highlights these differences.

For the concept domain of science practice, Kyle had a clear idea of the interdependence and connections among the science practices, with a focus on the investigation aspects of practice from asking questions through data collection and explanation building. Early in the interview process he described the science practices as, "all inter-connected in some way, but because one really can't exist without the other" (p 5, pre study interview). In a journal entry he described scientists utilizing all seven science practices when doing science and communicating scientific ideas to community and society. When asked about whether the science practices were discrete, he responded one could separate them to build understanding and ability to do the practice, but if the goal was deeper understanding then it was important to inter-weave the practices together. The object of one of his example activity systems explicitly stated building student understanding of mathematical models. However, his actions and instruments used in the classroom involved many, integrated science practices such as data analysis, experiment design, hypotheses, and questions. Even though it may appear that he was focusing on a single science practice as the object in this instance, the central activity system involved a much more integrated representation of practice. This view of the practices as mutually interdependent was more sophisticated than the step-like, discrete event of the “scientific method” present in Mark’s and Ajay’s goals, which places Kyle in the scientific inquiry phase of the continuum.

An important distinction of the models and discourse phase of the continuum is the use of models and meta-knowledge of models. Early in the study, Kyle described models as physical entities that have an important role in student learning of science concepts, specifically those too small in scale to observe. From an activity theory perspective, Kyle used models as instruments to facilitate student learning of explaining phenomenon they cannot see. For example, he applied models when teaching genetics to show students abstract processes, like transcription, and provide them with concrete evidence that will help them answer “how do we know that” question of science (pre-study interview). His attention to this question and based on observations and interviews, Kyle appeared to use models as a form of evidence of concepts. This use of models as an instructional tool, as well as evidence to validate how knowledge is established in science, was unique from the other case studies. Notably, this use of models is different from Melissa’s instructional goal. Despite Melissa’s and Kyle’s goals being both within scientific inquiry, this difference indicates the two belong to different AP micro-communities.

Even though his *instructional goal* was unique from the other case studies, there were gaps between his goal related to models and the AP Biology course goal. While discussing in the pre-study interview how knowledge shifts due to new evidence and studies, he used the changes in the “theory of inheritance” as an example. I mentioned the shifts as the “model of inheritance,” and he replied that he did not understand how the change would be a model. He considered it theory refinement (p 5, pre-study interview). At this point in time (beginning of the year), he did not view models as a type of knowledge or he was not able to show relationships of an abstract theory like inheritance. When asked about his use of Gibbs free energy equation as a mathematical model, he did not see it as a model, but rather a formula that, “gives us a value of interest,” where a mathematical model “simulates a hypothetical scenario, a biological concept, that uses math to represent change” (p. 3, post-observation 1 interview). Even though there was an object (student outcome), much later in the school-year, that had students using a model to demonstrate evidence of a disturbance in the ecosystem, his incorporation of models into his *instructional goal* appeared inconsistent and not complete compared to the AP Biology instructional goal.

Despite the inconsistent incorporation of models in his *instructional goal,* his epistemic domain of science practice was centered on investigation and theory building, which placed his *instructional goal* within the scientific inquiry phase of the continuum. Based on observations of his central activity system and interviews, Kyle reflected an understanding of science epistemology to be the construction of knowledge through collaboration to extend and refine theories. He described it as a “series of events that occur over a long period of time where scientists…one builds upon the other with research and the knowledge is gained through investigations, research, different things like that” (p. 3, pre-study interview). During interviews and classroom discussions, he often described new studies and research with the investigation performances (i.e., hypotheses, data collection and analysis) and the evidence that resulted from investigations as being the drivers of changes to theories. He stated during an interview that he saw science practice and the nature of science as being the same, with nature of science being the tentativeness of science, refining our ideas of how phenomenon works. When he described the nature of science, he said, “There are theories that are supported by empirical evidence and by data and by trials and by research, but we are not going to use the word truth or absolute because we always have to be open to that refinement” (p 4, pre-study interview). During his third observation Kyle told the class that science is about changing based on empirical evidence, not throwing one idea out to replace another, but to elaborate understanding of the phenomenon. This focus on investigations as the primary mechanism of theory refinement and the tentativeness of theories placed him within the scientific inquiry portion of the continuum. His minimal mention of other types of knowledge or their predictive and explanatory power placed is further evidence of his placement, but placed him further along in the continuum than Melissa.

Based on his own description of knowledge construction, his *instructional goal* included a more sophisticated social domain than the other cases. The objects of his central activity system and his actions during teaching stressed the importance of the scientific community, specifically peer review, to critique and provide objectivity to data interpretation and conclusions. With students he consistently emphasized discourse based on evidence as a means for scientists to support and evaluate conclusions, to extend their own ideas into other research, and to settle disagreements between scientists. During a population dynamics lesson, he used a research article about zombie alligators to connect concepts to research. In class he said,

> One person doesn’t build all of it, we I get into politics here, but you don’t build, one person doesn’t build this entire area of science, it’s a collaborative effect. It’s collaboration among everyone together to get to these results and then that one specific case study of zombie alligators over years and over numerous researchers and lots of in the laboratory research and in the field research they discovered something that was going on around this area around Lake Griffin. (p.1, observation 3)

During interviews and in his central activity, he often described the importance of evidence-based discourse as a means of settling disagreements among scientists in the community. The classroom community rules and culture valued student's use of evidence to back claims and predictions, in classroom discussions and their work product from a classroom task. At one point during a class discussion when two groups of students did not agree on an answer to a question, he made the point with students that as long as they backed their statement up with evidence, and their interpretation of the concepts, then he could see their point of view and would not count it incorrect.

His central activity objects and discussion of science practice during instruction often emphasized the importance of discourse and collaboration among scientists, in particular their role in peer review. Peer review was often discussed during interviews; however, the creation of classroom space for peer review was not observed as a part of this study. He described peer review as providing objectivity to data interpretation, conclusions, and experimental design. During the second observation, he explained to the students that theories were refined through collaborative investigations and peer review, where scientists are running different trials, making different errors, and studying different aspects of a theory, like the Human Genome Project. His instructional activity consistently demonstrated the importance of evidence and discourse in the science community, although the complexity of this discourse practice, based on the evidence from this study, was not fully realized. He appeared to be relating discourse at the experimental, or individual, level of practice, rather than to the greater community, and the establishment of norms and rules of knowledge construction associated with practice within a community. This community discourse is an important aspect of the models and discourse phase of the continuum. Therefore, Kyle's simplified implementation of the social domain of science practice and focus on the peer review roles of the community, placed him within scientific inquiry instead of the models and discourse phase in the cultural-historical continuum.

Even though Kyle and Melissa were both within the scientific inquiry portion of the continuum, they exist in different, but fairly similar AP micro-communities. They were fairly similar in their epistemic domain and most aspects of the conceptual domain of science practice, except their inclusion of models. Their differences in the social domain were nuanced, but significantly different in how they put their internalized model into practice and the culture of their classroom. Both teachers used discussions as a primary mode of instruction. Kyle and Melissa were similar in their descriptions of the science community providing an objective lens for evaluating experimental conclusions. Kyle's attention to peer review and explicit instruction on the importance of discourse and backing claims with evidence created a different culture in the classroom community, one focused on explanations and predictions based on evidence as a part of discourse. Socratic seminars appeared to be a regular part of his central activity. As a sign of the division of labor and rules within the classroom community, students understood and readily performed the protocol associated with this form of classroom discourse. However, Melissa valued discussion and strived for students to share and test each other's ideas, but her observed central activity did not create a space or present tools for peer review interaction. Peer review was a regular part of Kyle's central activity, according to interview data, and he consistently presented examples of actual scientific research and explicitly brought to student's attention the collaboration of scientists. For Kyle, the discourse was a part of his *instructional goal*, an outcome for students. Melissa used discussions as a method of instruction, an instrument of the central activity system, rules and norms of discourse were not a learning outcome for her students.

As previously discussed language provided evidence of Mark and Ajay belonging to the same micro-community, and language was further evidence of Kyle and Melissa belonging to different micro-communities based on the nature of their activity system goal. Both Melissa and Kyle had a simplified view of the epistemology of science, but Kyle regularly drew attention to the question of “how do we know what we know,” which was an important part of the reform goal of science practice. They both understood the dependencies, and integrated nature of the practice of science, and focused on the refinement and establishment of theory through evidence. A key difference was their use of the term “model,” and understanding of models in relation to science practice. Both Kyle and Melissa initially described models as physical, instructional tools. However, Kyle’s actions and language in his central activity system regularly referred to models. His students even used the term in class discussions. He intentionally tried to address student’s meta-modeling knowledge. Melissa incorporated model-oriented activities into her central activity system, but did not use the term and did not bring to students’ attention the relationship between models and phenomenon.

Contradictions within each case. The distance of each micro-community’s goal from the reform-oriented goal of science practice as represented by the AP Biology course goal also provided insight into contradictions or conflicts that must be recognized and overcome in order to move micro-communities of teachers toward the reform goal. If these gaps remain unrecognized, then no movement of the micro-community will occur (Engestrom, 1987). For each component (node) of the central activity system there are several conflicts that could be found. For example, Mark was conflicted by the instruments used in his central activity system, and whether and how to use “cook book” types of labs compared to more “inquiry” types of labs. While Melissa demonstrated conflict with her inclusion of models and meta-modeling in her central activity system objects. Whether these conflicts will be addressed and overcome is dependent on whether they were recognized and actively pursued by the teacher (subject) as a part of his/her learning activity. If the gap is not within the teacher's "sight" or zone of proximal development, it may not be recognized or overcome without the appropriate support. Mark was aware of his conflict and actively pursued to address it. Much of his awareness was a result of discussions with the researcher. However, it is unclear based on the evidence collected in this study whether Melissa recognized and attempted to address the conflict of models in the object of her central activity system.

In summary, the cultural-historical continuum used to frame each teacher's *instructional goal* provided a CHAT perspective to the development of the reform-oriented goal of science practice represented in the AP Biology course goal. Each teacher's *instructional goal* was placed along this continuum as evidenced through their actions, instruments, objects of their central activity system, as well as interview discussions and journal reflections. As the findings of the case studies elaborated, for the four cases there existed three different micro-communities with *instructional goals* oriented to two of the phases of the cultural-historical continuum. Mark and Ajay's *instructional goals* were both representative of the scientific method phase of the continuum. Based on the evidence available, their *instructional goals* had limited inclusion of the social or epistemological domains of science practice. The language of their classroom did not include models, and the incorporation of "science practice" into the language of the greater AP Biology community appeared to cause confusion for their organizational structure of the science enterprise. While Melissa and Kyle's instructional goals were both placed within the scientific inquiry phase of the continuum, their difference in incorporating models and the social domain of science practice placed them at different points within the continuum. Thus Melissa and Kyle could be representatives of different micro-communities along the continuum, but within scientific inquiry. They both had *instructional goals* that included the social aspects of science practice and a slightly more sophisticated epistemology of science than Ajay or Mark. Their goals included the integrated and interdependencies of science practices placing them closer to the AP Biology goal compared to Ajay and Mark. However, when comparing Melissa and Kyle to the models and discourse portion of the continuum (the AP Biology goal), Melissa's inclusion and Kyle's initial use of the role of models in science practice were not as sophisticated. Kyle's incorporation was more sophisticated than Melissa's, separating them into different micro-communities. Kyle had incorporated the term models and attention to meta-modeling knowledge with his students, placing him a little closer to the models & discourse phase of the continuum. Kyle was also closer to the reform-oriented goal of science practice because he demonstrated understanding the complexity of the discourse practices of the community and created an evidence-based and collaborative culture in his classroom.

Analysis of Kyle's Expansive Learning

In this next section of findings, research question #2, *What does a teacher's learning activity look like as s/he progresses along the cultural-historical continuum?*, is addressed by describing in more detail Kyle's learning as a representative of his AP Biology micro-community[3] described in the first section of findings. Through a CHAT perspective, Kyle's active pursuit to address a conflict and transform the central activity system is his learning activity. The analysis includes descriptions of consistencies and shifts that occur across concrete series of actions within the central activity system that emerge from this conflict. Evidence of

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[3] Kyle is considered a representative of an AP Biology micro-community based on the orientation of the community's goal within the cultural-historical continuum of scientific acts and reasoning. To simplify language for the rest of this study, the use of *Kyle's micro-community* is referring to Kyle as a representative of the AP micro-community with instructional goal oriented within the Scientific Inquiry phase of the continuum, which is different from his more local, classroom community or the greater AP Biology community.

purposeful changes in his central activity system is evidence of Kyle’s learning. The in-depth description of Kyle’s learning through an expansive cycle of his central activity system includes the conflict between the goals of the current form of AP Biology teaching and the future form of AP Biology teaching that motivate Kyle’s learning. The descriptions also include the context, tools, actions, and objects involved in the shifts of the central activity (AP Biology teaching). Since Kyle’s learning activity is situated within his classroom community, the contextual factors such as rules and division of labor are included in the analysis as a part of his central activity system.

Kyle’s case is ideal for studying the phenomenon of learning as his AP Biology teaching progresses toward the AP goal of science practice. He is reflective of his actions during planning and classroom instruction and recognizes a conflict between his implementation of mathematical practices and the AP Biology definition and expectation of mathematical practices. The fact that he recognizes this conflict is unique amongst the teachers included in this study, in that unlike the others, it appears from his language and actions that the reform oriented definition of models is within his sight (i.e., within his zone of proximal development). Through reflection and action, he consciously addresses this conflict and attempts to close this gap through the expansion of his activity system. The continuous processes of internalization and externalization of Kyle’s activity system in response to the conflict provide a lens for describing the evolution of Kyle’s micro-community toward the desired goal of the redesigned AP Biology course. Kyle’s proximity to the AP Biology goal of science practice along the cultural-historical continuum also makes him an ideal case to study teacher learning. Ken’s description of learning attempts to describe an instance of this movement at the more granular level of his classroom actions, objects, and tools during meaning making, as well as more broadly as Kyle's central activity system transforms and the goal of its activity shifts toward the AP goal of science practice.

This next section of findings also intends to address the second part of research question #2, *Can a teacher's specialized content knowledge of science practice be used as a metric of teacher learning?,* by describing in more detail the use of the psychological tool of specialized content knowledge in the transformation of Kyle's central activity system. The analysis includes tools, both technical and psychological he used to facilitate his actions. In particular, it focuses on the presence of and any shifts in his specialized content knowledge of science practice, which is considered a psychological tool used to mediate his actions toward the object. This analysis focuses on specialized content knowledge situated within particular actions and activity system context, and is not meant to make generalized statements about Kyle's overall specialized content knowledge with respect to models or science practice.

The following section will describe four concrete examples of Kyle's AP Biology teaching. Each central activity system description includes examples of Kyle's actions that are mediated by technical as well as psychological tools (i.e., specialized content knowledge), and have a conscious purpose aimed at the object and, ultimately, the goal of the central activity system. Then, an activity theory triangle is used to describe the actions, how these actions are interpreted, and how the actions relate to the overall central activity system, in particular, the specialized content knowledge of science practice and object. Finally, the analysis will step back and look across the example central activity systems and analyze an expansive cycle as Kyle acts to address a primary contradiction. This recognized gap is the motive for Kyle's learning. The following section describes the primary conflict of Kyle's micro-community goal with respect to mathematical practices.

Primary Contradiction of Mathematical Practices

Prior to describing Kyle's micro-community's contradiction, this section revisits the key concepts of contradictions and zone of proximal development described earlier in this paper. Contradictions are an essential part of learning activity. These disturbances or gaps motivate particular actions of the individuals within the community and lead to the evolution of the system as a whole (Barab et al., 2004; Engestrom, 1987). With the reform launch, all teachers within the AP community attempt to appropriate and take on the cultural practices of the reform goal of science practice. The primary contradiction is between the teachers' current central activity system goal and their appropriation of the future form of the activity system, which is the AP Biology course goal. This type of contradiction is ill-defined and considered a "need state" that the subject grapples with in order to make decisions and to consider competing alternatives when engaging in science teaching practice (Engestrom, 1987). As the subject adjusts his instruction to resolve this primary contradiction other secondary types of contradictions emerge, which are more defined. He attempts to address these contradictions, resulting in new objects and instruments, which are created in an attempt to resolve the conflicts.

