Activity-Theoretical Research on Science Teachers' Expertise and Learning

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Abstract: Teachers serve as critical mediators of student learning. As such, teachers' expertise and learning remain important foci for theoretical development and empirical research. Cultural-historical activity theory (CHAT) has been forwarded as an underutilized but potentially powerful tool for educational research, including teachers' expertise, practice, and learning. However, as yet, little CHAT-based research has been undertaken focused on science teachers and teaching. In this paper, we draw upon two such empirical studies in which CHAT was used as an explicit theoretical and analytical framework to explore CHAT-based perspectives on science teacher learning. We present findings from these studies to highlight important themes in CHAT-based research on science teachers' learning in and from practice. These findings can not only inform programmatic efforts to better promote teachers' learning, but also theoretical perspectives on science teachers' expertise, practice, and learning across the science education and learning sciences communities.

Background and Theoretical Framework

In this paper, we present results from two CHAT-based studies of science teacher learning and practice to discuss theoretical contributions of CHAT to perspectives on science teacher learning and practice. In Study A, Forbes uses 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 use CHAT to investigate how lesson planning, enactment, reflection and peer exchange influence experienced secondary science teachers' development of pedagogical content knowledge (PCK) in a professional development context. Full findings from each of these studies have been presented previously. We therefore summarize here the study populations and designs, their explicit theoretical and analytical grounding in CHAT, the CHAT-based models we employed, methods of data collection and analyses, and main findings from each study. The primary purpose of this paper is to instead synthesize findings across these two studies to highlight and explore implications they hold for CHAT-based perspectives on teachers' learning and practice. These new theoretical insights can inform future research on science teachers and teaching.

Situated Perspectives on Teachers' Knowledge and Expertise

Teaching is a complex and dynamic activity that requires teachers to develop robust expertise in order to best promote and facilitate student learning of science through inquiry. Teachers' expertise, and the manner in which it develops over time (i.e., learning), is fundamentally situated and embedded in contexts of practice. Participation in these communities of practice (Wenger, 1998), 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. Through participation in existing practices, participants become more established participants and practitioners by aligning their own skill sets to conditions afforded in the setting where the activity occurs (Barab & Roth, 2006). 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, 2000).

This perspective has important implications for understanding teacher learning. Teachers derive socially-constructed and culturally-mediated principles of teaching from practice and reinstantiate these principles in future practice. 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. Over time, their practice becomes more routinized. In teaching, it is routinized action that characterizes teachers' knowledge, demarcating the transitions from novice to expert teachers along the teacher

professional continuum. 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, 2009). This developed alignment represents teaching expertise.

Questions surrounding teachers' knowledge, expertise, and learning have held a prominent role in education scholarship for many years (e.g., Putnam & Borko, 2000; Shulman, 1986). While such research has made invaluable contributions our understanding of teachers' knowledge, beliefs, identities, and orientations, a great deal remains uncertain about the nature of teachers' expertise and learning. Like many practitioners, teachers often struggle to articulate and represent the principles and rationales underlying their professional practice. There remains little to no consensus as to what exactly constitutes teacher expertise and how to differentiate between expert and novice teachers. We suggest that there exists a strong rationale for exploring the utility of novel theoretical and analytical perspectives in subsequent research on teachers' expertise and learning.

Cultural-Historical Activity Theory (CHAT)

To better operationalize, capture, and describe expertise for teaching, cultural-historical activity theory (CHAT - Engeström, 1987) has been forwarded as a potentially useful tool for educational researchers (Grossman, Smagorinsky, & Valencia, 1999; Roth & Lee, 2007). Cultural-historical activity theory is a psychological, activity-based perspective on human activity and development. 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 (1987) notes, it is a "concept of activity based on material production, mediated by technical and psychological tools as well as by other human beings" (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 Vygotsky, 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.

