Activity-Theoretical Research on Science Teachers' Learning: Challenges and Opportunities

Cory T. Forbes[1], Cheryl Ann Madeira[2], Elizabeth A. Davis[1], and James D. Slotta[2]

1. Department of Educational Studies, University of Michigan
ctforbes@umich.edu
betsyd@umich.edu
2. Ontario Institute for Studies in Education, University of Toronto
cmadeira@oise.utoronto.ca
jslotta@oise.utoronto.ca

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Teachers play a crucial role in facilitating and promoting student learning. To do so effectively, however, they must possess relevant knowledge and expertise. Teachers need to exhibit, for example, a rigorous knowledge of the subject(s) they teach (content knowledge – CK or SMK), an understanding of general pedagogical strategies (pedagogical knowledge – PK), and knowledge of how to effectively teach specific topics (pedagogical content knowledge – PCK). However, teachers' expertise is characterized their ability to effectively employ their knowledge in the classroom. As such, knowledge serves as one important component of teachers' capacities for pedagogical design (Brown, 2008), or how they draw upon their knowledge, beliefs, and identities, as well as both symbolic and material tools, to design learning environments oriented toward the attainment of particular objectives while accounting for affordances and constraints of context.

Teachers' knowledge and expertise has been a consistent focus of education research for many years. While this research has made invaluable contributions to perspectives on teachers' knowledge, expertise, and learning, a great deal remains uncertain about the nature of teachers' knowledge and expertise. There remains little to no consensus as to what exactly constitutes teacher expertise and how to differentiate between expert and novice teachers beyond the number of years spent in the classroom. As with many practitioners (e.g., Hutchins, 1995), teachers often struggle find ways to articulate and reify their tacit, routinized knowledge and expertise, though it is precisely this automization or routinization of knowledge in practice that mark transitions from novice to expert teachers (Berliner, 1986; Feiman-Nemser, 2001; Richardson, 1996). This is one reason research on teachers' knowledge and expertise has proven challenging and led to repeated calls for research on a knowledge base for teaching.

If teachers' knowledge and expertise is to be made public in an effort to help support teaching and learning, new modes of representation and methods of research must be explored. In recent years, there have been calls to use cultural-historical activity theory (CHAT - Engeström, 1987) in education research (Grossman, Smagorinsky, & Valencia, 1999). CHAT affords a concrete theoretical and analytical framework that foregrounds collective activity as both the site for and evidence of learning. In recent years, CHAT has been employed in studies of elementary science (Reveles, Kelly, & Duran, 2007), school leadership (Spillane, Halverson, & Diamond, 2004), identity development of preservice elementary teachers (Smagorinsky, Cook, Moore, Jackson, & Fry, 2004) and teachers and students in urban schools (Roth, Tobin, Elmesky, Carambo, McKnight, & Beers, 2004), and classroom artifacts and tools (McDonald, Le, Higgins, & Podmore, 2005). As Roth (2004) suggests, "the potential of cultural-historical activity theory for research practice and practice research has not yet been realized" (pg. 7).

However, CHAT-based research on science teachers, teaching, and teacher learning is limited. More CHAT-based science education research is needed. In this paper, we present methods and findings from two parallel CHAT-based studies on science teachers (elementary and secondary) in professional learning contexts (formal teacher education and professional development). The specific purpose of this paper is threefold. First, we describe two studies that use cultural-historical activity theory to investigate science teacher learning through iterative cycles of instructional planning, lesson enactment, and reflection on practice. Second, we identify and discuss the operational challenges associated with using third-generation CHAT to conceptualize, design, and interpret data collected in our studies. Third, we highlight the advantages using CHAT as a sociocultural model to explore teacher-classroom environments and describe cohesive and synergic approaches with CHAT to study teacher learning. Research methods, findings, and research-related issues discussed in this paper will help other researchers employ CHAT in research on science teachers, teaching, and teacher learning.

Theoretical Framework

Teaching is a complex and dynamic activity that requires teachers to develop robust knowledge and expertise. To meet the real-time demands of teaching, teachers need to develop robust pedagogical content knowledge (Shulman, 1986; 1987). Shulman identified PCK as a unique teacher knowledge which integrated teachers' content knowledge and knowledge of pedagogy. PCK represents knowledge of subject discipline content, relevant instructional strategies, powerful analogies and illustrations, targeted examples and demonstrations, and specific understanding of student misconceptions and student learning difficulties (De Jong, 2003; Shulman, 1986). It is difficult for researchers to measure PCK accurately, given its largely tacit nature and the nuanced, often split-second decisions that teachers make in the classroom (De Jong, 2003). Much of teacher knowledge is bound by classroom events and the 'how to' enact the appropriate tasks within the classroom (Marx et al., 1998; Carter & Doyle, 1989). Furthermore, this knowledge cannot be learned independent of the situation that it will be used (Marx, Blumenfeld, Krajcik, & Soloway, 1998). Teachers develop this knowledge in order to understand their implementation of new pedagogical strategies and to relate this understanding to the nature of learning and instruction.

Science teachers require highly-nuanced PCK to address student misconceptions and effective applications of computing and information technology. PCK involves representing domain-specific content in the most accessible way to learners and an understanding of science curricula, instructional strategies such as inquiry, student prior knowledge and assessment (Magnusson, Krajcik, & Borko, 1999). In their a social and cultural examination of science classroom life, Tobin and McRobbie (1999) recognized that science teachers have differentiated ideas about how to teach the content of science, for instance in mediating student understanding of prediction, experimentation and student explanations. In other research, which has examined science teacher learning through science content representations, evidence suggests that science teachers shift towards more student-centered instructional practices but still struggle with linking student prior knowledge to subject-specific content (Zembal, Starr, & Krajcik, 1999). Viable ways for teacher to construct PCK is intimately linked with experiences and context.

Teachers need to continue to develop and construct new knowledge to become more effective teachers and develop expertise. Formal teacher learning experiences, such as teacher education and professional development, are one means for them to do so. However, teachers' own practice, or their experience in the classroom, is also a crucible for learning. It is this learning in and from practice that, as Richardson argues, "is the only way to develop the practical knowledge that eventually makes routine at least some aspects of classroom practice and provides alternative approaches when faced with dilemmas" (1996, pg. 13). However, education scholars and researchers often discount the knowledge of practitioners as 'craft knowledge' – a sort of ill-informed, less robust, anecdotal, experience-based complex of understandings. On the other hand, teachers often view the discourse of educational scholarship, particularly in the context of teacher education, as marginally relevant and significantly divorced from the daily realities of actual classrooms. In many ways this lack of understanding is manifested in the oft-referenced disconnect between theory and practice, or formal knowledge and practical knowledge (Fenstermacher, 1994; Hiebert, Gallimore, & Stigler, 2002).

There are persistent tensions, then, in understanding the nature of teacher's knowledge, how it is developed (i.e., teacher learning) and employed (i.e., expertise) in practice, and how teachers' practice is culturally-mediated. How can these tensions be reconciled? In both theory and research, it is essential to position teachers' knowledge in their professional practice rather than as an extant entity devoid of contextual basis. This view of teachers' knowledge, expertise, and learning is aligned with situated perspectives on knowing and learning, to which we turn next. In the following sections, we present a detailed discussion of situated perspectives on teaching and teachers' knowledge and learning. Then, we present cultural-historical activity theory (CHAT) and its utility for research on teachers, teaching, and teacher learning.