Contradictions can only become motives for transforming the activity system if the subject becomes conscious to the conflict through a reflective event. The reflective event makes a conflict for activity conscious as the subject becomes aware of discordance between their current form of the central activity system and some future form of the central activity where the contradiction does not exist. This future form becomes the goal of the central activity and closing the gap becomes the motive for transforming the activity system. This future form of the central activity system is established by the subject as a part of the reflective event. It must be within reach, within the zone of proximal development, for the transformation to take place. If a conflict is not conscious, then a future form of the activity system does not exist for the subject and there is a lack of motivation to transform the activity system. The current form of the activity system and its goal persist and the activity system does not transform.

Kyle' contradiction. As a representative of Kyle's micro-community, Kyle was motivated by a primary conflict which existed between the object and goals of his current form of AP Biology teaching and the object and goal of a more culturally advanced form of activity (Kyle's interpretation). This is the *instructional goal* that was described in the first section of these findings. More specifically for this analysis, discordance existed between Kyle's existing mathematical practices objects of his AP Biology teaching and his *instructional goal*, what Kyle would like his central activity system to look like and achieve.

This primary contradiction was motivating for Kyle because a reflective event occurred, drawing Kyle's attention to the conflict. This reflective event most likely occurred before this study was initiated. As he aimed to rectify this conflict, secondary types of contradictions emerged throughout the activity system as the system transformed. Kyle must transform his instruments, actions, and objects in order to reach the desired, future form of the central activity. Figure 4.1 represents the primary conflict of Kyle's object of the current central activity system and the future form of the activity system. It also includes examples of other primary and secondary contradictions (e.g., 2a and 2b) that were observed as a part of the study. These conflicts serve as evidence of the transforming activity system. For example, Kyle stated in his pre-study interview that his challenge was getting students to understand the conceptual application of math and move away from pure calculations and plugging numbers into formulas (pre-study interview). These contradictions are included in Figure 4.1 as 2a and 2b, as Kyle's struggles with the community and instructional tools necessary to achieve the object. All of these conflicts were specific to Kyle’s unique central activity system which was observed as a part of this study. Kyle, as a representative of his micro-community, can bring light to the nature of conflicts and the process associated with movement of a central activity system along a cultural-historical continuum of scientific acts and reasoning.

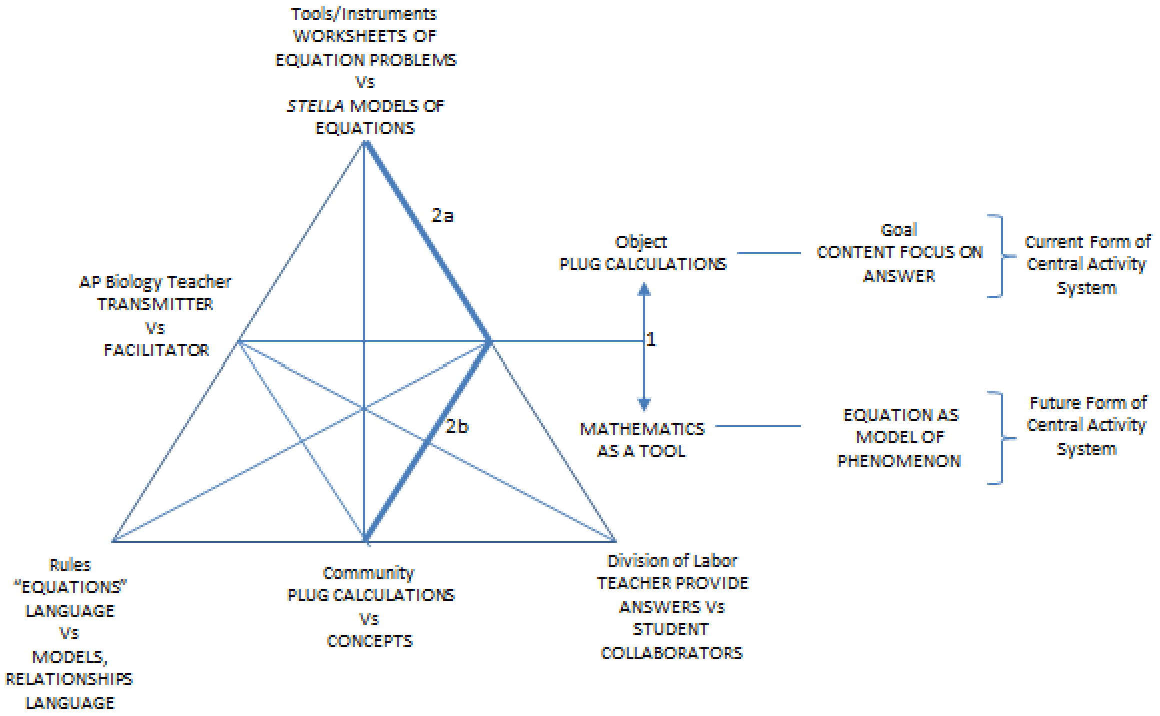

Figure 4.1. Kyle’s Contradictions within the Central Activity System

The next section uses concrete examples from the classroom to describe Kyle’s emerging actions with respect to Kyle’s primary and secondary conflicts. To examine the action and conflict interaction, the findings include actions in Kyle’s planning and instruction that are representative of Kyle’s AP Biology teaching. To analyze the impact of Kyle’s actions toward this conflict on the potential transformation of the central activity, I describe actions that emerged as a result of this contradiction and provide the transcripts for these actions. Prior to the transcript for each action, I present the context of the classroom central activity. Following the actions, Engestrom's (1987) activity triangle (Figure 4.2) is used to describe the action. The description includes how the action is interpreted with respect to the primary conflict and how it relates to the overall system, in particular, the specialized content knowledge of science practice and the established object for the activity. Each example also includes a representation of the components of the activity triangle model. This approach to capture emerging actions resulting from a conflict is similar to Barab, et al.'s (2002) study of conflicts and actions in an astronomy course. After this detailed analysis of Kyle's actions, I then pull back and describe any shift in the central activity system through the lens of an expansive cycle, which would capture Kyle's learning.

Example 1: Calculating Gibbs Free Energy

The central activity system for the following actions occurred during the middle of a 90 minute block period. Prior to this example, Kyle reviewed energy concepts such as metabolism, forms of energy, and laws of thermodynamics. For this central activity system example, Kyle established the object (student outcome) as students understanding the equation for Gibbs Free Energy and what it represents conceptually, connecting the molecular level of energy to the bigger picture of ecology and relate it to current research (pre-observation 1). The activity triangle model provides a mechanism for analyzing individual actions and their purposes as well as their relationship to the object as a collective series of actions. The individual actions selected occur in a series, and the beginning and ending are defined by the conscious purpose of the action. The purpose of each action was associated with different variables of Gibb's equation (i.e., delta S, delta H), but Kyle's collective series of actions was aiming toward the overall object of the central activity. Early in the class period, Kyle shared this object with the students: "not just calculations, not just plugging numbers in and seeing what the number and value is but understanding what that value means” (p. 1, observation 1). The students then used a two-part worksheet (technical tool) that broke down and walked them through the calculations for Gibbs Free Energy equation in part 1. In part 2, there were five questions that connect the equation and calculations to making predictions about free energy in relation to photosynthesis, cellular respiration, ATP, organisms, and ecosystems (i.e., the “bigger picture”). Action A below took place after the students worked on the calculations (part 1 of the worksheet) in groups, and Kyle had brought the class together to go through the steps as a class. They were currently working on Step 5, which had students calculating delta S, using the white board at the front of the room. In Action B students were working on Step 6, calculating delta H and then the final answer for delta G. Action C took place after Kyle completed the steps of the equation with students. He was referencing questions in part 2 of the worksheet, about the delta G of photosynthesis and respiration, helping the class to make connections to the bigger picture.

Action A

Kyle: There we go. Now, we’re adding, how many moles of oxygen do we have?

Student A: One.

Kyle: Just one. What’s the value? All right, let’s put this together, and then we have to subtract [*drawing on the board*]. Now, we’re on this side of the reaction, [*drawing on reactant side of equation on the board*] okay, and we only have one reactant, it’s right here. How many moles? Two moles times...

Student A: One-O-nine.

Kyle: One-O-nine point six, (109.6). Okay, after going through this mathematically, what are we getting?

Student B: Eight-four-four point... [*incorrect answer*]

Kyle: Maybe, this is where we need to make sure we know how to use our calculators properly. And we’ll practice, I’m not going to go through each of these steps today, write them out for you but we'll look at this first. This value right here [*pointing to board*], what's?

Student C: One-three-nine-nine.

Kyle: What is it?

Student D: Three-nine-nine (399.) point [*incorrect answer*]

Student E: one-twenty-five (125)

Kyle: 125? I know you guys got this right.

Student E: 125.76.

Kyle: There you go, thank you. That's what, we're jumping ahead, okay. Oh, you thought I was doing this? [*pointing to summation of product on the board*]

Students: Yeah.

Kyle: Okay, I'm sorry. Thank you. Okay, I'm making sure we're all on the page because you guys were throwing me off there. All right, so one, you guys got it right. 125.76, I'm just taking, guys, all of this right here. We've already calculated it. So I'm asking you, Hey, what is this? [*interrupted by students*] Oh, I'm sorry. Okay, so we've got that now, 125.76, and we need to convert that to this unit [*draws on board*]. So what do we do?

Action B

Kyle: We're going from this unit to this unit [*writing on board*]. So we divide by a thousand now. We will have more practice with this later. Guys, listen up. We'll have more practice with the calculation later. I wanted to drive the point with what Gibbs free energy is and kind of extend this into where we're headed. Step 6, we needed to calculate Delta H. Without writing it out, it was that formula that was given, very similar to the one we just saw previously except we are summing the number of moles for the Delta H values of the products minus the sum of the Delta H values for the reactants. And what number did you get for that Delta H? Negative, what's that final value?

Student E: If you divide by one thousand, and you put this down...

Kyle: Negative one-ninety-six (-196). How many of you guys got that right? Okay, and I went, just real quick, guys, I went around, you guys got it, most of you just got it just now, don't be afraid to answer. That's the value, that's it. Now, if we just plug it in to calculate into this equation here, changing free energy, and we put our values in, assuming that temperature is at what, Kelvin? Okay.

Students: 298.15

Kyle: 298.15, what's our final Delta G value from this reaction [*putting square on board around reaction*]? Negative two, (-2) how many of you guys got that?

Student F: Not me.

Kyle: Okay, yes.

Student F: What answer are we supposed to get?

Kyle: Hang on, just one second. No, the units on this one are, you're talking about to get the final one you're just plugging in your values here. Step 6...

Student E: You're asking if we get that answer, right? But we don't have a decimal point.

Kyle: Yeah, negative one-ninety-six-point-one (-196.1)?

Students: Yeah.

Action C

Kyle: Yeah, that's it. Because your units are already in. All right, let's look at what this means most importantly right now, and then we'll go through these calculations later on slowly but surely throughout the week together. The question, and when we look at the decomposition of hydrogen peroxide, is that spontaneous? Okay, let's answer that first. Is it a spontaneous reaction?

Students: Yes.

Kyle: Yes it is, and how do we know that it's a spontaneous reaction?

Students: It's negative

Kyle: Because our Delta G value there is a negative value, meaning that disorder is increased. Okay, free energy, obviously, like we've been trying to make this, paint this whole picture, free energy is an important thing to living things. Based on what we know about free energy and living things and different organisms, do you think photosynthesis has a positive or negative Delta G? [*referring to question #1 in the worksheet*] Okay, photosynthesis, does, well let's ask this question, does photosynthesis require energy input? Okay, so you said it's what value Delta G, do you think?

Students: Positive

Kyle: Probably, a positive Delta G, good. And that would consider it a non-spontaneous process. Let's finally predict where we are headed in the next two chapters after we learn how to calculate free energy and we kind of get some different ideas about what this means. We'll be headed in to photosynthesis and cellular respiration. So let's go and ask the other one there about respiration [*referring to question #2 in the worksheet*]. Predict with justification the Delta G for respiration. And we can't do the Internet search right now, we'll do that later on in the week. But what do you think the Delta G will be for respiration, negative or positive?

Students: Negative.

Kyle: Negative. Okay, good. So we're seeing that concept of Delta G values, we need some work with the calculations a little bit, which is fine. As I was going around, I think, you guys got it. I think, you were not really understanding what I was asking but that's all right. So we ended up with the same answer in the end with that Delta G.

The example above demonstrates a series of actions that are directed toward the desired object of the central activity, to build students' understanding of Gibbs Free Energy equation and what it represents in the bigger picture. Figure 4.2 represents Kyle's central activity system for this example. Across all three actions, Kyle pushed through the calculations, at times skipping calculation steps stating they would work through the calculations at a later time. His actions appeared rushed in an attempt to get to the object of connections of the equation to the bigger picture. During Action C, Kyle finally arrived at the point when he elaborated on and made connections to delta G and the spontaneity of photosynthesis and cellular respiration. At this point in the example, Kyle's actions were focused on the overall object of the central activity system - connections of the equation to the bigger picture. After the lesson, when Kyle was asked if students achieved the outcome of the object of this central activity, he responded, "yes." When asked about the observable evidence of this achieved outcome, he identified that students answered his questions, although they were a little hesitant, but most of the groups were calculating the right answer. His response provides evidence of the presence of the conflict driving Kyle's learning. Initially, the desired object was performing calculations and making connections between Gibbs equation and the bigger picture, but he considered the outcome to be met because students could complete the calculations. The outcome related to calculations was in line with Kyle's current activity system, but fell short of the desired object, which represented Kyle's internalized model of the AP Biology course goal of math-based conceptual understanding, Kyle's *instructional goal*.

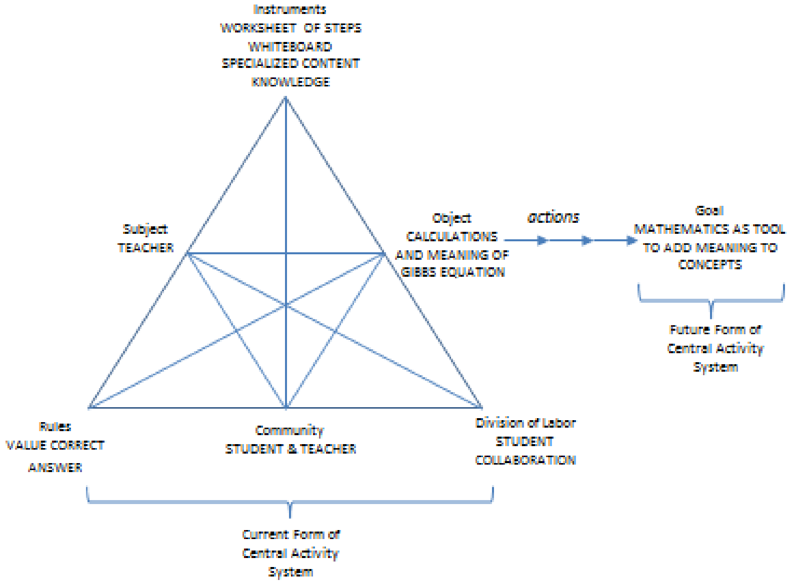

Figure 4.2. Example 1 Kyle's Central Activity System

The example actions above, despite their purpose, were all mediated by the Gibbs Free Energy Equation worksheet, equations and calculations written on the white board as well as Kyle's specialized content knowledge. One way to analyze Kyle's actions associated with these instruments is through the amount of time spent on certain parts of the tool to facilitate student learning. The first portion of the activity took 31 minutes, 51 seconds to complete compared to the second section of the activity, which took roughly two minutes before Kyle moved on to another part of the lesson. This second part included five questions focused on tying the calculations to broader conceptions. When Kyle reached this portion of the lesson, instead of spending equal if not more time on the concepts, he skipped 3 out of the 5 questions in this part of the worksheet.