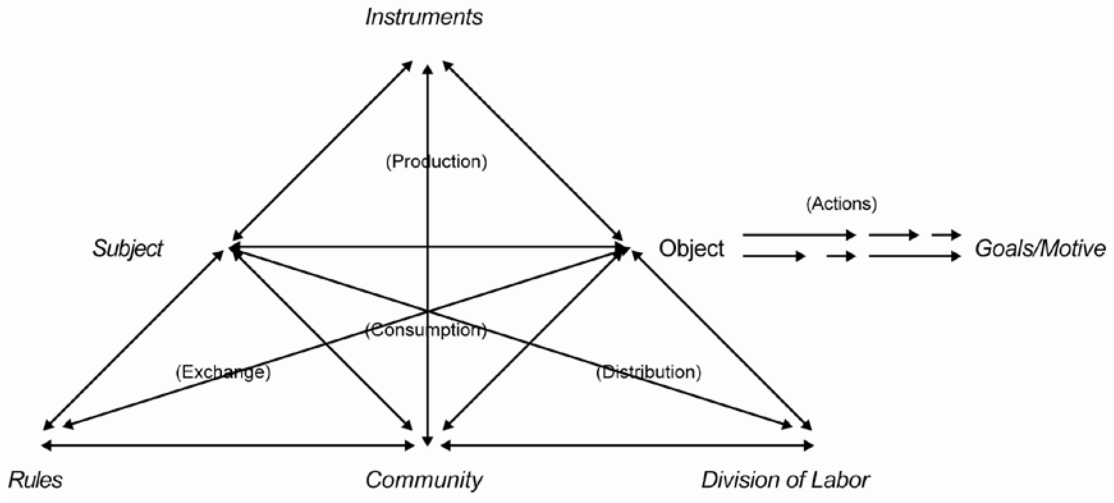

Figure 1. Cultural-historical Activity Theory Model of Human Activity (Engeström, 1987)

Activities are driven by their objects and motives. 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 are 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. 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. 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. Cultural and social influences on activity include three elements: rules, community, and divisions of labor.

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. As such, a particular activity system is itself embedded in networks of activity systems. While these 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. Contradictions are important because they lie at the heart of learning in practice. These contradictions, which develop within and between bounded activity systems or practices, like at the heart of learning in practice in that they must be negotiated and addressed to engage in culturally-more advanced forms of an existing practice. 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.

However, CHAT-based research on science teachers, teaching, and teacher learning is limited. 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 twofold. First, we describe two studies that use CHAT to investigate science teacher learning through iterative cycles of instructional planning, lesson enactment, and reflection on practice. Second, we identify and discuss important theoretical contributions to perspectives on teacher learning and expertise that have emerged from these studies. Research methods, findings, and research-related issues discussed in this paper will not only help other researchers employ CHAT in research on science teachers, teaching, and teacher learning, but also inform theoretical discussions of the nature of teachers' expertise and learning.

Methods and Main Findings

Study A –Preservice Elementary Teachers' Development of Pedagogical Design Capacity for Inquiry-Based Science Teaching and Learning

Science curriculum materials remain one of the most widespread and important tools for teachers. However, rather than enacting them '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 (e.g., Roehrig, Kruse, & Kern, 2007). Together, these three factors, as well as the goals toward which classroom activity is oriented, constitute the pedagogical design capacity a classroom activity system affords a particular teacher (Brown, 2009). In order to leverage and maximize the capacity for pedagogical design afforded them, teachers need to learn to use curriculum materials effectively (Remillard, 2005). This is particularly important for preservice teachers who tend to rely heavily on curriculum materials as beginning teachers and who struggle to translate their reified understandings of inquiry-oriented teaching and learning into classroom practice. This study extends recent research on the use of curriculum materials in science teacher education (e.g., Forbes & Davis, 2008; Schwarz et al., 2008) by focusing on how preservice elementary teachers translate their espoused inquiry frameworks into planned and

enacted science lessons, as well as how the curriculum design process is socially- and culturally-mediated across contexts.