Situated Perspectives on Teachers' Knowledge and Expertise

In recent years, situated and sociocultural perspectives on knowing, learning, and practice have emerged from cognitive science and learning theory. These perspectives on learning have been characterized by a reinterpretation of the relationship between the individual and the external world and have sought to deemphasize the dichotomization of two by foregrounding the social, cultural, and activity-based nature of knowing and learning. These theoretical perspectives share a number of common assumptions. First, people engage in collective action in particular settings at particular times with particular tools. In this way, knowing, learning, and doing are fundamentally embedded in localized contexts. Second, participation in these communities of practice (Lave & Wenger, 1991), activity systems (Engeström, 1987), or ecosocial systems (Lemke, 2000) is one characterized by the process of semiosis, or meaning-making. Regular patterns of semiotic activity within such contexts, which develop over time and therefore have histories of their own, are characterized as practices (Greeno, 1998; Lemke, 1997). Through participation in existing practices, participants become more established participants and practitioners, moving from legitimate peripheral participation to more central participation by aligning their own skill sets to conditions afforded in the setting where the activity occurs (Barab & Roth, 2006; Lave & Wenger, 1991). However, by working to reconfigure constituent elements of existing practices, individuals can also fundamentally alter them. Learning, then, is defined as engaging in fundamentally new forms of practice (Engeström, 1987; Lemke, 1997).

Ultimately, knowing and learning in and from practice involves two essential, mutually-constitutive elements: the process of doing, or activity, and representations that are produced through and/or employed in activity. This essential dualism between internalization and externalization has been articulated in different ways, such as participation and reification (Wenger, 1998), activity and instrument-production (Engeström, 1987), and circulating reference between form and matter (Latour, 1999). What this suggests is that while practice-specific representations take many forms, they are both used *in* activity and developed *through* activity.

This perspective has important implications for understanding how teachers construct new knowledge through teaching practice and apply that knowledge in practice. In teaching, it is routinized action that characterizes teachers' knowledge, demarcating the transitions from novice to expert teachers along the teacher professional continuum (Feiman-Nemser, 2001). This routinization is evidenced in a developed alignment between teachers' personal characteristics and features of their contexts, both material and symbolic (Barab & Roth, 2006; Brown, 2008). This developed alignment is teaching expertise. Through the process of reflective practice (Schoenfeld, 1998), teachers derive socially-constructed and culturally-mediated principles of teaching practice and reinstantiate these principles in future practice.

Teachers' knowledge production and use. Within such activities, groups of people engage in semiosis through the use of tools that orient and link the individuals, as well as groups of individuals, with the socio-material environment. These tools have to be both developed and used. Vygotsky (1978) described the dual nature of psychological tools. They are, on the one hand, externally-oriented, serving as a means through which humans affect material objects towards which an activity is directed. However, they are also internally-oriented in that they serve in self-regulation of individuals as well as the social negotiation of meaningful activity. Teachers' knowledge serves similarly as both externally- and internally-oriented tools.

To develop knowledge and expertise, teachers first reify their past experiences as principles of practice that take the form of knowledge, beliefs, identities, and general orientations. These constructs do not exist as extant entities – rather, they are constructed and negotiated through activity and mobilized as tools in activity in light of norms and conditions of the contexts in which activities occur. Classrooms are inherently unpredictable and teachers are routinely faced with novel scenarios. When such situations arise, teachers are faced with new affordances and constraints, or new combinations of them, which present them with novel activity structures which they must navigate by reorienting knowledge in practice.

For teachers, routinized knowledge constructed from previous experience serves as a guide for future practice. For example, Schön (1983) articulated this as 'knowledge-in-action', or cognitive processes embedded in activity as the fundamental essence of teaching practice. As this learning progresses, some knowledge is prioritized over others in a sort of practice-based queuing process. Some operationalize these in terms of knowledge structures (Ball & Bass, 2000) where pieces of pedagogical knowledge, subject matter knowledge, and pedagogical content knowledge are 'accessed' in variable combinations in practice and episodically and/or conceptually integrated through learning. It is therefore "not just what…teachers know, but how they know it and what they are able to mobilize…in the course of teaching…it is this pedagogically functional […] knowledge that seems to be central to effective teaching" (Ball & Bass, 2000, pg. 95).

Knowledge transfer across settings. As discussed in the previous section, teachers generate principles of practice from classroom practice and reapply these reifications to practice. However, many programs designed to promote teacher learning, including university-based formal teacher education and off-site and/or curriculum non-specific professional development, occur in contexts external to sites of authentic practice (i.e., classrooms). This arrangement is based on more traditional views of learning where knowledge exists internally, is possessed by the individual, and can be carried and applied across contexts. The ability to promote the transfer of expertise across settings, however, remains one of the most significant challenges facing both science educators (Bransford, Brown, & Cocking, 2000) and science teacher educators. A significant body of research has illustrated the difficulties teachers face in translating new ideas into classroom practice.

Transfer remains a complex phenomena to understand. Reified knowledge is based on experience. Experiences are both context-dependent and culturally-mediated. Emergent knowledge reflects features of context, such as tools (tool constellations – Engeström, 2007) and culture (rules, norms, divisions of labor, etc.). Ability to apply this knowledge in certain settings to accomplish particular goals is definition of expertise – pedagogical design capacity. Often individuals will exhibit knowledge in one setting but be unable to apply it in another. For effective transfer to occur, knowledge must be useful in both settings, possessing use-value as well as exchange-value (Barab & Roth, 2006). However, even if knowledge is viewed as relevant by an individual, the degree to which it can be effectively mobilized is dependent on consistencies between affordances and constraints across settings.

One might assert that expertise for teaching can only be developed through classroom practice. For example, as Ball and Bass (2000) point out, "no amount of pedagogical content knowledge can prepare a teacher for all of practice, for a significant proportion of teaching is uncertain" (Ball & Bass, 2000, pg. 89). While such an assertion can be reasonably derived from situated perspectives on learning, we argue, as have others (Putnam & Borko, 2000), that classroom-based and non-classroom-based experiences can both serve to support teacher learning. What this does suggest, however, is that fundamental characteristics of opportunities for teacher learning should be fundamentally aligned across settings. Such experiences can help teachers develop frameworks for knowledge construction and the development of expertise that account for underlying affordance structures across settings (Barab & Roth, 2006; Zembal-Saul, Blumenfeld, & Krajcik, 2000).

Cultural-historical Activity Theory (CHAT)

Cultural-historical activity theory is a psychological, activity-based perspective on human activity and development. Based in Marxist notions of the material basis for consciousness, activity theory emerged from the work of Russian cognitive psychologists Lev Vygotsky, A. R. Luria, and A. N. Leont'ev in the 1920s and 30s. Consistent with situated perspectives on knowing and learning, CHAT affords a perspective on consciousness as an emergent property of interactions between groups of people in certain cultural contexts rather than an entity 'in the head'. As Engeström notes, it is a "concept of activity based on material production, mediated by technical and psychological tools as well as by other human beings" (1987, pg. 25). In this way, CHAT is fundamentally concerned with socially- and culturally-mediated, as well as object-oriented, activity and the evolution of established practices over time.

The fundamental unit of analysis in activity theory is human social activity itself, driven by a goal-orientation relevant to a particular need or motive as defined by members of the community. Activity undertaken by an individual (subject) whose particular motive or need impels action oriented toward a particular problem or purpose (object). Consistent with the foundations of cognitive science laid by Vygotsy, such activity is also mediated by tools and artifacts (instruments) and by other human beings (community) within the activity system. The nature of activity as it develops is also structured and shaped by norms of the community (rules) and specialization or social stratification (division of labor). These complex relationships are embodied in the CHAT activity triangle, a generalized model for analyzing social activity, which is shown in Figure 1.