Another interpretation of Kyle's actions is Kyle's selection of this particular instrument to facilitate students toward an object of calculations and relating molecular Gibbs to the bigger picture. The instrument's focus on the step by step solution to a problem involving the breakdown of hydrogen peroxide did not appear to facilitate a more conceptual understanding of Gibbs Free Energy. His actions for instrument selection and usage and priority appeared to emerge from this conflict of goals for the central activity system, connecting Gibbs to the bigger picture versus plugging in numbers to complete calculations. His choices and priorities for the use of this tool seemed to be in sync with his current form of the activity system – plugging numbers to find an answer.

Kyle's actions with the worksheet calculations demonstrated some specialized content knowledge related to connecting the equation to appropriate mathematical routines such as summation of products versus reactants. However, his effective use of the worksheet (instrument) to facilitate student learning toward the more conceptual understanding of Gibbs

Free Energy equation may be limited by Kyle's specialized content knowledge (SCK) of mathematical models in this particular example. During the post-observation interview Kyle made the following comments when asked if he considered Gibbs Free Energy equation to be a model:

Kyle:	No, when I think of mathematical models, I think of models that a lot of times simulate something like population changes or allele frequency changes. I think of those mathematical models as something that mathematically models a scenario, a biological concept. I think of that as a formula, when I think of Gibbs Free Energy or water potential, I think of that as a mathematical formula.
Interviewer:	How do you distinguish between the two?
Kyle:	A formula gives us a value of interest; a mathematical model is a hypothetical scenario that uses mathematics to represent changes (p.3, post-observation 1 interview).

To Kyle the equation's purpose was not to serve as a model that represents reactions in a living system. Given the object of his actions throughout the central activity was to build students understanding of the meaning of Gibbs free energy equation toward the bigger picture, referring to the equation as a model could have facilitated students' connections of Gibbs to phenomena. Kyle's interview statement and actions focused on calculations provide evidence that Kyle's *instructional goal* of mathematical practices was missing a complete conception of mathematical models compared to the AP Biology goal. Kyle's choice in language also demonstrated a lack of awareness of a conflict and inclusion of certain types of mathematical models in his future form of this activity system. Despite the object of knowing what the Gibbs Free Energy equation represented in terms of energy of living systems, Kyle did not use the language of mathematical models when referring to the equation to help students build the conceptual understanding of the variables and their relationships. In comparison to the AP Biology course goal, Kyle's *instructional goal* for mathematical practices included using math as a tool to understand concepts and mathematical models as simulations (explored later), but not equations like Gibbs free energy as a mathematical model. Based on observations and interviews at this point in the study, Kyle was not aware of this gap with mathematical models, so it was not a part of his future form goal or his *instructional goal*. If it was not a part of his goal, then Kyle's specialized content knowledge of mathematical models was also limited. At this point in the study, his conflict with calculations and using mathematics as tools to understand phenomenon and the bigger pictures continued to exist within the central activity system.

In terms of the classroom community of the central activity system, a secondary conflict appeared to exist between the students' perception of the object and Kyle's actions toward the object. Even though Kyle told them the object and reinforced the object of connections to bigger picture in his actions, the students' actions and motivation were directed toward getting the correct answer and doing the calculations correctly. Kyle's actions in skipping steps and rapid pace stimulated some confusion among the students, in terms of which answer he was working on and what the actual answer was for that portion of the activity. It was as if the rules and values for engaging in this example of the central activity system were different among the community members. Kyle's view was that correct answers aren't as important as the bigger picture, while the students viewed the correct answer to be a priority.

To summarize the first example, Kyle's selection of and use of the technical tool (worksheet) as well as his identification of the lesson's success based on students' calculations indicates that the conflict persisted in this example. Based on this conflict, Kyle's future form activity system (*instructional goal*) includes mathematics used as tools to build conceptual understanding of concepts, but does not include some equations as mathematical models. Despite the conflict being present, Kyle was not aware of the conflict and so the central activity was not anticipated to transform and expand Kyle's *instructional goal* to include equations as mathematical models.

Example 2: Population Density

To place the following three examples in context, it is important to point out that the "lesson" described here from Kyle's perspective had three parts. The Population Density example and the related series of teaching actions were within part 1 of the lesson. The next set of actions associated with the example Mathematical Models occurred within part 2 of the lesson. The third part of the lesson involved students creating a poster of an ecosystem and their own hypothetical mathematical model to represent the ecosystem before and after a disturbance to the ecosystem. This is the fourth example, Models of Disturbances in Ecosystems.

The central activity system represented by the Population Density example occurred during the second period of a block schedule. The student learning event from the preceding period included a discussion of the impact of deer population on the ecosystem and a Misconception Check of various population concepts, such as growth curves, carrying capacity, food webs, and biomass. Kyle started the lessons with students spending time on the concepts of population attributes and then followed those concepts with mathematical calculations of some of these concepts, which was the focus of the next example's set of actions.

Kyle established an object for students to use "mathematics as an appropriate vehicle to find estimates or to understand changes in an ecosystem, so hopefully they will be able to tie in mathematics utilizing appropriate mathematics to understand the dynamics in play in an ecosystem" (p. 1, pre-observation 2 interview). He shared this object with students prior to the start of the lesson. This example included students rotating between five different stations. Each station presented a scenario with data and questions. The questions required the use of simple mathematical routines to quantify attributes of a population (e.g., density, species diversity, per capita rate increase, etc.). As students rotated through the stations, Station 1 seemed to cause the most confusion and questions. Question 1 asked about the population density of sheep on the entire island, and question 2 asked about the density of sheep for the grassland area, where the sheep live. The actions below are representative of the interactions between Kyle and the students who asked questions about Station 1. Action D was related to question 1, and Action E was related to question 2. Action D and E were the same group of students. Similar to the first example central activity system, the actions selected occurred in a series. For each action the conscious purpose was associated with the question the students were answering at the station, but Kyle was aiming toward the overall object of the use of mathematics to characterize population attributes.

Action D

Student (male): For number 2, are they asking for sheep or all of the animals in general?

Kyle: What is the initial population density for the sheep population on the entire island? So you are going to take the total number, adults and juveniles add it together.

Student: Divide by 3,840

Kyle: The number of acres, right, which is 3,840, and you're going to get… that number is going to tell you a population density which is telling you how many sheep per acre.

Student: Do you multiply that by 100?

Kyle: You would add the total number of sheep, divide it by the acres and that tells you how many sheep you'd find per acre. That's a population density.

Student: That is less than 1 though?

Kyle: It is, but that is important data. Population density are important, even if it is per acre, even if it's a decimal it's still a number, so what's the number you get when you do that?

Student: Point 009

Kyle: That's right, point 009. So that tells you, I know that sounds weird that you have 0.009 sheep/acre on that island.

Action E

Student (same male): And for the second one, is it asking for the density of the grassland? Is it talking about the sheep or all of the animals?

Kyle: What is the population density for the grassland area only? [*reading from the station prompt*] So how many sheep divided by...in the grassland?

Student: They said the soil conditions are enough wheat to support 15 sheep per acre. They already gave us the answer.

Kyle: No, it tells you… it's going to tell you how many sheep are in the grassland areas.

Student: Cause there is 35 minus 2, so 33.

Kyle: So there are 35 sheep in the grassland area, how many acres are grassland?

Student: 3,000

Kyle: So there you go, 35 divided by…

Student: But it says that two died, so you subtract 2?

Kyle: No, take 35 divided by 3000. That will tell you the population density of the grassland area.

Student: Point 011 [*This is the correct answer*.]

Kyle: Point 0011 [*This is the incorrect answer*.]

Similar to the first series of actions in example 1, the object was the use of math to understand and represent ecosystem changes and dynamics, which Kyle selected in an attempt to move toward the future form of the central activity system. Figure 4.3 represents Kyle's central activity system for example two. He took the time to walk students through the calculations, although many times he set up the calculations for the students. For example, he provided students with the appropriate mathematical routine "35 divided by…" and "add the total number of sheep; divide it by the acres." In each of the actions, a student provided incorrect assumptions about the problem, one about subtracting the dead sheep, and another student assumed the answer should be larger, so he wanted to multiply by 100. Kyle made a decision at this point in time to not pause and explain why these assumptions were incorrect, but decided to move forward to get the answer. Kyle missed a teaching opportunity when the student was confused by the number being less than one. He could have emphasized the conceptual meaning of these calculations and elaborated on the connections to communities or ecosystems. Prior to this lesson, Kyle indicated that he continued to struggle with moving students past "simple calculations" toward understanding the meaning behind them and connecting them to dynamic living systems (pre-observation 2). He hoped at this point of the year (February) they would be able to achieve this. His actions emerged from this conflict between performing calculations and getting answers and the future form goal of using mathematics to understand and represent phenomenon. He aimed for this *instructional goal*, but his actions and decisions reflected his actual or current central activity system, often focusing on calculations and answers.

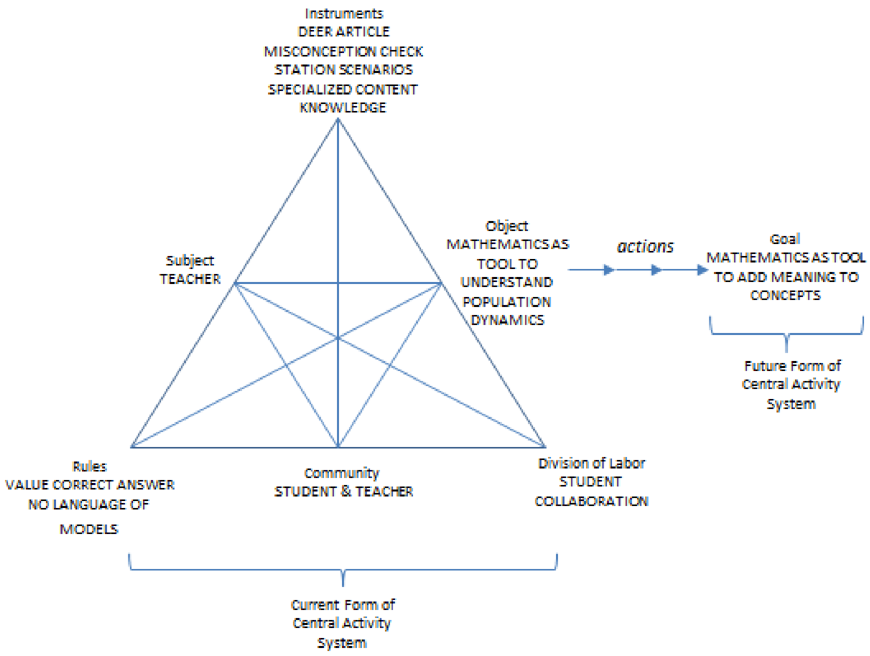

Figure 4.3. Example 2 Kyle's Central Activity System

The actions in this example were facilitated by the Station Scenarios tool (technical) as well as Kyle's specialized content knowledge (psychological), which included recognition of errors and the connection between the mathematical routines, representations, and concepts. Kyle selected the Station Scenarios tool to achieve the object. The technical tool itself facilitated the student outcome of a variety of mathematical calculations that represented population characteristics, but some stations did not facilitate the conceptual connection of these mathematical routines to ecosystem dynamics. Question 1 in Station A provided a realistic scenario and opportunity to calculate population density in terms of the whole island and the grassland area. However, after the students completed the calculations, students' conceptual meaning of these numbers was not facilitated. They were not asked to compare these two densities or explain how there could be 0.009 sheep. Kyle attempted to fill this gap in the tool by asking and alluding to a larger meaning, but he only referred to the units (sheep/acre) and left the fact that the answer was a fraction or ratio undeveloped. To several groups of students he asked, “What does that [number] tell you?” and he accepted as satisfactory students provided the unit or his own response “sheep per acre…so you have a fraction of a sheep” (p. 15, observation 2).

Since the tool itself fell short of facilitating student learning of the object, Kyle relied on his specialized content knowledge as a psychological tool to complete that facilitation. Specialized content knowledge also includes recognition of student errors or misconceptions. Kyle’s own errors, as well as lack of attention toward students’ errors, provided additional evidence of the limits of his specialized content knowledge. In Action E, Kyle’s answer to the problem was incorrect. He did not point out or acknowledge that his response and the student’s response were different. He moved on to the next group. Two rotations later, Kyle realized his answer was different from the response he received from students for Question 2. At another point, he asked a student “what does 0.009 mean” and, after a pause, he told her the unit. The student responded, “900ths of a sheep,” Kyle responded yes and moved on to the next question (p. 16, observation 2). Similar to the first example, Kyle’s specialized content knowledge did not consider some of the mathematical equations to be mathematical models. During the interview after this lesson, when asked about the authentic scientific inquiry associated with this lesson, Kyle responded that “I think it was more of a straight forward calculation…I don’t think that was actually authentic inquiry” (p. 2, post-observation 2). One of the students exhibited their confusion over the correct answer being a decimal (0.009), and Kyle did not elaborate on the meaning of the decimal or fraction. The unit was a ratio of sheep per acre that can be correlated, compared, or used as a tool to make predictions or explanations of population or ecological phenomenon. All of the characteristics of ratios as mathematical models were not communicated by Kyle. To connect the mathematical routine to the concepts, Kyle restated the units (sheep/acre). By simply saying those words “sheep per acre,” Kyle did not enable student understanding that the number functions as a ratio that can be compared to other ratios. Viewing these calculation results as models could have connected the math symbols, equations, and calculated results to specific concepts, relationships, and phenomena.

Similar to the first example, the language of models was not used by Kyle or his students, despite the object of the central activity being the use of math to understand and represent ecosystem changes and dynamics. At this point in the study, Kyle was not aware of this conflict, so equations as mathematical models were not a part of his future form activity system (instructional goal). In this example, Kyle experienced some challenges with enabling student understanding of how the equations represent the dynamics of the ecosystems. Based on the observed evidence, these challenges may also be an indication of gaps in Kyle's specialized content knowledge with respect to mathematical practices and more specifically, mathematical models. If the future form central activity system contained gaps in mathematical models, then shifting students toward math as a tool to represent and understand biology concepts may be challenging.

The lower components of the activity system model for this series of actions are also similar to example one. The students worked in groups to complete the calculations, with Kyle validating answers and answering students' questions as they finished the calculations. Kyle's role involved stretching student understanding toward the concepts associated with each calculation. The class as a whole did not use the language of models, representations, and mathematical symbols for the various calculations. Similar to the first example, a conflict existed in the priorities and goals of the students compared to Kyle's priorities and goals. They were focused on getting the right answer and not the conceptual representation of these calculations.

In summary, example 2 included actions that were oriented toward mathematics as a tool to represent ecology dynamics and relationships, which facilitated student meaning making. The Station Scenarios tool did place emphasis on the mathematical routines, but not enough on the object. Kyle’s specialized content knowledge as a psychological tool did not supplement student meaning making and appeared to have a gap with respect to mathematical models, which may have limited student achievement.

Example 3: Mathematical Models

As previously mentioned, this series of actions was part 2 of Kyle’s lesson. The series of actions below took place the next day after the Population Densities example, during the first part of the block period. The Population Densities example and the Mathematical Models example were within different representative activity systems because each example focused on a different object as a continuation of the class’s study of community interactions. The object for the central activity system of the Mathematical Models example was to use a research study as an example of real science related to community interactions and an example of the use of mathematical modeling.