This mixed-methods study involves 46 preservice elementary teachers in an elementary science teaching methods course and in-depth case studies of four elementary preservice teachers during the final year of their teacher education program. The focal point for data collection and analyses were science lessons the preservice teachers planned and enacted in elementary classrooms during the methods and student teaching semesters. Drawing on activity-theoretical frameworks, two interacting activity systems are articulated 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, 2005). This model provides a number of specific affordances. First, it highlights 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. Second, the model affords the ability to map the construction of science lesson plans as boundary objects between curriculum planning and enactment domains. 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 in curriculum design activity over time.

Data were collected throughout the academic year and included interviews, lesson plans, instructional artifacts, reflective journals, and observations of enacted science lessons. To code this data, a series of coding keys were developed that are explicitly aligned with the CHAT-based model used in this study. These coding keys afforded the ability to identify the preservice teachers' curriculum design decisions, assess the inquiry-orientations of their planned and enacted science lessons, and identify contradictions that emerged in their curriculum design activity. Using coded data from the total population of preservice teachers in the methods semester (n=46), quantitative analyses were performed to describe patterns in their curriculum design decision-making and to assess how inquiry-based their planned science lessons were. A regression model was also constructed to provide causal explanations for why their lessons were or were not highly inquiry-based. Qualitative methods were used to analyze data from the four preservice teachers studied over the year. These analyses were 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. The primary goal of these analyses was to identify contradictions within and across curriculum design contexts that explained the preservice teachers' curriculum design decisions. Multiple 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.

Results from Study A illustrate how extant, reified models of classroom inquiry served as crucial instruments in the preservice teachers' curriculum design for inquiry. They developed their capacities to transform their professed models of inquiry into classroom practice by delimiting particular aspects of inquiry as the object of their curriculum planning activity. However, their curriculum design efforts led to emergent contradictions within their placement classrooms. The preservice teachers worked to resolve these contradictions in various ways, including constructing specialized, interim instructional plans; restructuring and reordering time; and reprioritizing particular facets of inquiry in ways that reflected these constraints. While the curriculum materials they used largely defined the material and conceptual space in which their curriculum design efforts occurred, it was the influence of their placement classroom contexts that ultimately determined how they were able to translate the abstract into the concrete. The preservice teachers ultimately represented the challenges they experienced enacting their science lessons as a fundamental contradiction between two object-motives of curriculum enactment focused on student learning. All were still struggling to reconcile this contradiction at the end of the study.

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

While many researchers have advanced the notion of pedagogical content knowledge (e.g., Shulman, 1986; Loughran et al., 2001), 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 likely influence the development of PCK, including the teacher's content knowledge within a subject domain, the students' prior knowledge, the pedagogical approaches employed, 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 influence of the teaching of any subject area on teacher knowledge (Magnusson, Krajcik, & Borko, 1999; 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, pg. 203). However, most teacher professional development is decontextualized. This study examines the role of reflection and peer-exchange in helping science teachers develop PCK though their design, enactment, and revision of a technology-enhanced, project-based lesson. An intervention is introduced where teachers reflect on their planning, enactment, and revisions, as well as with their peers in a community. CHAT is employed to analyze the connections among the activities in which teachers are engaged, the context in which these interactions are occurring, and the teachers' development of PCK.

This three-year longitudinal study uses an 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 sources include teacher surveys, interview questions, lesson plans, reflections (captured in a wiki), videotaped classroom enactments, field notes, student artifacts and responses, and peer exchanges (on wiki, and in group meetings). Following Koehler and 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 when combined with other enactment coding measures were used as data for subsequent CHAT analysis.

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. 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. 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. A within case and cross-case analysis of actions and operations (Miles & Huberman, 1994) provided evidence of challenges, contradictions and tensions that resulted in emerging knowledge or new learning opportunities for teachers.