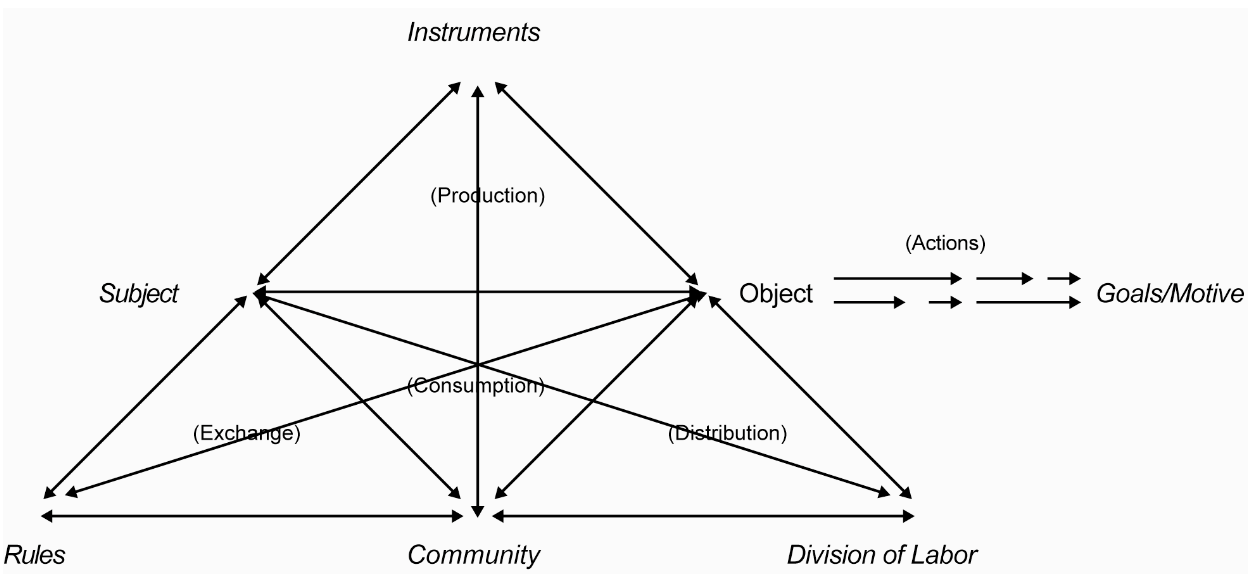

Figure 1. Cultural-historical Activity Theory Model of Human Activity (Engeström, 1987)

Activities are driven by their objects and motives. In effect, the nature of objects are twofold. First, in their physical form, they are the material space being worked on. Second, in their ideal form, they are motives and envisioned outcomes of activity. Because activity is collective, the object is continually negotiated, evaluated, and constructed.

Activities are, however, also composed of composite actions which, in turn, are constituted by conditioned operations. Operations are best characterized as the kinesthetic foundation upon which sets of actions and, ultimately, activities, are based. These operations the product of direct response to environmental stimuli, typically unconscious, routinized behaviors. In contrast, actions are consciously-driven by goals. Both actions and the goals toward which they are oriented are given meaning by the activities in which they are situated while, at the same time, constitute the achievement of the collective motive of activity.

The mediating influence of tools is a key assumption of activity theory, consistent with its origins in Vygotsky's work. Vygotsky (1978) noted the importance of tools in transforming human activity from a direct to an indirect, or mediated relationship to the environment. This is shown in the 'production' triangle in Figure 1, which illustrates the iconic triadic relationship between the individual, the environment, and mediating influence of available tools. Vygotsky argued that it is tool-use that serves to differentiate between elementary functions and higher psychological functions:

> The central characteristic of elementary functions is that they are totally and directly determined by stimulation from the environment. For higher functions, the central feature is self-generated stimulation, that is, the creation and use of artificial stimuli which become the immediate causes of behavior (1978, pg. 39).

Vygotsky further differentiated between technical tools and psychological tools, the latter of which includes signs and other referential symbols. Technical tools are simply those material tools which help individuals accomplish a particular task. Psychological tools, on the other hand, include representations and signs and are part of activity directed not just at an object but the larger ecosocial system in general. As Engeström 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" (1987, pg. 18), thus reinforcing the inherent relationship between them. Within teaching, one might extend this definition to that of conceptual tools and practical tools employed in teaching practice (Grossman, Smagorinsky, & Valencia, 1999). Curriculum materials, for example, are practical tools with which teachers engage in teaching practice. However, they are also shaped by teachers through curriculum planning and design, in which teachers employ conceptual tools, such as their knowledge and expertise, to make curricular decisions. As such, teachers' knowledge and expertise (psychological tools) support their shaping of practical tools (i.e., curriculum materials) with which they engage in teaching practice.

Production processes, however, do not occur in the abstract. Rather, they are embedded in particular social and cultural contexts that serve to mediate and shape the relationships between individuals, their tools, and the particular focus of their efforts. As shown in the CHAT triangle in Figure 1, cultural and social influences on activity include three elements: rules, community, and division of labor. Rules and norms can include both explicit regulations as well as implicit, subtle expectations about how individuals engage in relevant practices. The activity community includes all relevant individuals and can serve to facilitate or impede the attainment of motives and goals. Finally, the roles individuals assume in activity are defined through divisions of labor, which dictate both distribution of duties as well as sanctioned authority.

The CHAT model in Figure 1 provides a complete account for the structure of a given activity system, or the central activity. However, third-generation activity theory assumes that the constitutive elements of a given central activity (i.e., nodes of the triangle) are themselves the products of related, interconnected activities. For example, in classrooms where students employ inquiry frameworks as instruments to investigate scientific phenomena, these inquiry frameworks are themselves the product of scientific practices and curriculum development efforts that translate them into epistemological tools for classroom use. These networks of activity systems are illustrated in Figure 2.

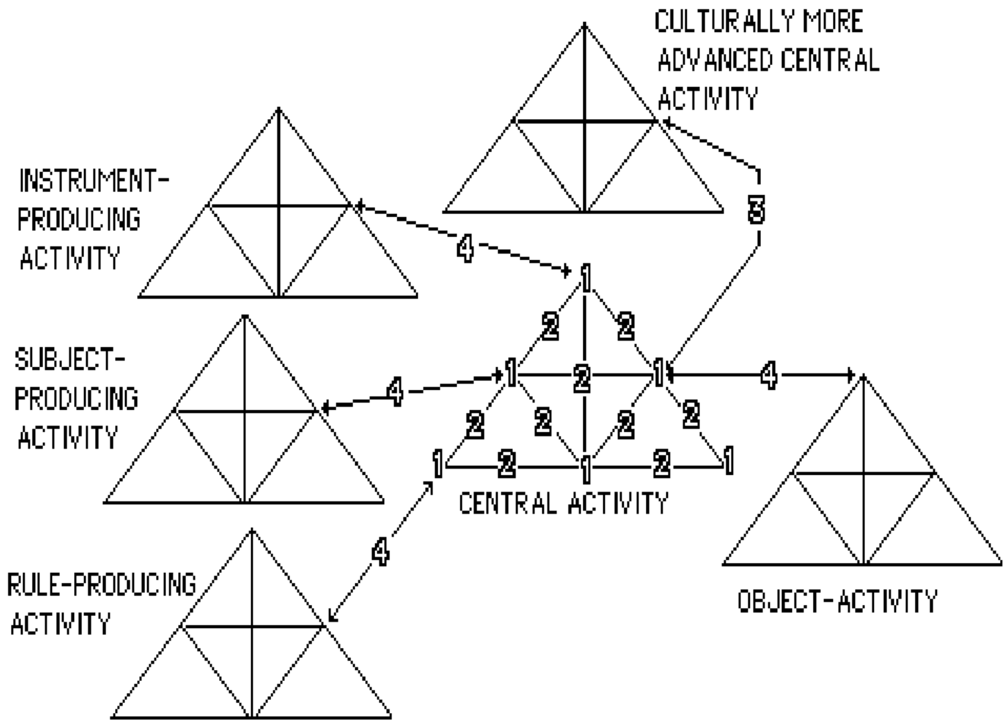

Figure 2. Networks and Contradictions of Human Activity Systems (Engeström, 1987)

Recent CHAT-based research has begun to explore the interactions between networked activity systems and this remains an important emphasis moving forward.

While activities may appear stable, there exist ever-present tensions within and between nodes of activity systems and neighboring activity systems. These contradictions arise as "the clash between individual actions and the total activity system" (Engeström, 1987, pg. 30) and are the motor for and harbinger of change in activity. There are four primary types of contradictions (Engeström, 1987). Primary contradictions (1) are those that manifest themselves within each constitutive component of the CHAT triangle. Secondary contradictions (2) arise between these nodes. Tertiary contradictions (3) arise between the object and goal of the current form of the activity and the object and goal of a fundamentally-different, often more advanced form of activity. Finally, quaternary contradictions (4) arise between the central activity and neighboring activities. These contradictions are illustrated in Figure 2.