This example of Kyle’s central activity system included a Socratic seminar where students read an article the night before the lesson. The article for the Socratic seminar was Carl Zimmer’s (2012) article on the University of Wisconsin-Madison’s study of Peter Lake. This article described how ecologists were using mathematical models to represent food webs. Each student was expected to come to the class with one or two valid questions or ideas that contributed to the discussion. The following actions took place in the middle of the class discussion. Prior to this part of the Socratic seminar students were discussing why the scientists would manipulate a real ecosystem without a control and the accuracy of a model of an ecosystem that was set up in the laboratory. The subsequent period of the block provided additional context, in that it was directed at the same object of mathematical models of community interactions. The students studied an ecosystem and created their own hypothetical mathematical model to represent the ecosystem before and after a disturbance to the ecosystem.

Action F

Kyle: So just to get off on a few of you guys with these comments about… thought it interesting that they would do this in an actual lake, could we use models in the classroom, could we do that? And you know just on a personal note, you know this classroom is ever changing. One of the things, one of my goals was with zoology last year, was to set up model ecosystems of fresh water lakes, rivers, swamps and what I tried to get the students to realize is that all of that probe wear we have with dissolved oxygen and pH and temperature, could they get how many factors there are in that outside world that we can't simulate in a classroom or a laboratory setting.

All right, let's talk more about these mathematical modeling tools, some of you have comment on how they do these mathematical models?

Student: Well I was going to say like I thought it was cool where they said like the weak links.

Kyle: Yes.

Student: Still have a big part in like the food webs, because like over time they like, they link predators together and …

Kyle: Yes, they were mentioning something about these weak links and basically those are a little more, have more of an influence if you will, on some of these food webs than all the other things combined. Okay Devon.

Devon: Through the mathematical models they are writing "an equation for the growth of one species by linking the reproduction rate to how much food they can obtain how often they get eaten" [*quoted directly from the article*]. That's pretty much what it says. But also it keeps talking about how the variables keep changing so it's kind of hard to have accurate data?

Kyle: That's a good point.

Student: But due to computers they are able to do it more

Kyle: Computer is definitely, as a tool. Okay? But one very interesting thing especially in biology, we take you know, we take math courses and we take these classes in statistics and AP. AP statistics or what we call bio statistics or biometry later on maybe in graduate school, but one thing you have to consider when you run these statistics is that, like Devon said there are so many other variables that change and that can change when you just put in you know pieces of data, other things you have to consider, Ethan?

Ethan: Mathematical models are important because they can help you think about the ecosystem changes and what caused it.

Ethan: You know science like.

Kyle: Yes.

Kyle: And that's why I guess the holistic picture of this whole thing is predictions. Because if we have mathematical models and we can show this and make these predictions from what's going to change in this food web, what he said is now, we can put in place, some, we call these sometimes environmental mitigations. We can mitigate the problem and show, hey if we do this, now let's look at what happens in this food web. Tamara?

Tamara: Because like in the mathematical [pause] model.

Kyle: The model.

Tamara: Whatever, yeah, the variable points in the food web can change, like the small ones can change and affect the whole, like the bigger picture of the ecosystem.

Kyle: So you say that like they'll have a much bigger effect, like one little small component has a much bigger effect on the entire thing. Like one little miniscule thing could have such a drastic effect on that mathematical model. But then that tells us what? What we need to focus on.

Tamara: Is the smaller …

Kyle: Is maybe those smaller weak links.

Kyle: Yes and it is little, sometimes those little things might be microscopic. Sometimes they might be like something you see like a gopher tortoise here in Florida, key stone species, so those things like that sometimes having a much greater effect when you alter their numbers in some way for the entire food web itself. Okay Tyler did you have, I thought this table had something.

Action G

Tyler: I am just adding on things like whole point of predicting, they said it was hard, once it changes, to get back to how it was.

Kyle: Right, the prediction model and how this actually is used as a predictive thing and how it's, and the other thing you have to say is, okay the mathematical models what we always talk about with math is okay it's math it's absolute. That's the way it is let's go fix the problem. Is that exactly accurate? To say that if we put this data into a mathematical model, this mitigation or how we fix this is definitely going to restore this?

Students: No.

Kyle: No and why not?

Tyler: There are so many changes available.

Kyle: Think that's coming back to like we said, Devon said and Tamara and Valerie, there are so many other variables which come into play, which is why it comes back to whatever it originally said putting these, making models, it would be interesting if we could put these models in a laboratory setting if you will, and study them there. That's sometimes difficult because of all the parameters and the things that are in that natural setting that we cannot simulate exactly, but we can still use them.

Okay I understand, they are important you have to see both sides of this because they are both used and they are sometimes pretty darned accurate these mathematical models, but you have to consider, you can't just go in you have to consider much more about the community. James?

James: I was just going to say that like the microcosm models can be useful even though they can't pick up all the variables, they kind of get you to a hypothesis.

> Kyle: There you go and that is the thing, they can get at least they'll give you some directions as to where to head okay, somewhere where to go.

For this example, the object of the central activity system was to use a real world science study of community interactions as an example of how mathematical modeling is used to represent ecosystem dynamics. Figure 4.4 represents Kyle's third example of his central activity system. This consecutive series of actions captured Kyle's *instructional goal* related to mathematical models as simulations, which is an extension of his aim to build students' understanding of the meaning of their answers to mathematical equations in a dynamic living system. Kyle's actions emerged as he attempted to close the gap of students' abilities to connect mathematical answers to dynamic living systems. The division of the different actions was based on the conscious purpose of the action. Action F focused on the use of the mathematical models to represent weak links in the ecosystem and the variables of the ecosystem. The purpose of mathematical models to make predictions emerged from the discussion and Kyle's actions in Action G. Both of these purposes behind the actions F and G were important toward gaining an understanding of actions and tools directed at the object.

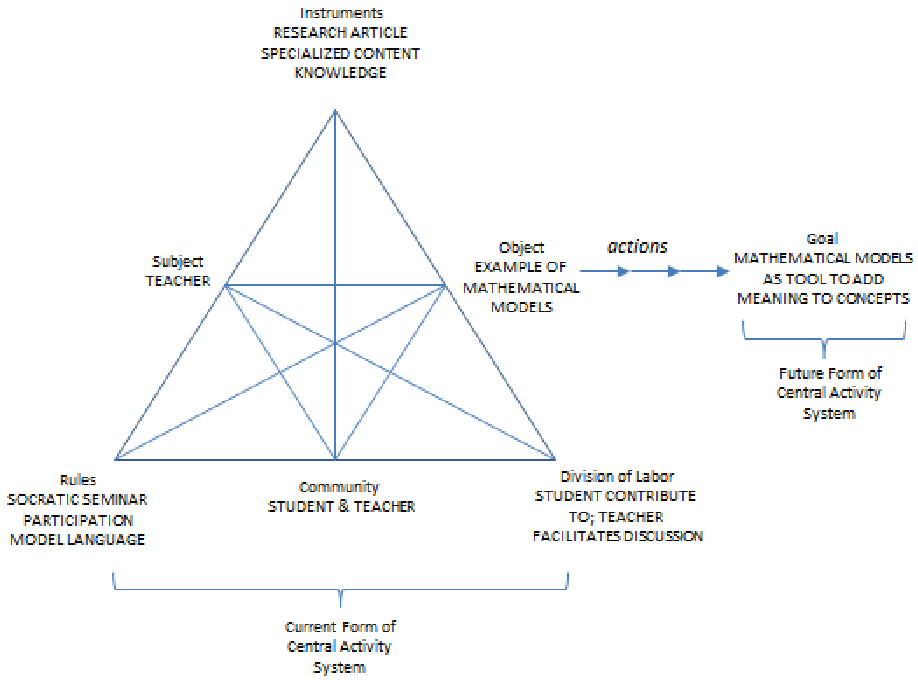

Figure 4.4. Example 3 Kyle's Central Activity System

Given these two different purposes, it was Kyle's actions that tied the discussion together into a coherent high level view of mathematical models, and therefore, mediated students toward the object of the central activity. In Action F, the discussion included a student mentioning weak links as a variable and a separate, not necessarily related consecutive comment, about the actual equations of the model and how variables keep changing in the ecosystem. After each student's comment, Kyle took action to direct the discussion back to some aspect of mathematical models. The purpose of Kyle's actions were not pre-planned, they emerged and were facilitated by Kyle's desire to overcome the conflict - to connect mathematical answers to dynamic living systems. Given this conflict, I anticipated that Kyle would directly address Devon's quote from the article, "an equation for the growth of one species by linking the reproduction rate to how much food they can obtain how often they get eaten." His response validated the point, and after the comment about computers, he focused on the inexactness of models because of changing variables.

For the series of actions included in Action G, Kyle used a student’s mention of predictions of irreversible effects on ecosystems to direct the discussion toward the purpose of models as tools for making predictions and the accuracy of those predictions. He connected the perceived “absolute” and exactness of math with the inexactness of models to offer solutions. At the end of this example, he also tied in the model’s role in providing direction through a hypothesis. In this series of actions, he weaved together the purpose of models to make predictions and hypotheses and the precision of modeling with the impact of other variables of the model. Kyle’s actions were directed at giving students a conceptual sense of the use of mathematical models in ecology – the object of the central activity system.

When analyzing Kyle’s actions against the full activity triangle model, the Zimmer (2012) article was only a part of the tools used to facilitate student meaning of mathematical models. Kyle’s specialized content knowledge contributed significantly to student mediation toward the object. The article was a technical tool that provided students with a concrete ecological phenomenon represented as a mathematical model, giving students necessary prior knowledge and terminology to engage in the discussion. Kyle’s specialized content knowledge of mathematical models as simulations helped him to interpret the various, disjointed comments made by the students as they contributed to the discussion, and connected them back to either a feature of mathematical models or the purpose of the models. He connected students’ comments about weak links, changing variables, and computers as tools into a statement about the need to understand the variables when interpreting the results of the data put into the computer model. His decision to connect the models to “absolute math” also provided evidence of this unique form of subject matter knowledge. Individuals who know how to break down, connect, and provide examples of science practices, demonstrate their specialized content knowledge, a form of knowledge unique to teaching.

This third example is different from the previous examples in terms of where Kyle placed his instructional priorities and the reliance on Kyle's specialized content knowledge. Throughout the discussion, Kyle made decisions to put some of the ecology concepts in the background, and instead, foregrounded the high level appreciation of mathematical models as tools to understand the dynamics of living systems. The previous example relied heavily on the technical tools of worksheets to facilitate student meaning, and not as much on his specialized content knowledge. This reliance on Kyle's specialized content knowledge in this third example was essential for moving students toward the object of the central activity.

Analysis of the lower portion of the activity triangle provided insight into the classroom community that contributed to student meaning making toward the object. Each student that contributed to the discussion participated as a member of the community, presenting ideas, and using language that contributed to the greater understanding of the community. This lesson demonstrated the situated and social nature of knowledge and learning, each student contributed ideas which were molded together by Kyle to shape the meaning. Kyle's role within the classroom community as expert member inside the periphery of the community facilitated the discussion and moved the community toward the object. The article Kyle introduced to the classroom community provided language such as mathematical models, models, variables, predictions, and accuracy. Students attempted to use these terms and some of these terms took root into the community dialogue and appeared again in the subsequent poster project. Kyle's role was facilitator, and he mediated all comments back to the object of the activity. This central activity system best demonstrated the division of labor in this classroom, and Kyle's role as "weaver of the story" facilitated the central activity system toward the object.

Example 4: Models of Impact of Disturbance on Population

This example was part 4 of Kyle's lesson after students completed the Socratic Seminar of example three. The object for this example central activity system was to design an experiment to study an ecosystem disturbance and use a mathematical model to represent an ecosystem before and after a disturbance. The following actions took place during the second block of the period. In groups, students studied an ecosystem using different text resources and created a poster that contained information about the ecosystem, an experimental design and their mathematical model. The actions below occurred when Kyle introduced this portion of the lesson and the guidelines for the poster. Action H was when Kyle showed the students an example of a mathematical model used to study impact and possible mitigation of blast and cyanide fishing. Action I included Kyle's summary of the research and use of the mathematical model. Action J was when Kyle described the expectations, essentially describing the student outcome, for the mathematical model portion of the poster. After this series of actions, the students worked in groups researching the ecosystem and creating the poster.

Action H

Kyle: This is, these are some various models that were used, [*holds up an article with STELLA models in it for all students to see*] I'm not going to pass this out. I am not passing the models out today. We'll look at these later. But there are various models that can be used to create these like we are talking about these mathematical models that can be used to make these predictions and form, help us to formulate mitigations. One of you guys will have coral reefs today, because that obviously is a Florida ecosystem. And this one is done about coral reefs.

Action I

Kyle: So their idea, just as a round about to give an idea, they set up, they thought that basically, this is a mathematical model a representation of one hypothetically showing us what would happen. You know, if the destruction rate and with the cyanide and blast fishing what would happen with coral reef. And they could actually input this data if you will, into certain computer programs or mathematical models, and they could predict in graph what would happen to coral reef communities over a period of I believe this one is over 50 years. And those results look pretty scary. You can see obviously what's happening there to these coral reef communities over 50 years *[continues to hold up the article with the STELLA models]*.

One thing, James said is sometimes we can use some of these models to maybe give us direction on how to implement a change to get this community back. So what they've done in this mathematical model is they've implemented these MPA's, okay? [*he continues to describe Marine Protected Areas*]

And then they made a prediction on what would happen to these coral reefs, and you get a little better news. [*Kyle continues to hold up the article with the STELLA models*] I know this is hard to see, and I don't want you to memorize it, because you are going to have to come up with some of these models today. But basically over time, the coral reefs basically, it's saying about 20% of the reefs will be left. So it gives them direction, and then they have a third model they constructed where Marine Protected Areas are increased and if you increase those MPA's, in other words you add on you are actually going to it says within approximately 31 years the amount of coral reefs could up to double within the protected areas.

Action J

Kyle: Then what I wrote [*in the guidelines*] is, describe specifically what populations will be affected, describe why they are affected, and then this is where you become the scientist. Set up a scientific investigation on how you are going to determine the extent of the damage, describe the details of the investigation in the laboratory, outside the laboratory. Include what would be tested in the field and we said that give hypothetical data. In other words you can give some population density numbers that are hypothetical you can make those up in your study, give your results, come up with it, based on all these fictitious data, come up with an environmental mitigation, a plan to fix it now and then use the example of a model just like I showed you with coral reef model or like without our mitigation this is what would happen sketch it out. With our mitigation this is what would happen based on

> a mathematical model. Before and after the proposed mitigation and you will represent that model with a sketch.

The object for these actions was for students to design an experiment to study an ecosystem disturbance and use a mathematical model to represent an ecosystem before and after a disturbance. These actions provided more detail of Kyle's central activity system that aimed toward his mathematical model *instructional goal*. As a whole, this series of actions described how Kyle established the expectations for the mathematical models in the posters. Actions H and I were directed at the purpose of providing an example of a real mathematical model to set expectations. The purpose of Action J was to directly tell students the expectations for the poster by clarifying the guidelines he provided students. In Action H, he decided not to provide students with examples of a STELLA model, but instead decided to describe the research and models at a high level. In his description he presented the general mechanism for how data and mathematical models work together to produce a prediction, "they could actually input this data if you will, into certain computer programs or mathematical models, and they could predict in graph what would happen." He also connected this mechanism back to the population dynamics of example 3 by characterizing population density as data that could be inserted into the model and then sketched out the model on the poster.