Contradictions are important because they lie at the heart of learning in practice. And, as Engeström (1999) argues, "the internal contradictions of the given activity system in a given phase of its evolution can be more or less adequately identified…and any model for the future that does not address and eliminate those contradictions will eventually turn out to be nonexpansive" (pg. 34-35). Learning activity, or expansive learning, on the other hand, is the fundamental goal within an activity-theoretical framework. It represents capacity for expansion from actions to new activity – it is essentially an activity-producing activity. Learning activity may be conceived of as expansive movement between the act of representing to the methodology of representation. As Engeström (2000) notes, "expansive learning is energized by historically accumulated developmental contradictions within and between activity systems and is triggered by disturbances and concrete innovative actions" (pg. 309). The goal of such learning is expansive development of new, more culturally-advanced and articulated forms of activity.

CHAT can serve as a useful tool to study teachers, teaching, and teacher learning (Grossman, Smagorinsky, & Valencia, 1999). CHAT centralizes activity itself as the fundamental unit of analysis, emphasizing goal- and object-oriented material production, the cultural mediation of these processes, and how a particular activity is nested within broader networks of systems. As such, it highlights the importance of learning in context (Putnam & Borko, 2000). Teachers learn from classroom practice but these are not the only settings in which they go about their work. Especially in respect to preservice teachers, who traverse multiple activity settings on their way to becoming full-time, practicing teachers, accounting for these unique settings in which learning occurs is essential. Such a perspective also prioritizes the importance of tools, whether curriculum materials or others, that teachers use to structure and guide classroom practice. In this way, the CHAT model provides a mechanism through which to attend to both individuals and the worlds in which they learn and develop. It is hoped that through this work, we may move closer to better describing the ways in which various knowledge forms influence, and are developed within, authentic teaching activity (Cochran & Jones, 1998). However, to fully realize the potential for CHAT-based research on teachers, teaching, and teacher learning, more work is needed to inform and facilitate such research.

Methods

In this section, we present and describe two CHAT-based studies of science teacher learning and practice, providing a description of their explicit theoretical and analytical grounding in CHAT. In Study A, Forbes and Davis use CHAT to investigate preservice elementary teachers' curriculum design and development of pedagogical design capacity for inquiry during the final year of their formal teacher education. In Study B, Madeira and Slotta adopt the theoretical perspectives of CHAT to understand how the various teacher activities of planning, enactment, reflection and peer exchange influence the secondary science teachers' development of PCK in a professional development context. For each study, we provide a justification and grounding in the literature, overview of the study population and study design, the explicit CHAT-based models we employed, and finally our methods of data collection and analyses.

Study A - Preservice Elementary Teachers' Development of Pedagogical Design Capacity – An Activity-Theoretical Perspective

Background. To best promote student learning, teachers need to engage students in scientific inquiry (AAAS, 1993; NRC, 2000). While there are many ways to support teachers' understanding of and engagement in reform-minded, standards-based, inquiry-oriented teaching practices, curriculum materials remain one of the most widespread. However, rather than enacting science curriculum materials 'as-is', teachers actively mobilize, evaluate, critique, and adapt curriculum materials (Remillard, 2005). The curriculum design process is a function of teachers' personal characteristics (knowledge, beliefs, and identity, etc.), features of the curriculum materials, and features of their professional contexts (Enyedy & Goldberg, 2004; Roehrig, Kruse, & Kern, 2007; Schneider, Krajcik, & Blumenfeld, 2005). Together, these three factors, as well as the goals toward which classroom activity is oriented, constitute the pedagogical design capacity a classroom system affords a particular teacher. In order to leverage and maximize the capacity for pedagogical design afforded them, teachers need to learn to use curriculum materials effectively (Brown, 2008; Remillard, 2005; Shulman, 1986).

Because beginning teachers tend to rely heavily on curriculum materials (Valencia, Place, Martin, & Grossman, 2006), it is important for preservice teachers to begin to learn to how use curriculum materials to engage in inquiry. Some science teacher educators have begun to investigate the use of curriculum materials in science teacher education (Davis, 2006; Forbes & Davis, 2008; Schwarz, Gunckel, Smith, Covitt, Enfield, Bae, & Tsurusaki, 2008). While this research has provided some insight into preservice elementary teachers' use of science curriculum materials, more work is needed to inform the design of science teacher education so as to facilitate preservice teachers' developing pedagogical design capacity for inquiry. The goal of this study is to develop a better understanding of how preservice teachers instantiate their espoused inquiry frameworks in the instructional plans they develop and teach, as well as how this curriculum design process is socially- and culturally-mediated across contexts.

Study overview. This study involves in-depth case studies of four elementary preservice teachers during the final year of their teacher education program. Using qualitative research methods, we investigated these four preservice teachers' development of pedagogical design capacity for inquiry, first during an elementary science teaching methods course (for which the author was the instructor) and then during their subsequent full-time student teaching semester. The four preservice teachers were voluntary participants who were selected using maximum-variation and typical-case sampling (Patton, 2001). The focal point for data collection and analyses were four science lessons the preservice teachers planned and enacted in elementary classroom during the academic year (2 during the methods course and 2 during student teaching).

CHAT-based model. Cultural-historical activity theory was used in this study as an explicit theoretical, analytical, and explanatory framework. Drawing on activity-theoretical frameworks, specifically Engeström's (1987) model of interacting activity systems (Figure 2), we constructed a model for preservice teachers' curriculum design for inquiry. This model is shown below in Figure 3.

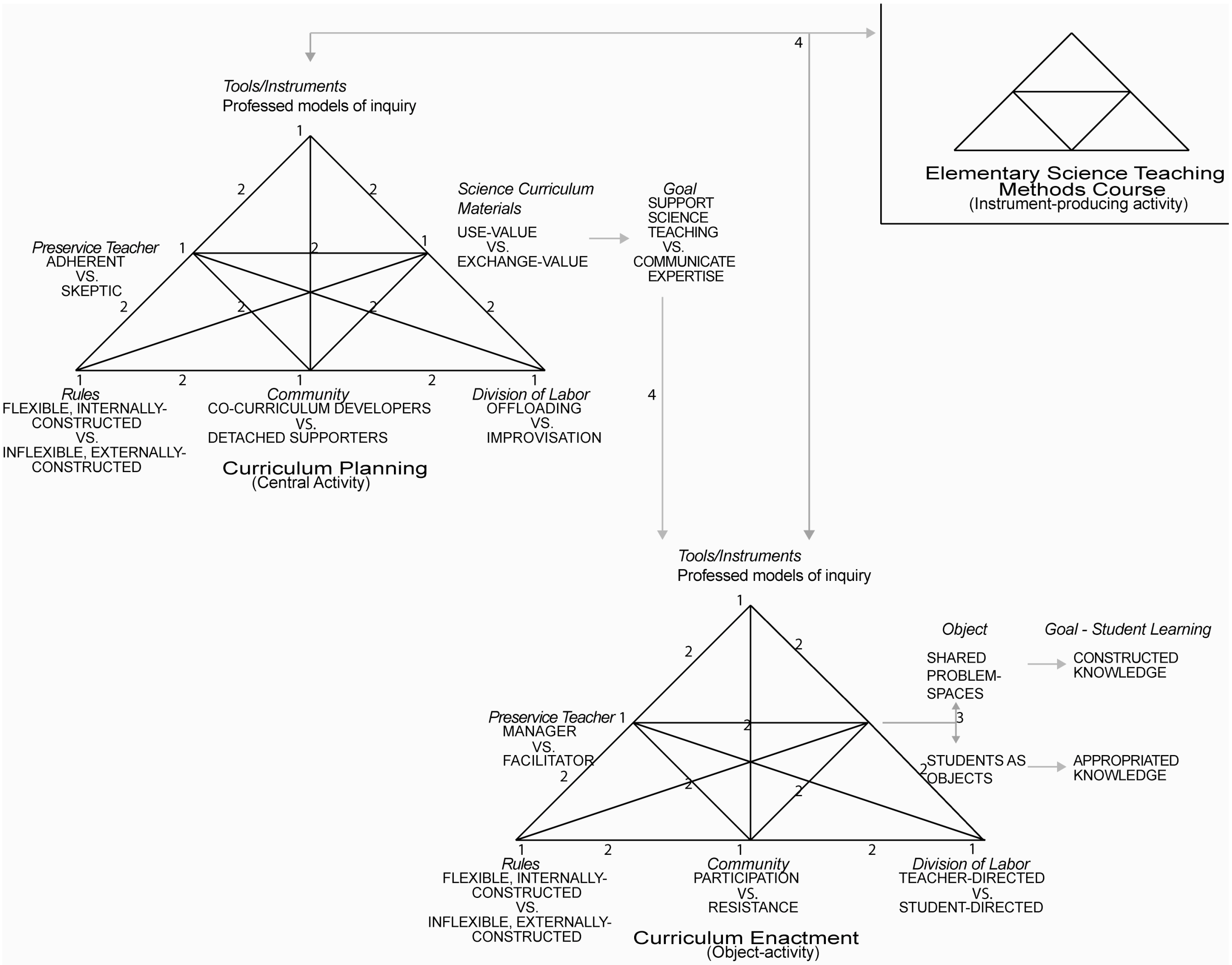

Figure 3. Activity-theoretical framework for preservice teachers' curriculum design for inquiry

In this model, there are two interacting activities that are relevant to this study. Curriculum planning (central activity) and curriculum enactment (object-activity) are foregrounded as constituting curriculum design for inquiry, consistent with existing descriptions of teachers' practice (e.g., Remillard, 1999). These activity systems are inherently interrelated. In both the curriculum planning and curriculum enactment activities, the preservice teachers are the subjects whose perspective is assumed in curriculum design. In curriculum planning, they employ their espoused inquiry frameworks (instruments) to work with curriculum materials and produce inquiry-based instructional plans (object-motive). In curriculum enactment, they employ these instructional plans as instruments to either construct problem-spaces through which students construct explanations or act upon students to insure their appropriation of existing scientific explanations (object-goal). Curriculum planning is mediated by structures and guidelines provided by the methods course (rules/norms), the preservice teachers' peers, methods instructor, and cooperating teachers (community), as well as the inherent roles the preservice teachers and other associated community members fulfill (division of labor). Similarly, curriculum enactment is influenced by classroom- and school-based regulations, as well as norms of professional teaching (rules/norms), cooperating teachers (community), and the ways in which the preservice teachers, cooperating teachers, and students actively negotiate their roles in classroom activity (division of labor).

The model in Figure 3 provides a number of specific affordances. First, it highlights of the use of both symbolic and material tools (preservice teachers' espoused inquiry frameworks and science curriculum materials), what Engeström (2007) refers to as 'tool constellations', with which they engage in curriculum design for science. Second, the model affords the ability to map the construction of science lesson plans as boundary objects between curriculum planning and enactment domains. Finally, third, by identifying contradictions that the preservice teachers articulate within and across settings, it is possible to link their curriculum design decisions to underlying contradiction-specific rationales. Ultimately, this model, in addition to other representational tools described in the next section, affords the ability to trace the emergence and resolution of contradictions over time.

Data collection and analysis. Data were collected throughout the academic year and included interviews, lesson plans and instructional artifacts, reflective journals, and observations of enacted science lessons. To code this data, three coding keys were developed. The first two were descriptive coding keys used to identify the types of curriculum materials the preservice teachers used and adaptations they made in their lessons. A third coding key was developed to identify contradictions and was explicitly aligned with the CHAT-based model in Figure 3. Codes were included for each node of the curriculum planning and curriculum enactment triangles, as well as for the elementary science methods course. The core component of this coding key is a set of codes for the essential features of inquiry promoted in *Inquiry and the National Science Education Standards* (NRC, 2000).

Qualitative analysis involved standard qualitative research methods, characterized by an iterative process of coding, reduction, displaying, and verification of data (Miles & Huberman, 1994) that were directed towards the development of case studies (Yin, 1994). To analyze the coded data, we engaged in a stepwise process of data representation and reduction, the goal of which was to identify contradictions in within and across curriculum design contexts that explained preservice teachers' curriculum design decisions. This process involved two important steps. First, to identify contradictions, coding queries were performed on codes from the primary coding key for each activity node and overlapping node codes. Second, to link contradictions to curriculum design decisions, additional coding queries were performed to identify overlaps between identified contradictions from the previous step and codes for curriculum design decisions (coded with the other two coding keys). Two coding matrices were used to display these relationships, one that was lesson-specific and one that was contradiction-specific. The latter was necessary to trace the resolution of particular, pervasive contradictions over time and characterize preservice teachers' evolving inquiry frameworks and curriculum design practices.

Summary. In this section, an overview and description of Study A has been provided, focusing specifically on its grounding in and alignment with CHAT. Ultimately, the goal of this CHAT-based study was to provide evidence for how the preservice teachers engaged in curriculum design for inquiry, perhaps in fundamentally novel ways, to alleviate the contradictions they articulated within and across teacher education and elementary classroom contexts.

Study B – How Pedagogical Content Knowledge Develops: The Impact of Reflection and Community

Background. While many researchers have advanced the notion of PCK (Shulman, 1986; 1987; Roth, 1998; Loughran et al., 2001; De Jong, 2003), there remains a gap in our understanding of how this knowledge develops over the course of a teacher's career. There are many factors that would likely influence the development of pedagogical content knowledge (PCK) such as: the teacher's content knowledge within a subject domain (CK/SMK), the students' prior knowledge, the pedagogical approaches employed (PK), interactions between students and teacher, student assessments, and how the teacher reflects on these experiences before, during and after the instruction (Morine-Dershimer & Kent, 1999; Magnusson, Krajcik & Borko, 1999). Many scholars comment on the complex and cognitive nature of teacher planning and the teaching of any subject area, influence on teacher knowledge (Magnusson, Krajcik & Borko, 1999; Resnick, 1987; Leinhardt & Greeno, 1986). Teachers' knowledge growth can occur through professional development, which can "help teachers develop cohesive understanding about inquiry instruction by building on their existing ideas about student learning, technology and the role of the instructor" (Slotta, 2004, p 203). However, most teacher professional development is decontextualized. This study is designed to investigate the development of a teacher's PCK in relation to their instructional practices within the classroom (e.g., lesson design, preparations, classroom interactions, assessment and feedback), and student understanding. It will explore two interventions of reflection and peer-exchange.

Study overview. This three-year longitudinal study uses iterative design-based methodology to investigate the development of pedagogical content knowledge of nine science teachers' (*N*= 9) in relation to their instructional practices (e.g., lesson design, preparations, classroom interactions, assessment and feedback), and student understanding. The focus is on two specific interventions that serve to promote professional development: reflection and peer-exchange. Teachers co-design and then enact a project-based, technology-enriched science lesson. Four main phases of teacher activities were captured by this study: (1) Prior teacher knowledge and experience; (2) Lesson design; (3) Classroom enactment; (4) Revision of lesson design.

Data collection and analysis. Data sources include teacher surveys, interview questions, lesson plans, reflections (captured in a wiki), videotaped classroom enactments, field notes, student artifacts and responses, peer exchanges (on wiki, and in group meetings). Following Grossman (1990), Gess-Newsome & Nederman (1999) and Koeher & Mishura (2005), all wiki documentation, interviews and field notes were coded for different categories of teacher knowledge, including: pedagogical content knowledge. For each coded knowledge element, a qualitative score of 0-3 was assigned. For PCK, 0 represented the absence of that knowledge, while 3 represented a very clear understanding of students' prior knowledge and appropriate teaching strategies. These coded knowledge elements were used as data for subsequent CHAT analysis when combined with other enactment coding measures.