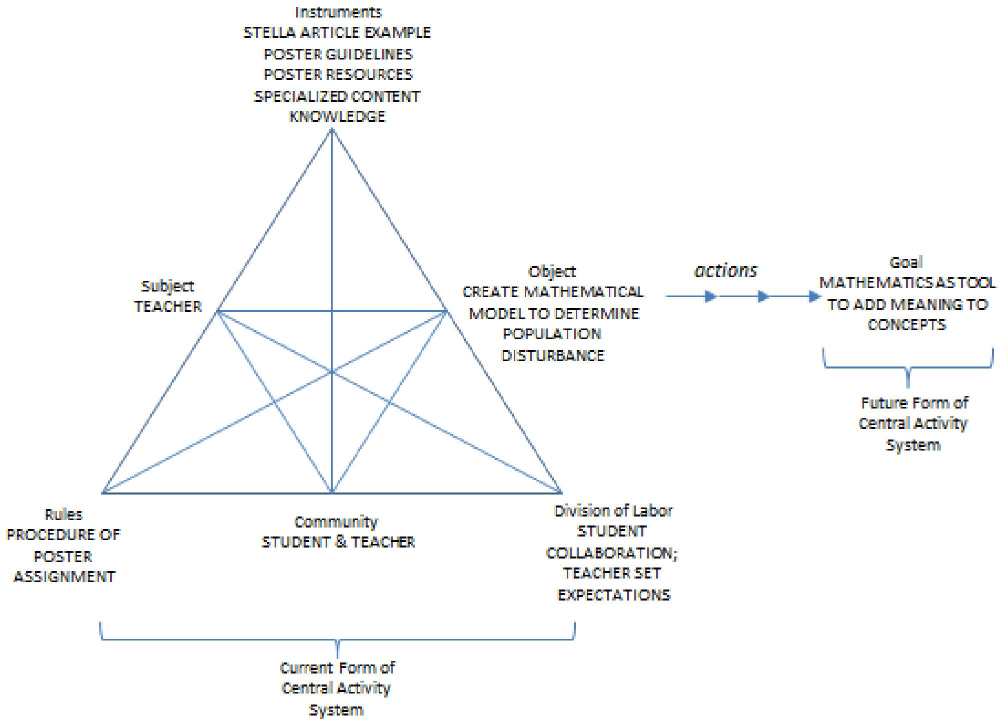

Figure 4.5. Example 4 Kyle’s Central Activity System

When analyzing Kyle’s actions against the full activity system model, Kyle introduced a new technical tool into the central activity system, the article that included the STELLA models. However, his actions did not effectively use the tool to facilitate learning. He relied on his specialized content knowledge to describe and elaborate on the example and to make the essential connections that he deemed crucial to achieving the outcome. His specialized content knowledge was reflected in his simplified description of the mechanism of using mathematical models and his connecting the hypothesis of the MPAs to the resulting mathematical model to support the hypothesis. His descriptions of the study’s use of models were kept at a high, conceptual level. In Action J, he referred to the exemplar models he showed and described them as a means of clarifying the expectation for the task. This action did not provide further clarification on the mathematical models expected on the poster. They were kept at a more abstract level.

When analyzing Kyle’s actions against the lower portion of the activity system model, the community context appeared to have clear roles and division of labor. Kyle’s role was to set the expectations and give directions to students, while the students were expected to work together to generate the final work product. The students immediately formed into groups and started creating the posters, asking some clarifying questions. Kyle’s action to not show the exemplar models could be analyzed from the community perspective. Perhaps a culture exists of memorization or copying of answers that Kyle anticipated, which impacted his actions. There isn’t sufficient evidence to support this interpretation, but his actions could be interpreted through that lens.

During reflection on this lesson, Kyle became aware of another contradiction within his existing central activity system. In the interview after this lesson, Kyle reflected that he expected students to create a STELLA type model in the poster, but the resulting student artifacts (Figure 4.6) included the data represented in a graph. He reflected that his actions did not lead to attaining the lesson object. This lesson was the students first time working with mathematical models. They had never done the “input of numbers, but we’ve talked about modeling when I do any” (p.10, post-observation 3). He also stated that he should have projected the STELLA models and included more background on how mathematical models could be used. He believed the detail was not at the appropriate level. He should have included how the computer programs work, how the numbers are plugged into the programs, and what the numbers mean when they come out of the program.

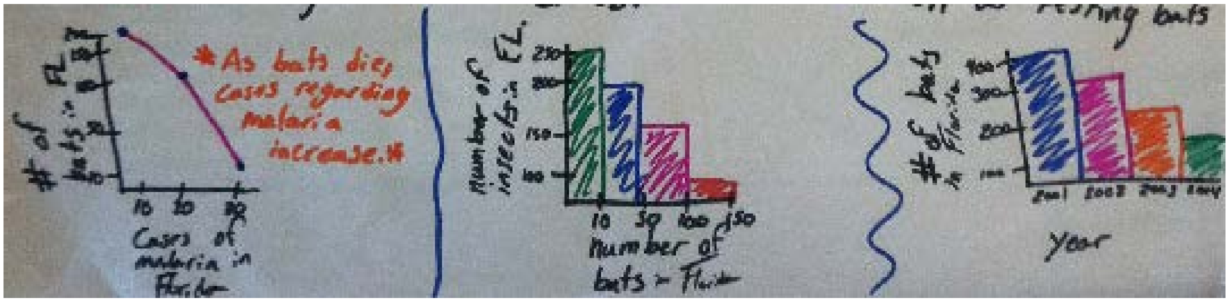

Figure 4.6. Student artifact of the mathematical model

This contradiction appeared to be a secondary level contradiction between the object and Kyle’s psychological tool of specialized content knowledge (SCK). Kyle set the object to be student creation of a STELLA mathematical model based on his *instructional goal*. This goal appeared to be at a superficial level. He reflected that he struggled with knowing how to measure their understanding of mathematical models and knowing what that understanding looked like. In the observed actions of teaching, Kyle’s specialized content knowledge of mathematical models as simulations was also at a high level and simplified. He did not clearly break down how to create a model or know how to effectively use an example of a model. He considered population density to be the data input into a model and the outcome of the model to be a prediction in the form of a graph. Given that the student posters included graphs as the model, Kyle admitted that he “didn’t know where they were at” in their understanding of mathematical models (p. 10, post-observation 3). He believed they understood them conceptually, but they did not know mathematical models in more depth. Based on Kyle’s description of expectations, classroom actions, and reflections, Kyle continued to have gaps in his SCK of mathematical models as simulations and mathematical models as equations. This gap in SCK would indicate the depth of the gap of his *instructional goal* as well. Perhaps this recognition of a contradiction served as a reflective event that stimulated awareness of this contradiction and will lead to closure of this gap within his *instructional goal*. There was insufficient data in this study to determine whether

Kyle became aware of this conflict and during future instruction attempted to resolve the conflict.

Expansive Cycle Description of Kyle's Learning

The previous sections described Kyle's series of actions for four examples of the central activity system, and an interpretation of these actions, along with the nature of the conflicts through the lens of the activity theory model (Engestrom, 1987). The next step is to analyze the transformation of the central activity system (learning activity) in response to the primary contradiction through an expansive cycle that cuts across these four examples. The contradiction was between his current activity system, which included math computation, and the intended future form of the activity system, which emphasized the meaning of and connection of mathematics to phenomenon and other areas of the course (Kyle's *instructional goal*). This recognized gap was the motive for Kyle's learning. To transform the central activity system, Kyle should learn what actions, instruments (both technical and psychological), and community culture were needed to achieve the instructional goal. Kyle's awareness of and reflection on this conflict was a critical part of the expansive cycle that transformed the central activity system. The description of an expansive cycle is based on Kyle's actions, components of the central activity system, and his reflections on his AP Biology teaching. Transformation of an activity system is fluid and occurs over a period of time. Since Kyle's learning did not begin with the start of the study, the description can only include a small portion of Kyle's larger cycle. The next section includes an exemplary, in-depth analysis that includes his internalized mental model and then his multiple attempts at externalization as he consciously attempts to address the conflict.

Internalization. An expansive cycle is initiated with an early emphasis on internalization, which is the socialization and appropriation of the future form of the activity system (Engestrom, 1999). This study does not capture Kyle's full internalization process of AP Biology's goal of science practice. This process was most likely initiated when Kyle first received training and materials that described and explained the revised AP Biology course and its goals. The process continued as he discussed the goals with peers. The study also assumes that at the moment of his initial exposure and learning about the new AP Biology course, Kyle had a reflective event that established his interpretation of the AP Biology course goals, and therefore, his *instructional goal* for his course.

Based on interviews described in the previous sections, Kyle's internalized model (*instructional goal*) of the mathematical practices of the AP Biology course goals included the expectation that students would perform the simple, straightforward calculations associated with concepts, such as water potential and free energy. His model also included students connecting concepts to the phenomenon and mathematical models as simulations. He ultimately would like the mathematics to contribute to the abstract evidence of a phenomenon so students can visualize concepts at the molecular level (p. 7, pre-study interview).

Based on early observations and interviews, there were aspects of the AP Biology definition of mathematical practices that were missing from Kyle's internalized model and therefore his *instructional goal*. To highlight these missing aspects, while describing the transformation of the central activity system, I am focusing on Kyle's use of mathematical models. Kyle's internalized model considered mathematical models to be a hypothetical scenario that uses mathematics to represent or simulate changes (post-observation 1 interview). As the previous central activity system examples demonstrated, Kyle did not consider equations such as

Gibbs Free Energy or equations associated with population dynamics to be models. He also had a more superficial understanding of mathematical models as simulations and the relationship of simulations to equations. In comparison to the AP Biology goal of mathematical practices, Kyle's internalized model at the onset of the study did not include a complete definition of mathematical models. The emergence of a contradiction and a reflective event are needed to stimulate internalization and adjust his internalized model.

Externalization. Internalization leads to externalization as the subject attempts to resolve these disruptions or contradictions. Eventually, transformation of a central activity system occurs through production of new objects and instruments and through actions that target the contradictions with the existing activity system (Engestrom 1987, 1999). The four examples of the central activity system described in the previous section also provided evidence of Kyle's externalization within an expansive cycle as he attempted to expand his AP Biology teaching (central activity system) toward the future form of the central activity system. Kyle externalized his mental model by creating an object for the first example activity that focused on the connections of the concepts of Gibbs Free Energy to the bigger picture. He also selected a worksheet (instrument) that broke down each step of the calculations and asked students to make delta G predictions about biological processes, such as photosynthesis and cellular respiration. Kyle's actions to rush through calculations in order to discuss the connections to the bigger picture were also evidence of his externalization.

Kyle's externalization attempts did not result in a resolution of the conflict. Based on Kyle's planning, his desired outcome was for students to have an understanding of what the equation represented in biological systems, but after the lesson he considered the outcome to be met because students could complete the calculations (post-observation 1 interview). It is as if his conscious actions were toward the future form object, but when considering student success his more operationalized, existing activity system predominated, demonstrating continued evidence of the conflict. If a reflective event does not alert Kyle to this conflict, then the gap goes unnoticed and does not become a motive for Kyle's continuing expansive cycle (Engestrom, 1999). Kyle's additional reflection after the lesson recognized that the conflict of achieving a conceptual understanding through math routines still existed, and he needed to spend time making more connections of concepts to the equations (p. 1, post-observation 1 interview). This reflective event adds to Kyle's internalization of the future form of the activity system. As the expansive cycle continues, internalization starts to shift from socialization to self-reflection (Engestrom, 1999). During reflective events, the subject internalizes and adjusts the mental model. Through additional internalization, the gap identifies what is needed to transform the current activity system into the future form. So Kyle's additional attempts to externalize and resolve the gap with the future form occurred during the second, third, and fourth examples of central activity system.

It is important to note that the previous reflective event may not have occurred if Kyle was not being interviewed by me. Socialization is a significant part of the initial part of internalization. It is feasible to believe that I played a role in Kyle's socialization during internalization. This socialization is important. Similar to student learning, teachers as learners through their practice also require the support of an expert member of the community they are on the periphery of entering (Lave & Wegner, 1991). Engestrom (1994) refers to a "*context of criticism*" [italics in original] at the beginning of an expansive cycle, a critical stage where the subject becomes aware of the conflicts at the core of his/her practice, which lays the groundwork for new forms of practice. During this phase, it is important for the subject to have support and honest feedback to recognize the limits and contradictions of his/her practice. This idea of appropriate support for teacher learning will be explored in the discussion section of this paper.

Transformation of Kyle's Activity System

The detailed description above of Kyle's internalization and externalization through his established object, selection of tools, actions, and intended student outcomes in example one captured only a portion of the expansive cycle. Examples two through four provide additional examples of Kyle's externalization and reflective events of internalization. Upon analyzing all of Kyle's observed attempts at externalization and his internalization through his classroom practice and reflective events, Kyle's central activity transformed. Kyle's desire to shift the central activity away from calculations and plugging numbers toward seeing mathematics as a tool and way to represent phenomena progressed toward his *instructional goal* of mathematics as tools. However, Kyle's *instructional goal* with respect to the types and details of mathematical models as simulations did not transform beyond his current activity system and the initial need state that brought awareness of mathematical models. His *instructional goal* did not include some equations as mathematical model or more details about mathematical models. A gap between Kyle's existing central activity and the AP Biology course goal exists because Kyle continued to be unaware of a more defined, secondary contradiction.

The previous section also described the comparison between example central activity systems in detail in order to demonstrate the type of analysis involved when determining transformation of activity systems. The next section describes Kyle's observed expansive cycle for both aspects of his transformed activity system, but not at the same level of detail.

Kyle's transformation of the central activity system took place over a series of four different examples of the central activity (Table 4.2). The first example was guided by the object to build students' understanding of the Gibbs Free Energy equation and what this equation represents, connecting the molecular level of energy to the bigger picture. This object had two parts, the understanding of the equation and the conceptual connections of the equation. At the completion of the example, Kyle reflected on whether students met the intended outcome.

Table 4.2. List of Example Central Activity Systems

Example	**Object of Activity System**	**Technical Tool of Activity**
1	Understanding and meaning of equation	Gibbs Free Energy worksheet
2	Use appropriate mathematics to understand population dynamics	Population Stations – Apply Math to Community Interactions
3	Example of how to use mathematical modeling	Socratic Seminar with Research Article
4	Design experiment to study ecosystem disturbance and use mathematical model to represent ecosystem before and after disturbance	Ecosystem Disturbance Poster Guidelines

He felt the students could calculate, although there was some confusion on this, but were hesitant with answers to conceptual questions. To resolve this he said he would need to walk students through equations and spend more time on the conceptual connections during the activity as well as drawing those connections through the rest of the biology course (p.1, post-observation 1). Subsequent examples of Kyle's central activity demonstrated actions and externalization toward this recognized gap to reach the *instructional goal* of mathematics as a tool. During example 2 Kyle spent more time prior to the student station activity elaborating on and reviewing the concepts related to population dynamics. He reviewed the concepts, discussed an article about the impact of a growing deer population, and had the students complete a Misconception Check (instrument) to determine where they were in their understanding. While students were calculating population density, he probed their conceptual understanding instead of waiting toward the end of the lesson to pull it all together. When he reflected on example 2, he said to extend their conceptual understanding further he would want students to design scientific experiments that could use the population numbers (p.2, post-observation 2). Example 4 included that object – students were expected to design an experiment to study ecosystem disturbance and use a mathematical model to represent ecosystem before and after disturbance. His externalized selection of tools and actions toward the math as a tool goal were also presented during example 3, when Kyle spent classroom time discussing at a high level mathematical models of ecosystem variables and changes as well as the model's purpose. He didn't elaborate on and try to use the equations of population growth and specific feeding relationships or have students reconstruct and calculate the model first before moving to the conceptual connections.