The activity and action patterns from the teachers' classroom enactments were identified from video documentation and field notes, and these were coded for types of action: Small group interactions (SGI); Large group interactions (LGI); Logistic actions (Log); and Isolated actions (Iso). Both SGI and LGI were subdivided into management (M) and pedagogical actions (Ped). Each type of action became its own segment. A qualitative score of 1-3 was assigned for the content of interaction. A score of 3 represented strong engagement and strongly addressing student learning needs. A score of 1 represented poor engagement or poor interaction. SGI and LGI were then further coded and scored for content of interaction, such as revisiting ideas (Rev), performing important social community actions (SoC). The qualitative score for the content of interaction used the same criteria as SGI and LGI. Students' activities were coded as either SGI or LGI and given a qualitative score of 1-3 based on the engagement, either with student peers, or with teacher. A score of 3 represented high quality of engagement such as being on task and asking relevant questions. A score of 1 represents a weaker level of engagement. The SGI and LGI qualitative score was multiplied by the time frame of that segment and this value was then graphically represented, following Stussey (2002). These codes were then cross-referenced to the nodes on an activity triangle for teacher enactment of project-based lessons, providing an iterative activity-based analysis.

CHAT-based model. CHAT was employed to connect these scored knowledge elements with nodes on the activity triangles. Next, the activity and action patterns from the teacher classroom enactment were identified from video and field notes, coded for types of action: Small group interactions; Large group interactions; and Logistic and Isolated actions. These codes were also cross-referenced to the activity triangles, and subjected to an iterative activity-based analysis.

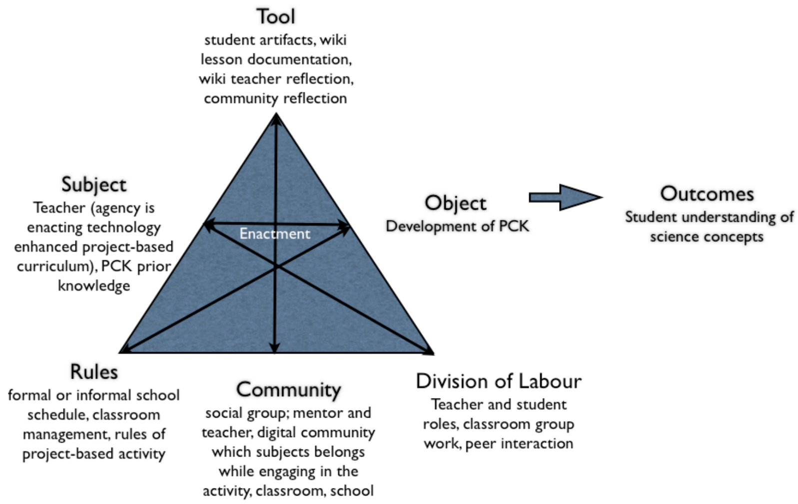

Figure 4. Adapted from Engeströms' Activity Theory *(1987)*

Study B utilizes activity theory to account for teacher-human activity as it transforms an object (their own PCK) in context (Engeström, 1987, 1999, Kuutti, 1996; Nardi, 1996) and provides new approaches to the analysis of activities. An activity system consists of a participant (e.g., the teacher or teachers) who has intent to act (e.g., teach) on an object (e.g., teacher development of PCK) as well as the tools (e.g., wikis, lesson plans, powerpoints) that mediate between the participant and object. Interpreting the activity through such a schema allows an emphasis on the connection between consequential actions and implicit knowledge related to those the actions. Teaching is often quite implicit with regard to the knowledge underlying any particular execution. The connections between the teachers' lesson plans and outcomes of student understanding are not straightforward. Activity theory offers a model for representing and interpreting the teachers' conscious teaching activities, and embraces the socio-cultural and historical perspectives of the teachers' day-to-day life.

Summary. In this section, an overview and description of Study B has been provided, identifying critical areas where CHAT provides a valuable analytical lens to connect with coding schemas of teacher knowledge development and classroom actions. In this study, activity theory identified the impact of the association between teacher knowledge and the development of PCK, mediated through wiki documentation of teacher lesson plans, reflections and student artifacts. The teacher's experience and prior knowledge (subject node), mediated through lesson plans (tool) is a key determinant in the development of PCK (object node). The tools within the activity system made knowledge more visible and indicated commonalities across all nine participants in their knowledge of problem-based strategies and its use within a science classroom. CHAT assisted in the recognition of tensions and contradictions that prompted the emergence of new rules and critical junctures for new knowledge development.

Challenges and Opportunities of CHAT-based Research on Teachers

There have been recent calls for increased use of cultural-historical activity theory in education research (Roth, 2004; Roth & Lee, 2007), including research on teachers' practice, expertise, and learning (Grossman, Smagorinsky, & Valencia, 1999). However, there remains little CHAT-based research focused on teachers and teaching, particularly in science. The two parallel studies presented in previous sections are unique in that they draw explicitly upon CHAT as both theoretical and analytical frameworks to investigate science teacher learning. In undertaking these studies, however, we have also experienced unique challenges to the use of CHAT in research on teachers that have generated theory- and research-related questions. We believe these are important issues to be addressed in future CHAT-based research.

Conceptualizing CHAT-based Models for Teachers' Practice and Learning

One primary affordance of CHAT is a concrete model applied to the analysis of various forms of activity. However, as with all models, the generalized version must be adapted to a particular activity setting of interest. A substantial amount of theorizing and model building must happen during research, as well as before and after data collection. In effect, theory building and data analyses are iterative processes. Just as one's model can shape research, so too do findings shape one's model.

In the two studies here, the CHAT-based models articulated by the authors were crucial tools in identifying and describing contradictions. For example, in Study A, CHAT was instrumental in identifying a tertiary contradiction in the preservice teachers' curriculum enactment between two objects and goals of curriculum enactment that should lead to student learning of predefined learning goals. This contradiction is illustrated in Figure 5 below.

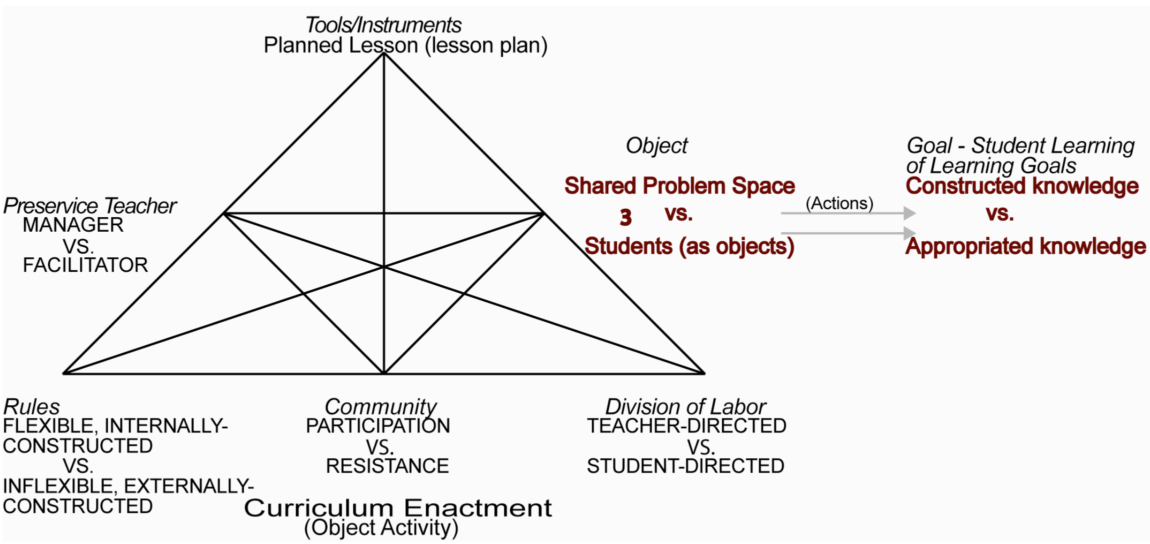

Figure 5. Tertiary Contradiction Between Traditional, Didactic and Constructivist Science Teaching

Ultimately, this contradiction revolved around the need for students to meet predetermined learning goals. On the one hand, classroom science could position students as objects of activity to appropriate these learning goals. While this perhaps afforded a greater degree of certainty that students could meet these learning goals, it also, to these preservice teachers, necessitated engaging in more teacher-directed instruction. On the other hand, students could be positioned as community members who, through the construction and shaping of shared problem spaces, could be provided the opportunity to construct scientific explanations. However, the preservice teachers perceived doing so as forgoing some of the certainty that students would construct the predetermined, scientific explanations which their lesson-specific learning goals emphasized. While there is evidence that some of the preservice teachers made progress in resolving this contradiction, all were still struggling to reconcile it at the end of the study.