Overall, Kyle's central activity system transformed with respect to the object, actions, and technical tools aimed at Kyle's *instructional* goal related to making calculations and connecting the concepts and the phenomena. The concepts represented by the mathematics were as equally important, if not more important than the calculations themselves. Kyle's selection of technical tools gradually shifted to focus more on the concepts represented by the mathematics and less about the calculations. Over time his actions prioritized classroom time on the concepts associated with the mathematical equations and eventually mathematical models as scenarios of phenomenon. The objects of each example externalized the reflection internalized from the previous example, actively moving the central activity system toward the future form of the activity system. His reflection after example 4 presented another contradiction related to students drawing meaning from the equations and models they use. This event should motivate Kyle’s central activity to continue to transform. Transformation appeared to have occurred at a superficial level, but these actions ultimately need to become a part of Kyle’s instructional practice as a new central activity system. Kyle’s externalization of this conflict will continue as his practice shifts from conscious actions to more operational actions that become a tacit part of his practice and a new activity system is established (Leont’ev, 1978).

Community expansion. Kyle’s transformation of his activity system with respect to math as tools does not involve a complete expansive cycle. Given the limits of this study, it was not clear whether Kyle’s transformation resulted in a closure of the gap and the reflective event initiated another expansive cycle. Theoretically, based on CHAT’s model of expansive cycles, over the rest of the year, even into the next year, Kyle could continue to externalize his mental model as he persistently attempts to resolve the conflict as well as any conflicts that emerge throughout this process. The creation of new artifacts and actions as a part of externalization would continue until the gap no longer existed, and another expansive cycle began as a conflict was recognized and internalization of a new future form begins. The initial part of an expansive cycle is socialization at the individual level, but over time, as all individuals wrestle with the conflicts, and generate artifacts and share those artifacts among the micro-community the micro-community as a whole shifts. Then the central activity system of the community transforms beyond the individual level (Engestrom, 1987). However, the critical part of continued movement of the central activity system and repeated expansive cycles is an individual’s reflection on the classroom action and social interaction or cognitive awareness to recognize conflicts within the central activity system. This social support and conflict awareness is what Vygotsky termed zone of proximal development (Engestrom, 1987). As mentioned previously the AP Biology course goal of mathematical models was within Kyle's zone of proximal development. His internalized model reflected in his *instructional goal* and therefore his central activity system included an understanding of mathematical models as simulations but a narrow definition of what equations are considered models. To initiate or continue his expansive cycle what he requires is awareness of the conflict of his specialized content knowledge. This awareness may start through social interactions and support, but eventually his personal reflective practices will continue the expansive cycle moving his central activity system toward the reform oriented central activity system.

Kyle's Practice that Did Not Transform

Kyle's *instructional goal* with respect to the types and details of mathematical models did not transform beyond the initial need state that brought awareness of mathematical models. Kyle's *instructional goal*, established during internalization after his primary contradiction, when compared to the AP Biology course goal, had a limited definition of what equations are considered mathematical models and the specifics of how to create and use mathematical models as simulations. Kyle was unaware of this gap, so it was not included in his *instructional goal* and therefore also not part of his SCK. However, these gaps in SCK and the *instructional goal* may eventually lead to the emergence of contradictions, especially if they impact student achievement of outcomes. If students do not meet an intended outcome, then a chain reaction of events could occur. The teacher may have a reflective event, which may result in a conscious contradiction; both of which are a significant part of teacher learning.

Gaps in SCK. Kyle's specialized content knowledge was a narrow tool, which impacts student meaning making. Evidence of this impact was presented in example 4, when Kyle's students did not produce the STELLA mathematical models he expected. Walking through the pieces of information the students would need in order to achieve Kyle's expectations helps to further reveal the gaps in Kyle's SCK. To create these STELLA models students would need to know the specific equations associated with the population characteristic they were using to represent their metric for determining impact of disturbance on the population. They would also need to be able to make assumptions about the variables associated with these equations. They would need to know what each variable of the equation represented in the population/ecosystem they were modeling. For example, a student who wanted to represent shifts in population density due to a fire would need to know how to mathematically represent population density, the variables impacting population density, and the relationships among these variables. Population density would be a part of the model instead of input into the model. However, these actions, using his psychological tool of mathematical models to facilitate student learning, did not occur because Kyle's specialized content knowledge of mathematical models did not incorporate "formulas," both Gibbs and population density, as models.

Impact to student outcomes. These gaps in Kyle's SCK impacted student learning outcomes. After examples 3 and 4, he reflected that he should have spent more time showing students how variables are represented in mathematical models and what the resulting number of the equation means (p. 9, post-observation 3). The extra steps he proposed would not be necessary if he included the equations students used in the population station activity (example 3) as mathematical models of characteristics of populations. During the station activity students would have been exposed to the equations and their answers would be enhanced if they saw them as models and described the variables and the relationships of those variables through the equation and population being modeled. He could have facilitated students' understanding to meet the desired outcome of mathematical models in example 3 by helping them draw connections between the models of central activity 2 and the ones from the article in central activity 3. In the end his specialized content knowledge facilitated student meaning making for high level understanding of mathematical models as simulations, but not the depth of mathematical knowledge needed to achieve the student outcome.

Reflective event. These gaps in SCK and their impact on student learning are a significant part of teacher learning. During example 4 a second level contradiction emerged between Kyle's object and his specialized content knowledge. His existing central activity system facilitated by his specialized content knowledge did not produce the outcome Kyle intended. Kyle's description of his expectations for the mathematical models in the posters resulted in students producing graphs instead of STELLA type models. Based on the observations and interviews, Kyle's internalized model did not appear to connect mathematical model simulations with equations. He interpreted population density to be input into the model rather than being a part of the model. Kyle was not aware of this secondary contradiction in his activity system involving his specialized content knowledge. The fact that his students did not meet the intended outcome triggered a reflective event, which will hopefully make the contradiction conscious and initiate another expansive cycle. The reflective event after example four alerted Kyle to contradictions in his existing activity system. Based on the interview data, it was not clear as to whether Kyle's reflective event resulted in an awareness of his gap in specialized content knowledge.

Awareness of contradiction. The key driver of transformation of an activity system is an awareness of a conflict and conscious actions during the central activity to resolve that conflict (Engestrom, 1987). As previously mentioned Kyle's existing central activity showed evidence of progressing toward the instructional goal of mathematical practices with respect to mathematics as tools to concepts. He was aware of this contradiction and was actively attempting to resolve it. Kyle’s awareness of a limit to his specialized content knowledge of mathematical models was not conscious throughout the study, so it was not a target of Kyle’s learning. His reflective event that occurred after example 4 could theoretically result in him internalizing an expanded definition and initiating the next expansive cycle. However, according to Vygotsky (1978) and Engestrom (1987), the reflective event should be followed by a socially mediated internalization of the future form of the activity system. If that occurred, then it would be reasonable to believe that Kyle would become aware of this gap and another expansive cycle would begin.

Summary of Research Findings

In summary, each micro-community was at a different point along the continuum as demonstrated by evidence of differences in their *instructional goal*, their AP Biology teaching, and their distance from the AP Biology course goal. The four cases for this study represent three different micro-communities of AP Biology teachers with three different *instructional goals*. The goals among the cases appeared to diverge the most in their inclusion of the social and epistemological dimensions of science practice. They also differed in their use of the term “models” and the inclusion of meta-modeling in their instruction. All three of these indicators of placement along the continuum have recently been elaborated upon in the reform goal of science practice, widening the gap between teachers’ existing goals and reform goals. Each micro-community structures its AP Biology teaching to achieve this instructional goal, which results in varying types of AP Biology teaching with varying gaps between the existing practice and the practice required to achieve the AP Biology course goal.

All three micro-communities recognized a primary conflict between their existing AP Biology teaching and the teaching required to achieve the goal of the AP Biology course. Each teacher internalized and set his/her *instructional goal* based on this conflict as well as his/her interpretation and perspective of the AP Biology goal. Among these micro-communities, individual teachers also vary in the contradictions that emerged and were recognized within their own central activity systems. Contradictions within the central activity system played an important role in the transformation of a teacher's AP Biology teaching. Without a reflective event to bring awareness of a contradiction and some form of socialization or support to assist in the internalization of the future form activity system, then transformation of the central activity system did not occur, and movement in the direction of the reform goals of science practice did not occur. The nature of contradictions recognized within a central activity system was different and may impact the transformation of the activity system. Some contradictions like calculations versus mathematics as a tool for conceptual understanding may be easier to address compared to depth of knowledge about mathematical modeling.

Based on the analysis of a single teacher case, Kyle had available psychological tools to guide his actions toward the object and to facilitate student meaning making within his central activity system. His specialized content knowledge was reflected in Kyle's actions toward the object, decisions, and use of technical tools. At times, such as in classroom discussions, the psychological tool played the primary role in facilitating student meaning. When selected technical tools failed to mediate student meaning toward the object, then the psychological tool of SCK played a more significant role in directing student learning toward the object. Across all of the examples of Kyle's activity system Kyle's limited SCK of mathematical models may have contributed to students not meeting the intended object. Seeing that this claim is not generalizable, the more important outcome of this finding is that CHAT provided a means for studying the mechanism that connects SCK to classroom actions and ultimately to instructional practice.

The in-depth study of four examples of Kyle's AP Biology teaching using a CHAT perspective revealed the value of using CHAT to study teacher learning and more specifically changes in SCK. As objects, tools, and actions shift in an attempt to resolve a contradiction within the existing activity system, then changes in objects, tools, and actions directed toward the tools can be considered metrics or indicators of progress of a central activity system. The evidence of this study indicates that SCK as a psychological tool could also serve as the metric for identifying progress within a central activity system.

Combining the findings of the three micro-communities and the in-depth analysis of an individual teacher's transformation, an analysis of teacher learning should include the following factors: 1) placement of micro-community along the continuum, 2) the existing conflicts, 3) the support during internalization, and 4) the recognition and active pursuit of these conflicts. Each micro-community dictates its path and motive to transform its AP Biology teaching based on the recognized contradictions and where it initially set their instructional goal with respect to the AP Biology course goal. Based on where each micro-community was placed along the continuum and the contradiction, each micro-community and teachers within those communities require different support to recognize the contradictions in their practice and to internalize and set their instructional goals in the direction of the AP Biology course goal.

Chapter 5: Discussion

This research attempted to address some of the problems associated with implementing reform goals of science practice into the classroom. With the recent reform movement, many teachers lack the appropriate content knowledge for teaching science practice, which is essential to build engaging environments and provide explicit instruction for students to gain the desired scientific perspective. To build teachers' content knowledge for teaching science practice, the science education research community should understand where their *instructional goals* lie in comparison to the reform goal of science practice and how to transform their knowledge and practice toward the reform goal of science as a practice. The findings from this study broadly contribute to the current research on teachers' content knowledge for teaching as it is actualized in their classroom practice (Alonzo et al., 2012; Avraamidou & Zembal Saul, 2004; Ball, Hill & Bass, 2005; Forbes et al., 2009) and the research on situated teacher learning (Borko, 2004; Loughran, 2007; Putnam & Borko, 1997, 2000). The findings also validate the recent calls to action concerning current gaps in teachers' instructional goals and impacts on implementation of reform (Bybee, 2011; Ford, 2015; Krajyck & Merritt, 2012; Stroupe, 2015). Finally, they also contribute to the theoretical perspective of CHAT-based research on teacher knowledge and learning (Ellis, Edwards, Smagorinsky, 2010; Forbes, 2009; Forbes et al., 2009; Grossman, Smagorinsky, & Valencia, 1999).

The findings of this study permit us to understand more about the nature of teacher communities that exist and some factors that contribute to transformation of micro-communities toward the center of the community of practice. In context of the launch of a reform movement, such as the redesigned AP Biology course or NGSS, a "new" community of practice is established. Members of the community find themselves dispersed throughout the "new" community. The continuum could be considered a circular map of this new community with the center defined by the AP goals. Within the map are concentric circles, and the regions expanding from the center are scientific inquiry and scientific method on the periphery. These findings describe the different micro-communities of teachers that exist at different points along the periphery. It describes their gaps between the AP goal using a comprehensive definition of science practice, which includes the conceptual, social, and epistemic domains. Although these findings were framed by the context of micro-communities of AP Biology teachers shifting toward a new goal of science practice, these findings do speak to the processes and challenges teachers in general face when presented, whether internally or externally instigated, with a need to shift practice within the community. The findings also describe the transformation of a representative of a micro-community in one performance of science practice – mathematical practices. In describing the transformation, the findings identify components of the central activity system that shift as the teacher learns and aims for the future form of the activity. These findings permit us to understand the importance of contradictions and reflective practice in teacher learning. Another factor is specialized content knowledge. As Hill, Rowan, and Ball (2005) have shown, SCK is predictive of student outcomes. This study's findings use a CHAT perspective to explore the relationship between SCK, actions, and teaching activity. Together, the SCK findings and the micro-community findings present a broad and deep perspective of the ground that must be covered as micro-communities of teachers transform their practice toward the center of the AP Biology, reform-based community. The findings also point to future research and professional learning support that should exist in order to cover that ground.

Contribution to CHAT-based Research

A situated perspective, specifically an activity system perspective (Engestrom, 1987), permits the researcher to examine the larger interactive system and go beyond just examining the individual. In a situated and social perspective, knowledge development is a contextualized act. CHAT provides a means for connecting an individual’s actions and the implicit knowledge related to those actions, and then connecting those actions to the intended object of the activity system. This study used a CHAT theoretical framework and analytical tool to create a cultural-historical continuum of scientific acts and reasoning that represents the historical development of the AP Biology goal of science practice and the past, present, and future expansive cycles of teachers’ *instructional goals*. The CHAT methodology provided a means for describing teachers’ *instructional goals* and the psychological tool used to facilitate student learning to portray some aspects of teachers’ specialized content knowledge. Engestrom (1994, 1999) indicates that more studies are needed to understand an expansive cycle from the community level, to the individual level, and back to the community level, in order to illuminate the contradictions and the community-individual relationship as the community’s central activity transforms. By using this approach, this study described the *instructional goal* at the micro-community level and then the individual level in-depth before using the expansive theory model to extrapolate the expansion of micro-community. This in-depth description of the central activity of AP Biology teaching sheds some light on the mechanisms between teacher knowledge and student outcomes. The description also includes the transformation of the central activity system as teacher learning and factors that contribute to teacher learning. The findings of this study extend previous work aimed to capture teacher knowledge actualized in their classroom practice using a CHAT perspective (Forbes, 2009; Forbes et al., 2009) by going into greater detail and connecting the research to the historicity or the cultural-historical development of the central activity system. This connection is a key aspect of using the CHAT perspective to understand any activity system (Engestrom, 1987).

Contributions to Science Practice

These findings, through a CHAT perspective, elaborate on our understanding of the variability of the micro-communities and the nature of the gaps that exist and should be addressed to implement the reform goal of science practice. These findings demonstrate that groups of teachers exist in micro-communities at different points along the continuum based on their instructional goal. Within their instructional goals, these micro-communities vary in their grasp of conceptual, social, and epistemic dimensions of science practice; all of which are established by each teacher's interpretation of the reform goal. With the release of the *Next Generation Science Standards* (NGSS), there are essays about science practice – defining it, defining classroom instructional shifts, and listing core instructional practices (Bybee, 2011; Ford, 2015; Krajck & Merritt, 2012; Stroupe, 2015). These calls to action seem to focus on the student. However, in order for students to achieve a scientific perspective, the teacher must hold the scientific perspective and have that unique form of knowledge (SCK) to create an engaging environment and mediate student learning (Barab & Luehmann, 2002; Driver et al., 1994; Lederman, 2007; Sandoval, 2005; Schwartz, Lederman, and Crawford, 2004). However, this unique form of specialized content knowledge and teachers' scientific perspective does not appear to be a focus in the literature or part of calls to action. This study found significant gaps in the inclusion of the epistemological and social dimensions in teachers' understanding of science practice as well as their use of models. All three aspects of science practice have recently been elaborated upon in the reform goal of science practice, widening the gap between teachers' goals and reform goals. The findings from this study provide a better purview of just how differentiated teachers' instructional goals are and how far they are from the reform goal of science practice. Significant support is required to transform these different micro-communities toward the reform goal.

Prior to this study and the NGSS and redesigned AP Biology course launches, teachers' unique content knowledge for teaching science practice was largely unexplored. Research focused primarily on nature of science and knowledge of content. The research was also lacking in a comprehensive framework of the various, historical articulations of scientific acts and reasoning, as well as a complete view of science practice that includes the conceptual, social, and epistemic domains (Duschl, 2008). Most research focused on teachers' conceptions of the scientific method (e.g., Windchitl, 2004) or nature of science and scientific inquiry (e.g., Lederman, 1992, 2007; Abd-el-Khalick and Boujaoude, 1997) epistemology (e.g., Sandoval, 2005), or individual practices like modeling or explanations (e.g., Schwartz & White, 2005; McNeill & Krajcik, 2008). This study aggregates all of these articulations into a single continuum that can be used to expose the gaps in teachers' instructional goals in reference to the reform-goal of science practice. Awareness of the placement of a micro-community's instructional goal along the continuum provides insight into the aspects of science practice that are "within their sight" and the type of support required to move each community in the direction of the reform-goal for all of the dimensions of science practice. Each community requires different support to build teachers' epistemological and social understanding as well as the different performances of science practice – such as creating, evaluating, and revising models and explanations. Not all of these domains of science practice can be addressed as if on a pre-determined path, the micro-community establishes the path, so the support must be reactive to the micro-community's transformation. However, the cultural-historical continuum from this study provides some insight into the past, present, and future expansive cycles of AP Biology teaching, establishing a high level path for micro-community movement toward reform.

Contributions to Specialized Content Knowledge

To address problems with reform implementation, it is not enough to know whether gaps exist and the extent of the gaps of *instructional goals* in relation to the reform goals of science practice. It is also important to understand more about the relationship of their *instructional goals* and the specialized content knowledge at the root of these goals with their instructional activity and ultimately student outcomes. These findings provide some insight into the value of using CHAT to describe teacher actions in relation to their *instructional goal* and explore potential mechanisms that connect teachers' implicit knowledge to their practice and ultimately to student outcomes. These findings provide an example of what the in-depth descriptions of these mechanisms may look like so corollary relationships can be drawn between knowledge and outcomes. This study has provided two instances where limits in SCK of mathematical models could have contributed to students not meeting the intended learning outcome or activity object. The mechanism identified in this study may indicate why specialized content knowledge is predictive of student performance (Hill, Rowan, & Ball, 2005).

These findings, along with the work of Alonzo et al. (2012) provide additional information about potential mechanisms for the relationship between content knowledge and student outcomes as well as relationships between common content knowledge, specialized content knowledge, and pedagogical content knowledge. Alonzo et al. (2012) points to specific support teachers with strong content knowledge (i.e., CCK) may need to develop and strengthen their PCK. I would interpret their support to be tasks that leverage specialized content knowledge. This study's focus and findings about specialized content knowledge adds to the conversations about the translation of content knowledge to PCK and makes more visible and explicit the role and mechanisms SCK plays in this translation.

The use of CHAT to study teachers' knowledge provides a methodology for moving beyond theoretical considerations of teacher knowledge structures and like Ball, Thames, and Phelps' (2008) work and Alonzo et al. (2012), it grounds this knowledge in teacher practice. These findings from a CHAT perspective provide an additional layer to Ball et al.'s (2008) work, which characterized SCK from the ground up by observing practice and characterizing SCK through the tasks of teaching. An activity theory model elaborates not only on the task or teacher conscious action, but includes the relationship of that action to the tools and object of the central activity as well as the greater classroom community. The CHAT perspective places SCK as a psychological tool that facilitates the actions or tasks, creating an idea of the mechanisms involved. An elaboration of the teaching tasks of specialized content knowledge (Figure 2.2) provided by Ball et al. (2008) to include variation of tasks, based on the tool or descriptions of these actions, could paint a more detailed picture of the desired SCK mobilized in classroom practice. These pictures could better inform the development of teacher support embedded in teacher practice.

Teacher's knowledge is difficult to study given the tacit nature of this knowledge and the difficulty of finding a way to represent this knowledge behind actions to others (Berliner, 1986; Richardson, 1996). According to a CHAT perspective, the reform goal of the AP Biology course caused a primary level contradiction for the AP teachers. This recognition of a new goal for instruction theoretically shifted teachers' actions from being operational to being conscious as they wrestle with their new instructional goal. The reform events of the AP Biology redesign provided an ideal case for studying this knowledge as it potentially experienced this shift.

Despite the AP Biology context, the findings expand beyond the AP context and can be applied any time communities of teachers are adjusting practice, and therefore, shifting their actions within an activity system making them conscious and eventually transforming them back to operational. In-depth CHAT analysis of teachers' instructional practice at the onset of reform movements may be the ideal case for studying the phenomenon of teacher knowledge actualized in practice, which has previously been problematic for researchers.

Contributions to Situative Teacher Learning

The CHAT perspective of expansive learning combines the situative perspective of learning as an enculturation into a community of practice (Cobb, 1994; Lave & Wegner, 1994) with the more individual, constructivist perspective of learning. These findings verify the need to describe learning from both perspectives. The early work of Borko and Punam (1996) created a model of teacher learning more in line with a situative perspective and constructivist model of teacher learning rather than a transmission model, often adopted in professional development. In their model teacher learning requires teachers' prior knowledge and beliefs to be challenged and for a cognitive dissonance to be generated to present opportunities for new learning. This cognitive dissonance and challenges to prior knowledge cannot always be externally induced upon the teacher. Reflective practice is another essential component to teacher learning (Loughran, 1996; Russell & Munby, 1991). The findings from this study verify the importance of the reflective event and awareness of a contradiction to catapult change and motivate teacher learning. Kyle's definition of mathematical models did not expand; however, his practice with respect to the use of mathematics as tools expanded through a series of reflective events. Both reflective practice as well as concrete and productive ways to frame practice improve the linking of teachers' conceptions and actions in the classroom (Loughran, 2007; Posner, Strike, Hewson,

& Gertzog, 1982). The CHAT framework also provides a way to frame teacher practice that connects teachers' conceptions to their conscious actions in the classroom. During this study the CHAT framework was unknown to these teachers, but perhaps future research could leverage the model as a tool for framing teacher practice. Barab et al. (2002) used activity theory to study their astronomy course, which resulted in several changes to the course structure. For example using CHAT changed how they perceived the role of the student to one of a participant instead of an object. Perhaps similar use of activity theory to frame teacher's instruction may help make some of the reform shifts, such as shifting toward student-centered instruction or shifting models to be outcomes instead of tools.

Based on Engestrom's (1987) model of CHAT and description of an expansive cycle and Vygotsky's (1978) zone of proximal development, the differences of the micro-communities can be understood and applied to the field's current understanding of teacher learning. Another way of thinking about this evolution is the community recognizes a gap in their goal and each individual within the community takes action to fill that gap. The actions of the individuals within the community result in the creation of new instruments, which mediate their understanding and move them toward the goal of the future activity system, filling the gap. Each community is attempting to internalize a model of science practice that is within their zone of proximal development and attempting to externalize this model and move the community toward this new goal. Through a series of expansive cycles, a community may progress from a scientific method view of science practice to a scientific inquiry view, but the path is not predetermined and the progression is local to the community. Given the possible number of micro-communities that could exist and the complexity of the knowledge and practice involved in the reform goal of science practice, a one-size-fits-all model of professional learning or curricular materials may not move teachers toward the intended goal. These findings, through a CHAT perspective, verify the importance of professional learning communities and having an expert within the community to facilitate the expansive cycles. An expert within the community plays a critical role in supporting individual movement toward central membership of the community (Lave & Wegner, 1991). In this study the researcher inadvertently played the role as expert within the community, stimulating reflection, but not assisting with the internalization of the instructional goal. A community member with a sophisticated grasp of science practice and the mobilization of this knowledge in practice could theoretically have a significant impact on the movement of the community.

Limitations

Findings from this study should be carefully interpreted as they represent qualitative case analysis of only four teachers and in-depth of only one teacher. This case study intends to describe the complexity of the gaps that exist between teachers' knowledge and practice against a reform goal of science practice. The study is not meant to be generalized beyond the cases of AP Biology teachers. The analysis includes only an average of 360 minutes of observations per teacher. The findings are descriptions of relationships and events and are in no way meant to be explanatory in nature. The findings result from the use of a CHAT framework to interpret evidence from classroom observations, which were triangulated with interviews and journal entries. The coding constructs went through an interrater reliability check, which confirms the constructs are reliably applied across the cases.

Inferring knowledge from teacher behavior. The study includes an analysis of teachers' specialized content knowledge, as it is actualized in their *instructional goal* as well as a psychological tool to mediate learning. Similar to PCK research, the observations of classroom events cannot provide a complete portrayal of teacher knowledge structures (Baxter & Lederman, 1999; Loughran et al., 2004). The study purposely includes observations with pre- and post-interviews to capture a more robust picture of teachers' actions. The study analyzed teachers' *instructional goals* through their instructional activity and actions as well as explicit reflection on their *instructional goals.* Observations captured the use of psychological tools in classroom practice through teacher actions and interactions with other technical tools. The value of observations is not relying purely on teacher articulation of knowledge or purely on their practice. The observations portray knowledge in practice, where it interacts with students and tools rather than interview or paper-pencil tests, which are removed from the classroom (Alonzo et al., 2012). The findings from this study are not claiming to characterize all of teachers' specialized content knowledge of science practice. The study admittedly describes unique cases of knowledge situated in a practice that is consciously trying to shift toward a future form of activity where science practice is prominent. To appropriately articulate teacher knowledge in this context, I relied on both observations and interviews rigorously using a CHAT model of analysis to discern the components, actions, and interactions of the activity to more thoroughly capture the phenomena of instruction and changes in instruction over time. This gave me confidence in the description included in this study.

Even though the specialized content knowledge construct was defined and validated through practice-based methods of analyzing a wealth of teaching tasks, there remains a concern about making claims about teacher's knowledge based on observations of behavior. Like Ball, Thames, and Phelps (2008) the study and analysis tries to focus on the acts of teaching, not attributes of the teacher. I am concerned with "fundamental attribution error" and aspects of the study design were included to address attribution error (Kennedy, 2010). The study intentionally collected interview and journal reflection data in order to triangulate with classroom observations of teacher actions. The CHAT methodology is meant to incorporate the contextual factors or situational characteristics referred to by Kennedy (2010) as missing from education researcher's interpretation and analysis of classroom behavior. However, the limited opportunities to observe all aspects that impact a teacher's classroom practice restricts what can be claimed about teacher knowledge structure.

To make the connections between knowledge and classroom practice, I am interpreting the CHAT framework of expansive cycles to involve the internalization of the reform-goals of science practice to form a teacher's mental model of scientific acts and reasoning as the future form of the activity system, which is equivalent to his/her *instructional goal*. This mental model of scientific acts and reasoning is actualized in the teacher's *instructional goal*, which I am assuming to be a proxy to specialized content knowledge. This assumption and interpretation tie together the use of CHAT with the descriptions of teacher knowledge actualized in their practice. Additional investigations and data would be needed to use a more grounded theory approach to establishing these assumptions into a model (Barab et al., 2002; Barab, Evans, & Baek, 2004; Forbes et al., 2009).

Activity theory methodology. Cultural-historical activity theory is a broad framework with complex ideas about the relationships within an activity and among activities. Teachers' learning through a CHAT perspective is challenging to articulate and capture through qualitative data. The amount of data required to appropriately capture the entire activity system as well as the expansion of an activity system is labor intensive and challenging for an individual researcher. There is a lot of flexibility of the model depending on the grain size of the activity being described, the perspective/agency of the subject, and the boundary of the community. These factors make it difficult to generalize or leverage findings among CHAT-based research. This study transitions among three different communities. The broad AP Biology community, the micro-communities of teachers defined by their *instructional goals*, and the classroom communities of the individual teachers. Moving between these communities to describe the expansion of an activity system is challenging to articulate and ensure consistency across the systems analyzed. This is the nature of qualitative research, and activity theory provides some consistent and rigorous structure to analyze these systems (Creswell, 2007; Engestrom, 1999).

Data collection. The data collected for this study expanded the entire year, but only captured four instances of instruction. Due to a lack of more frequent observations, there is limited information to describe more examples of the activity system, which could improve descriptions of the transformations and emerging contradictions. Additional observations, specifically after example 4, could have helped determine if Kyle recognized his gap in his types of mathematical models. There are aspects of the CHAT methodology that could not be leveraged in this research due to the lack of data over time and within the system. The process of internalization involves socialization and is influenced by a teacher's beliefs and perspective about the discipline as well as learning (Engestrom, 1994). This aspect of Kyle's expansive cycle was not studied in-depth due to the lack of available data. Once a contradiction has been resolved internalization continues as the conscious actions become operational and externalization continues. Additional data may have helped to describe the levels of conscious actions and operational actions within the activity system. As new objects and artifacts are generated and shared among the community, the community transforms (Engestrom, 1987). This is the portion of the expansive cycle that provides evidence of community learning, so additional observations could have facilitated observing not only Kyle's operationalizing the future form, but also observations of multiple members of the same micro-community may provide insight into community transformation.

Due to the district rules, video cameras were not allowed in the classrooms. This form of data collection would have been the most ideal for studying activity theory. I was limited to transcripts, which also limits the analysis and resulting descriptions.

Implications

Future research. *The Framework for K-12 Science Education Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2011) specifically points to the need for epistemology along with content and practices to be consistently and thoroughly integrated into classroom instruction. However, many students are being taught in an epistemological vacuum without any knowledge or experience with the norms for science practice (Duncan & Rivet, 2013). The findings of this study verify that there are significant gaps in the epistemological domain within teachers' *instructional goals*. The epistemological domain appeared to be the most significant gap for teachers and therefore students. The use of CHAT to analyze instructional practices that vary in their incorporation of the epistemological domain would provide some insight into the types of reflective events needed to stimulate teacher learning. This analysis could also provide awareness of the support needed to advance the internalization of epistemology into the *instructional goals* in the direction of reform. More case studies are needed that include instructional practice across the continuum with respect to epistemology in the classroom. These case studies should span the continuum and include a robust description of AP Biology teaching that is garnered by an *instructional goal* with a sophisticated epistemic domain all the way to classrooms that are just beginning to incorporate epistemology into their classroom.

Creating or experiencing a reflective event is a critical part of the expansive cycle and teacher learning. More research is needed to better understand how to challenge teachers' current conceptions of scientific acts and reasoning in a way that fosters their learning. More research is needed to better understand teachers' conceptions of science practice, leveraging a more comprehensive continuum. According to this study's findings, many teachers may be out of reach of the reform goals of science practice; therefore transforming their practice may require all phases of the continuum. Moving teachers along that continuum for all domains of science practice will take significant work on the teacher's part to reflect and monitor their understanding. These abstract definitions of science practice and the domains may not help teachers to actively reflect and notice gaps. More examples of science practice in the classroom are needed, highlighting the different dimensions. Teachers themselves need to participate in the engaging authentic disciplinary work over time themselves to provide concrete exemplars and evidence of these new outcomes of science practice (Stroupe, 2015).

To extend this study's findings, the researcher proposes to conduct an in-depth analysis of Mark's central activity system over time. Given his placement within the scientific method phase of the continuum and his propensity for reflective practice, Mark would be an ideal case for studying transformation of AP Biology teaching that has significant gaps from the desired AP Biology course goal. These findings could provide additional information on the nature of the transformation that must transverse such a gap. I believe Mark's case would be most representative of a majority of the AP Biology community and therefore valuable for providing more targeted support to teachers.