In Study B, the model helped identify the association and tensions between teacher-tool and-object, and was able to illustrate how this tension shifted in the activity system to augment PCK development (see figure 6 below). The use of the CHAT model was helpful to frame how teacher artifacts (such lesson design) can revise their knowledge and impact their PCK development. The coding of all the SGI and LGI instructional actions seen in the video tapes and field notes of teachers' lesson enactments provides a means of linking specific teacher moves with tensions seen in the activity theory model. The tensions within the AT model are critical to identifying learning moments within the lesson activity, which can then be traced to the revisions of lesson design, the wiki-reflections and the next iteration of enactment.

Using hierarchical structures first presented by Leont'ev (1978), three levels of the activity of project-based lessons can be described. Table 1 below, adapted from Barab's (2004) framework, illustrates the hierarchical structure of "automatic, conscious and cultural levels" of behaviour within one participant's lesson activity (Merle - pseudonym name). The table portrays this teacher's operations, actions and activities, allowing further analysis of the contradictions or tensions created within the teacher's activity system. These contradictions impact changes in teacher practice and most importantly are critical for the teacher in their development of pedagogical content knowledge.

Table 1. *Hierarchical Distribution of Components in Activity System: Teacher Development of PCK of Merle*

Hierarchy of Activity Components	Activity Systems Descriptions	Contradictions/Tensions	PCK development – as seen in Lesson Revisions and Revised Enactments
Activity	Project-Based Lesson – Podcasting of Physics Exhibits: outline goals - vision	First time through the lesson design: comments on assessment; and also on podcasting template design.	"Working on the lesson plan' have to change the working." *(quote in enactment video -11-10-08) This tension is seen as positive because it indicates knowledge acquired within enactment caused lesson design to change shape while lesson in process.*
Actions (s)	Development of wiki site for podcasting, podcasting approach, curriculum addresses, wiki reflection, community.	Recognized opportunity of using wiki-student template; went through in detail how to use the wiki and the lesson; wiki reflections about project-based learning, step-by-step organization of template. Wiki reflections, and wiki-lesson designing template.	Changed lesson to accommodate student-wiki template. Instructions on the wiki-student template. "I went through the process more for myself than the students" (*INT-15-10-08)*.
Operation(s)	Lecture, demos, taking attendance, lesson design, workshops for students, (different interdisciplinary assignments)	Teacher is new to her school, although is an expert teacher, learning about the community	

Table 1 provides the components for an activity triangle of this teacher's project-based activity, seen here in Figure 6.

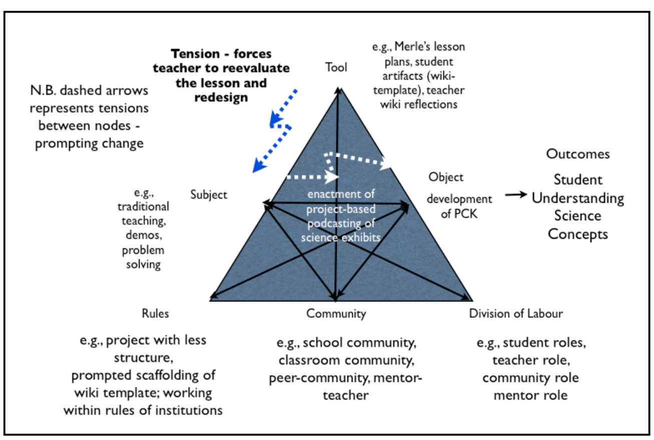

Figure 6. Activity Triangle of Merle's Project-based Lesson

However, in attempting to use the CHAT framework to study teacher learning, a number of issues have emerged. First, as others have argued, 'schooling' is an activity (Engeström, 1987; Roth, 2007). However, these conceptualizations have often been articulated with the student as the subject of the activity. The activity of schooling is reconfigured when viewed through the eyes of the teacher (as subject). In the two studies highlighted here, the CHAT-based models differed substantially. One key difference was the number of activity triangles used to represent teachers' professional practice. A question remains - do teachers' planning and enactment constitute distinct activities as often described (e.g., Remillard, 1999, 2005) or are they, as 'schooling' is for students, part of the same professional practice of 'teaching' for teachers?

Methodological Issues in CHAT-based Research

Just as focusing research on a defined, workable set of activity systems is essential in CHAT-based research, so too is identifying and mobilizing appropriate data and data analysis methods (Williams, Davis, & Black, 2007). Consistent with Vygotsky's (1978) emphasis on language, many CHAT-based studies have foregrounded the discursive nature of classroom activity (e.g., Barab, Barnett, Yamagata-Lynch, Squire, & Keating, 2002; Nardi, Whittaker, & Schwarz, 2002; Rainio, 2008; Roth et al., 2004). However, there are also some specific examples that employ other research methods. For example, Bodker (1995) provides an explicit observation framework for applying CHAT to the analysis of videocases. Similarly, Yamagata-Lynch (2007) describes the use of qualitative analytical methods to initially conceptualize the activity systems of teacher professional development. These studies are effective examples of how specific research methods have been used in CHAT-based research and provide insight into the mapping of specific analytical methods onto CHAT-based theoretical frameworks.

A crucial issue in CHAT-based research revolves around the identification of contradictions in activity systems. Contradictions are evidenced in observed shifts in actions that result from conflict between those individual actions and the collective activity, as well as how individuals reify such shifts. The two studies here took unique approaches to identifying and analyzing contradictions. However, we both identified a number of methodological challenges associated with identifying and analyzing contradictions. In study B, the video traced the actions within the classroom such as student activities and final student project artifact, and this triggered more scripted rules for lesson plans in the next cycle of lesson planning. The ability to move any node on the triangle triggered by tensions and contradictions has advantages when studying complex systems such as the classroom. This pattern of activity helps in understanding multiple activity systems. Given Engeström's emphasis on characterizing operations, actions, and activity, when observational data is analyzed, how can connections between the micro and macro levels of human activity can be made? Bødker (1996) provides guidance though analysis of video, by using terms of system, tool, and medium. In using these terms the focus shifts, or the breakdown of actions, which demark tensions and contradictions are identified. Below is an example of the triangles for two iterations of another participant - Charlie's enactment of lesson (pseudonym name) (Figure 7 and 8 below).

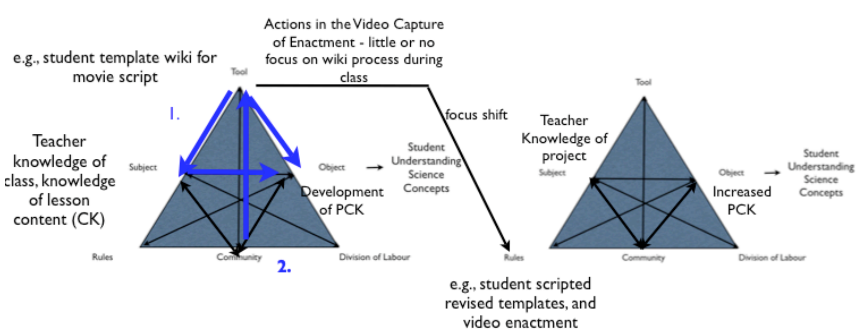

Figure 7. Activity System for Charlie's first enactment; Grade 11 Physics Sound -Video

Figure 8. Activity System for Charlie's second enactment; Grade 11 Physics Electromagnetism

* Tensions - blue arrows

1. No wiki script to follow student understanding and process within project;
2. Teacher and students engage in process of project - recognize process not clear)

In the first system two tensions or contradictions (blue arrows) identified through the coding of teaching knowledge and actions and the placement of these items on the nodes on the activity triangle. By documenting these tensions between tool-subject-and-object, and between community-tool-object (see Figure 7 and 8 above), the emergence of new rules and structures developed within next iteration of teacher enactment.

In Study A, data coding involved a coding scheme explicitly aligned with the CHAT-based model presented earlier in Figure 3. The objective of this approach was to identify contradictions underlying preservice teachers' curriculum design decisions and trace the resolution of these contradictions over time. For example, in their lesson planning, the four preservice teachers (subject) acknowledged, in nearly all of the science lessons they taught, the authority their mentor teachers held (division of labor) in determining how and how much they could modify existing curriculum materials to produce their planned science lessons (object). In many of these lessons, boundaries established by their mentor teachers ultimately limited the preservice teachers' abilities to plan and develop more inquiry-oriented science lessons. However, in each of these four cases, the preservice teachers accepted this division of labor as a natural part of student teaching and did not outwardly identify it as a tension or contradiction. This finding, while in some ways not unexpected, highlights challenges associated with identifying contradictions. What distinguishes a contradiction, often described as a tension, from a simple observed relationship between nodes of the activity triangle that might also comprise a rationale for particular action, in this case curriculum design decisions? What criteria would help operationalize the notion of contradiction and distinguish between the two with methodological rigor? These are crucial issues that must be resolved for specific activities to be mapped on to conceptualized CHAT-based models.

The previous paragraphs provide some insight into how we attempted to identify and analyze contradictions in teachers' practice. In existing CHAT-based research, however, both within education and without, there is limited guidance in terms of research methods. In many of the empirical studies we reviewed, specific linkages between research methods used and study-specific CHAT-based frameworks are not explicitly described and discussed. This trend risks creating a 'black box' scenario in CHAT-based social science research that is similar to that of research in the natural sciences (Latour, 1987), where the mechanics by which evidence collected, mobilized, analyzed, and used to make claims within CHAT-based research paradigms remains hidden. More clarity is needed to map the most useful research methods onto specific CHAT-based research and communicate those methods.

Using CHAT as an Explanatory Framework

It is critical for CHAT-based models to possess explanatory as well as descriptive power (Halverson, 2002). In addition to mapping analytical methods onto CHAT-based theoretical frameworks, researchers must also map resultant claims back onto CHAT-based models and employ these models as explanatory frameworks. Consider an example from Engeström's (2008) keynote paper from the annual meeting of the International Society of the Learning Sciences. In discussing the essential role secondary contradictions play in driving changes in practice, Engeström writes,

> A typical secondary contradiction in the activity of school-going may be, for instance, triggered by the introduction of computers and the Internet into the students' work. Internet opens up a huge range of interesting and entertaining objects that potentially jeopardize the school's control over students' attention and effort in the classroom (pg. 12)

While this is just but one example, the reader is left unsure as to the exact nature of the secondary contradiction. Does this indicate a contradiction between technology and new objects? Or perhaps it represents a secondary contradiction between one of the other nodes of the activity system and either technology or new objects. With no CHAT-based visual representation upon which to anchor the words, it is more difficult to derive meaning from the description. In order to locate empirical findings in the theoretical assumptions that drove the research, it is necessary to employ multiple CHAT-based representations.

There are some effective examples of this in existing education research (Barab et al., 2002; Yamagata-Lynch, 2007). However, there are many other examples in which CHAT-based models and frameworks fail to reemerge in the presentation, interpretation, and discussion of research findings. One possible reason for this is that the CHAT model is difficult to employ as an explanatory framework for phenomena that change over time. The prototypical CHAT triangle model is most helpful in capturing a snapshot of activity at any given time.

> Engeström's triangle, for example, although effective in representing the transactional relationships potentially at play within an activity system, nevertheless represents a moment frozen in time or, at best, a synoptic, atemporal generalization that subsumes many diverse, particular instances. For a theory that deals with situated practices dynamically unfolding in real time, it is ironic that its best-known representation should be so atemporally static. Let me hasten to add that this is not a criticism of the expanded triangle of activity as such, but rather an observation about all visual representations of dynamic processes. (Wells, 2004, pg. 76)

While change is inherent to the model, as Engeström (1987) argues, it nonetheless presents a challenge in actually representing change using the model in standard modes of research reporting and publication. One possible solution to this is to explore multi-model forms of representation to employ with CHAT-based explanatory frameworks. The evolution of activity, consistent with the theoretical foundations of activity theory and the results from this study, depends on a cascade of contradictions. In effect, the resolution of one contradiction often leads to another and so on until a new state of equilibrium is reached within activity. To account changes in activity, one needs to provide and illustrate a sequential accounting of the resolution of these contradictions. One cannot easily illustrate this in a static, unchanging CHAT-model. As has been argued by other education researchers (Ball & Lampert, 1999), new modes of representation should be explored and employed in education research. Here, animated versions of specific CHAT-based models could perhaps better illustrate the emergence and resolution of contradictions over time. Exploring new ways to enliven the CHAT model, and make it more dynamic, would help maximize the utility of CHAT as an explanatory framework.

Conclusion

The two studies presented here contribute to a limited but growing body of CHAT-based education research. This research has begun to, and will undoubtedly continue to yield new and useful insights into formal and informal teaching and learning. Specifically, the two studies described in this paper illustrate how CHAT can be employed in research on science teachers' expertise, practice, and learning. However, the fusion of the CHAT framework with the material and conceptual spaces in which teacher learning and practice takes place is not without its struggles. As an emergent research domain, it presents many questions to yet be addressed, particularly methodological ones as discussed here. Many questions remain as to ways in which to mobilize particular research methods to develop cases and make claims about teacher learning within the CHAT framework. We believe that these are important issues that should be further explored for the promise of CHAT to be more fully realized in educational research.

CHAT may well provide novel ways of conceptualizing, describing, and analyzing formal schooling and its constitutive elements. In order to do so, however, CHAT must be accessible and employable by a range of scholars for research in various contexts. Unfortunately, CHAT has arguably suffered from a number of challenges. First, CHAT has only recently begun to garner attention in the West, particularly the United States. As a result, while some U.S. scholars are familiar with CHAT, most have limited access to CHAT-oriented communities and resources. While there appears some critical mass for CHAT-based scholarship in the computer-support learning community, there is virtually no community of CHAT-based scholarship focused on teachers, teaching, and teacher education.

Second, there is little methodological guidance in existing CHAT-based research that provides in-depth, detailed examples of the mechanics underlying how CHAT has been operationalized and mapped onto the study of specific phenomena. In short, with the exception of a few individuals who are direct descendants in a lineage of CHAT-based scholarship, the U.S. educational research community has not been fundamentally shaken by the emergence of CHAT. Not only are most yet unfamiliar with tenets of CHAT, even fewer posses experience and expertise applying CHAT to research. As a result, within the U.S. educational research community, CHAT has thus far tended to serve as much as a badge of association as a tool for a community of empirically-based scholarship.

> This triangle has become a ubiquitous slide or overhead at countless conference presentations I have attended and numerous articles published in U.S. and international journals. And yet I do not see in U.S. research, for the most part, its relevance to the issues under study…the activity triangle, much like the oft-trivialized ZPD of recent years, has become for many a means of affiliation with a fashionable theory rather than a conceptual tool for conducting a rigorous activity analysis (Smagorinsky, 2009, pg. 93)

To be accessible and optimally-useful, CHAT must become more than an identity for its adherents – it must become an explanatory tool or instrument and mode of communication for its users. It is through this shift that the much touted and anticipated promises of CHAT-based research may best be realized.

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