Reform implementation. Like students, groups of teachers are at different points along a continuum at various distances from the intended reform goal. Teacher support cannot assume that all teachers have the reform goal of science practice “within their sight”. Given the varied teaching and AP teaching experience of the cases in this study and their location within the continuum, one cannot assume that teacher learning after a certain point of experience is the same. Steps should be taken to meet teachers where they are in their knowledge and learning, not necessarily experience, and create professional learning that is adaptive to teacher and micro-community placement along the continuum. This study supports the idea that a one size fits all model of professional learning for experienced teachers is not appropriate to move teachers and communities toward the reform goal of science practice. This may require providing an expert member of the AP community who is available to all teachers within the micro-community, an expert that is available to facilitate teacher’s transformation as they move toward the AP Biology course goal and become more central members of the community. Given the scalability of this solution more research and solutions should look to coaching and mentoring models of teacher support as well as online support. Virtual mentoring and coaching are growing as there are various video platforms that can host exemplar videos of teacher practice and provide a platform for virtual coaching that includes evaluation against rubrics and space for teacher reflection and coaching feedback on that reflection.

Conclusion

At the time of this study, the AP Biology revisions were just launching and NGSS was in the process of development. It is now 2016 and the reform goal of science practice has entered all AP Biology classrooms and a growing number of K-12 science classrooms. Given the findings of this study, there are many micro-communities of AP Biology, primary, and secondary teachers along the continuum. Some have significant gaps when compared to the reform goal, and some are very close to reaching the reform goal. The variation in practice that exists is astounding and from a CHAT perspective the components of practice and teacher knowledge that must transform is overwhelming. The findings from this case call for the following actions to stimulate research community discourse about the type of professional support required to address teacher's individual needs:

1. Additional CHAT-based research on teachers' *instructional goals* and science teaching, so the micro-communities across the continuum can be described at a level that will provide more insight in to the nature of the gaps among the micro-communities and movement along the continuum. Similar to learning progression research, the more the research community knows about the larger map and typical milestones along the way, the better set of tools and support that can be offered teachers (Schneider & Plasman, 2011; Thompson, Braaten, & Windschitl, 2009). The cultural-historical continuum of scientific acts and reasoning represents the past, present, and future expansive cycles of the AP Biology reform-based goal for the various micro-communities. Even though the continuum was used to frame the instructional goals of AP Biology teaching, the continuum could have application to broader science communities.

2. Broader application of CHAT research to study teacher's specialized content knowledge or knowledge models as a whole. Teachers' specialized content knowledge has shown promise for impacting student outcomes (Hill, Rowan, Ball, 2005; Alonzo et al., 2012). Practice-based studies leveraging a CHAT methodology could provide valuable insight into the mechanisms between teachers' SCK, classroom actions, and their overall activity of AP Biology teaching. Models based on statistical analysis of teachers' knowledge require refinement and instruments that measure teachers' knowledge require validation to help with the messiness of describing teaching and learning (Ball, Thames, & Phelps, 2008). The use of a CHAT

methodology presents an opportunity to describe teaching and learning at a finer grain size, providing a means to analyze and conceptualize the models in practice (Barab, Evans, & Baek, 2004). The expansive cycle model included in Engestrom (1994) incorporates teachers' orientations and beliefs into the descriptions learning. Even though these key aspects of teacher knowledge and learning were not a part of this study, CHAT provides a methodology for more comprehensively describing teacher's knowledge connected to their practice.

3. Use CHAT perspective to study professional development. As studying and developing teacher professional learning from a situative perspective gains momentum, CHAT can be a powerful tool to study teacher learning at the individual and community level. CHAT permits the description of an expansive cycle from the individual level, to the community level, and back to the individual (Engestrom, 1999). It provides insight into the context and emerging tools and objects within the community as it progresses toward the future form of the central activity. Analyzing the progress of groups of teachers as micro-communities, rather an individual teacher, seems less daunting and the prospect of reform more manageable (Grossman, Smagorinsky, & Valencia, 1999). A CHAT perspective may also highlight additional factors that contribute to teacher learning. Given the finding of this study, CHAT could reinvigorate the discourse among the research community of the impact of reflective practice and the need for cognitive dissonance to facilitate teacher learning.

Overall this study has shed some light on teacher knowledge and learning that could have a significant impact on science education reform. The cultural-historical continuum provides a comprehensive way for understanding instructional goals. Through a CHAT perspective, these instructional goals provide insight into teacher SCK, which shows promise for impacting student learning. The use of a CHAT methodology can also highlight some of the mechanisms that connect SCK to student outcomes, providing a clear target for teacher professional learning. There is a lot of promise for using CHAT to support micro-communities of teachers moving toward the goals of reform.

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Appendix A

Cultural-historical Continuum of Scientific Acts and Reasoning

The Scientific Method	**Scientific Inquiry**	**Scientific Models and Discourse Practice**
Philosophical View: Experiment driven enterprise (logical positivism)	Philosophical View: Theory driven enterprise (conceptual-change)	Philosophical View: Model driven enterprise
Description of School Science: • Recognize a limited conceptual domain of science • Hypothetico-deductive conception of science • Mathematical logic dominant • Experiments lead to new knowledge that accrued to established knowledge • How knowledge was discovered or refined, not a primary concern (for philosophers) • Focuses on the final products or outcomes of science • Oversimplifies observation • Linear process of discrete events, the parameters of each event are only considered after previous event is complete (Windschitl, 2004) • Sense perception dominates study of nature • Strategies for hypothesis testing are rule driven • Theories thought of as sets of sentences • Dialogic complexities are not embraced – don’t consider the functional and pragmatic parameters for understanding growth of scientific knowledge • Epistemological basis – phenomenon-based reasoning (strong H-D experiment driven notions, reliance on sense perception for evidence) (Driver, et al, 1994) • Social domain not considered	Description of School Science: • Recognize conceptual (except models) and social domains of science • Focus on improvement and refinement of a theory • Science is described as acquiring data and then transforming that data first into evidence and then into explanations • Includes social domain the idea of a community being guided by shared values and examples, but with little explicit attention or analysis of its contribution • Community through peer review brings objectivity • Epistemological basis – relation-based reasoning (Driver, et al, 1994) • Multiple steps are considered in relation to each other at the outset of the investigation; steps are mutually interdependent (Windschitl, 2004)	Description of School Science: • Fully recognize the conceptual, epistemic and social domains of science • Inclusive of all three forms of science (hypothetico-deductive – models) • Emphasizes the role of models and data construction in the scientific process and demotes the role of theory • Sees the cognitive scientific process as a distributed system that includes instruments • Involves complex set of discourse processes – knowledge claims and beliefs are posited and justified • Tool, technology, and theory-laden study of nature • Hypothesis testing strategies emerge from dialogical or dialectical practices of science • Theories thought of as families of models, models’ role between empirical evidence and theoretical explanations • Emphasis on discourse and dialogic strategies • Sees the scientific community as an essential part of the scientific process • Epistemological basis – model-based reasoning (Driver, et al, 1994)
Processes of Scientific Method Incorporate cognitive activities with no practice-based dialogical processes	**Processes of Scientific Inquiry** Incorporate cognitive activities with only one dialogical processes (the last one)	**Processes of Models and Discourse** Incorporate both cognitive activities and dialogical processes
		Posing, refining, evaluating questions

Make observations Formulate a hypothesis Deduce consequences from the hypothesis Make observations to test the consequences Accept or reject the hypothesis based on observations	Learners engaged by scientifically oriented questions Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions Learners formulate explanations from evidence to address scientifically oriented questions Learners communicate and justify their proposed explanations From *Inquiry and the National Science Education Standards* (National Research Council, 2000)	Designing, refining, interpreting experiments Making observations Collecting, representing, analyzing, recording, organizing, discussing data Writing and reading about data Relating data to hypothesis/model/theory Formulating hypothesis Learning, refining theories Learning, refining models Comparing alternative theories/models with data Providing explanations Giving arguments for/against models and theories Comparing alternative models Making predictions Discussing, explaining, writing about and reading about theories and models
Evidence in the Classroom: • Engagement thought to be only hands-on, focus on experimentation • Activities that focus on causal explanations grounded in control of variable experiments • Dialogic strategies focus on concepts, not the processes or aspects of science • Classroom instruction devoid of any epistemic framework (claims, arguments, alternative explanations, models, etc.) (Windchitl, 2004, 2005) • Generation of scientific questions based on interest not extant scientific models (Windchitl, 2004, 2005) • Focus on ordered, discrete steps and key vocabulary (Tang, Coffey, Elby, & Levin, 2010)	**Evidence in the Classroom:** • Focus on experimentation as the primary form of inquiry • Activities emphasize acquisition of the data, selecting data to become evidence, analyzing evidence to generate patterns, determining the scientific explanations that account for patterns of evidence • A dialogic strategy involves students making and reporting judgments, reasons, and decisions throughout process	**Evidence in the Classroom:** • Engagement in science both with and without hands-on, but with data provided • Activities that focus on statistical/probabilistic explanations grounded in modeling experiments • Hypothesis testing using complex frameworks requiring nuanced strategies for representing and reasoning with evidence • Dialogical processes include both construction and evaluation of knowledge claims

Appendix B

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

1.1 The student can *create representations and models* of natural or man-made phenomena and systems in the domain

1.2 The student can *describe representations and models* of natural or man-made phenomena and systems in the domain

1.3 The student can *refine representations and models of natural or man-made phenomena and systems* in the domain

1.4 The student can *use representations and models* to analyze situations or solve problems qualitatively and quantitatively

1.5 The student can *re-express key elements* of natural phenomena across multiple representations in the domain.

Science Practice 2: The student can use mathematics appropriately

2.1 The student can *justify the selection of a mathematical routine* to solve problems

2.2 The student can *apply mathematical routines* to quantities that describe natural phenomena

2.3 The student can *estimate numerically* quantities that describe natural phenomena

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

3.1 The student can *pose scientific questions*

3.2 The student can *refine scientific questions*

3.3 The student can *evaluate scientific questions*

Science Practice 4: The student can plan and implement data collection strategies appropriate to a particular scientific question.

4.1 The student can *justify the selection of the kind of data* needed to answer a particular scientific question.

4.2 The student can *design a plan* for collecting data to answer a particular scientific question

4.3 The student can *collect data* to answer a particular scientific question

4.4 The student can *evaluate sources of data* to answer a particular scientific question

Science Practice 5: The student can perform data analysis and evaluate evidence

5.1 The student can *analyze data* to identify patterns or relationships

5.2 The student can *refine observations and measurements* based on data analysis

5.3 The student can *evaluate the evidence provided by data sets* in relation to a particular scientific question

Science Practice 6: The student can work with scientific explanations and theories

6.1 The student can *justify claims with evidence*

6.2 The student can *construct explanations of phenomena based on evidence* produced through scientific practices

6.3 The student can *articulate the reasons that scientific explanations and theories are refined or replaced*

6.4 The student can *make claims and predictions about natural phenomena* based on scientific theories and models.

6.5 The student can *evaluate alternative scientific explanations*

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains

7.1 The student can *connect phenomena and models* across spatial and temporal scales

7.2 The student can *connect concepts* in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas

Appendix **C**

Interview Protocol Pre-Study

1. What is your personal interest in biology?
    a. Tell me more about ____
    b. How does ___interest influence your lesson planning and teaching?

2. What is the purpose of authentic inquiry experiences for students?
    a. Tell me more about “authentic”
    b. Can you give me a specific example
    c. What is another way you could phrase this?

3. Describe an authentic inquiry experience for students?
    a. Tell me more about the experiences
    b. Can you give me a specific example you’ve implemented
    c. How else could you describe these experiences?

4. What evidence of students practicing science do you look for?
    a. Tell me more about the evidence
    b. Can you give me specific examples
    c. What would evidence of argumentation/explanation look like?
    d. What would working with models look like?

Appendix D

Post-Study Interview Protocol

PLANNING

1. Did you think it was important to develop lesson plans when you did so? Why or why not?
2. What resources are most significant in supporting you when you plan your lessons?
    a. What about teaching science practice?
3. When you planned or developed lesson plans, what were some things that helped you? What challenges did you face?
4. NOTE: Probe here for any involvement of peers.
5. How do you think student learning goals impact your planning?
    a. [if not mentioned, what about the learning objectives from the AP Curriculum Framework]
    b. Do these learning objectives help you plan to teach the science practices?

MOBILIZATION OR TEACHING

1. What resources helped you enact your lessons? Why were they important? NOTE: Probe here for any involvement of peers
2. What are some of the challenges you faced?
3. Are there ways you'd like to teach differently?
    a. What are these barriers?
    b. What about teaching science practice?

SPECIALIZED CONTENT KNOWLEDGE (NOTE: Forbes considers this to be a symbolic tool of activity theory)

1. How is scientific inquiry for a student different from a scientist?
2. How does this shape your lesson design?
3. Is it important to explicitly teach student how to perform the science practices (write explanation, data analysis, use representations, design on investigation)?
    a. What aspects of science practice do you think is important to explicitly teach?
4. What type of investigations should students perform to provide them with an opportunity to authentically practice science? Can students learn to practice science not in an investigation?
5. Where did you learn to practice science?

Free Recall – so little probing by me

1. Use the following dimensions of science practice: (Forbes, 2009))
    a. Asking scientifically-oriented questions
    b. Gathering and organizing data/evidence
    c. Constructing explanations from evidence
    d. Evaluate explanations in light of competing evidence
    e. Communicate and justify explanations
    f. Use representations and models to explain, predict, or describe scientific phenomena

2. For each dimension have them answer the following:
    a. How would you describe [dimension]? Is it important?[clarify by saying – what is it in terms of science practice a textbook definition]
    b. How could you change a lesson to make it more [dimension]?
    c. How could you promote [dimension] in the classroom?
3. Do you think these dimensions represent authentic science practice?
4. How successful do you think you were this year at translating your ideas about science practice into your teaching?

Appendix E

Interview Protocol Pre-Lesson Implementation

1. What are the learning objectives for this lesson?
    a. Is there a specific science practice component associated with this lesson?
2. What specific student outcomes are you expecting? (What evidence are you looking for that students have met the learning objective?)
    a. Can you give me a specific example
    b. Tell me more about _____
3. Why did you select this activity?
    a. How does it help students meet the learning objective?
    b. Why did you select a specific representation/model?
    c. Why did you select a specific example?
4. How are you building students ability to practice science with this lesson?

Appendix F

Interview Protocol Post-Lesson Implementation

1. Did the lesson go as intended?
    a. What was a success? Why?
    b. What would you want to improve? Why? How?
2. Did the activities result in an authentic science experience for students? Why or why not?
    a. What evidence supports this? Can you give a specific example
    b. Tell me more about….
    c. How else could you describe the experience
3. Did ____representation work? Why or why not?
    a. What evidence supports this? Can you give a specific example
    b. Tell me more about….
4. Did____example work? Why or why not?
    a. What evidence supports this? Can you give a specific example
    b. Tell me more about….
5. Why did you explain _______ process or science practice in the way that you did? OR Why did you not include an explanation for _____process?
    a. Tell me more about….

Appendix G

Journal Prompt

Your response should be in context of the lessons you taught that week or are planning to teach next week.

1. Describe the science practice(s) you taught this week. What aspects of the science practice did you teach? (NOTE: This reflection should focus on your ideas about the nature of the science practice itself NOT how you taught it.)
2. Describe the strategies, lessons or activities you used to teach the students the science practice? Do you think they worked to improve students' understanding of the science practice?

Journal Prompt Starting Week 1/4/2013

For your reflection this week I'd like for you to respond to the table below. For each of the 7 Science Practices that are a part of the AP Biology Curriculum Framework, I'd like for you to describe what the science practice means (e.g., what does it look like when scientists do this practice, what all is involved when scientists do this practice). I'd also like for you to describe what this practice looks like in the classroom, when students are engaging in scientific inquiry or science practice.

Science Practice in AP Curriculum	What does this science practice mean?	What does it look like in the classroom?
1		
2		
3		
4		
5		
6		
7		