Results in this study indicate that tools such as scaffolded wiki-reflections and lesson designs offered a mechanism for participants to make their actions visible to themselves and to their peers. The CHAT-based framework used in Study B helped expose tensions between subject-tool-object and community-tool-object relationships, which in turn affected the next iteration of the lesson design and teacher knowledge development, while also identifying the tensions within activity systems and the emergence of new rules. For example, during the lesson revision phase of the teachers' activities, participants were able to see specific flaws in the lesson design. All teachers had a pattern of lesson revision, which identified the student wiki-templates in the project-based lesson as underutilized. Through the reflective practices, teachers (subject) acted differently in their lesson design incorporating more scaffolding (rules) within the re-design of the lesson and, subsequently, enacted the lesson differently. In addition, teachers participating in the peer-exchange activities began to emphasize the structured use of wiki-templates as part of their lesson design. Tensions in the community-tool-object relationship caused dynamic shifts in the activity systems from one iteration to the next. Thus, the generative knowledge construction was not limited to self-reflections but also occurred through community exchanges and community reflections.

Implications for Perspectives on Science Teachers' Expertise and Learning

There have been recent calls for increased use of CHAT in education research (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 teachers' learning, 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. Findings from these studies reinforce the context-dependent nature of teachers' learning and expertise assumed in sociocultural theory (Putman & Borko, 2000). However, they also advance the field's theoretical understanding of how and why teachers' learning is situated by illustrating underlying contradictions that explain change over time in particular cultural contexts. In this section, we highlight important theoretical and practical implications for CHAT-based perspectives on teachers' expertise and learning that have emerged from these two studies.

A crucial element of CHAT is the break it makes with cognitivist psychology. Rather than characterizing learning as an internalization of mental schema or concepts, it assumes instead that learning is evidenced in changes in activity, emerging from the synergistic interaction between the symbolic (cognitive and cultural) and physical environment. CHAT foregrounds the translation of the abstract to the concrete, or realization of the symbolic in action through activity. However, the origins of expansive learning lie in the initial recognition of emergent contradictions and questions about the object and motive of a given activity. So, in effect, the beginning of the process of moving from the abstract to the concrete is spurred by the objectification of activity, or the articulation of ideas, principles, and truths from experience. Because activity also involves deriving the abstract from the concrete, they are therefore temporal, and the symbolic is already a product of the history of the activity in which it is mobilized and used. Ultimately, then, networked practices, as illustrated here in both studies with curriculum planning and curriculum enactment, rely not just on moving from the abstract to the concrete, but also from the concrete to the abstract through a cyclical process of internalization and externalization (Engeström, 2008), participation and reification (Wenger, 1998), 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.

As a process of internalization and externalization (Engeström, 2008), activity systems appear twice to the subject, in this case the teacher; once in material form and once in symbolic form. Semiosis is an emergent property of both. For teachers, this highlights the dialectic by which they have, through activity, arrived at a particular point in their own learning, and has clear implications for perspectives on teacher learning. Most clearly, it highlights the need for teachers' to be engaged in teaching practice and for that practice to be foregrounded in programs designed to promote teacher learning. This is crucial not only for teachers to identify the contradictions and tensions that pervade classroom activity systems, but also for them to attempt to resolve those contradictions through activity. In Study A, for example, the preservice teachers articulated a fundamental contradiction in curriculum enactment for inquiry between two objects and motives of curriculum enactment. This tertiary contradiction emerged between positioning students as objects of activity who appropriate predetermined learning goals and as community members and co-collaborators involved in the co-construction of both the object and explanations of phenomena. This contradiction only emerged after engaging in multiple iterations of curriculum design for inquiry and was thus derived and objectified from activity. In Study B, teacher tools (such as online reflection notes, and lesson designs), highlighted teacher actions in classroom activities, and identified critical moments (tensions) where teachers recognized that a change in patterns of practice were required. The object in this study, PCK development, is connected to these tensions and contradictions. Through iterative activity-based analysis, these actions and changes in actions allowed the object in this study, PCK development, to be traced. These findings reinforce the importance of teachers' engagement in rigorous processes of self-reflection and analysis of practice.

From CHAT-based perspective, learning is defined as the evolution of an existing activity or practice to more culturally-advanced form of that activity. However, in addition to emphasizing teachers' learning as changes in practice, CHAT foregrounds the fundamental motives that drive activity and the physical and symbolic objects through which they are pursued. All activity, including science teaching and learning in the classroom, is situated. However, when cultural layers are removed from activities, they are left composed of the essentials of collaborative work – groups of individuals working together on a particular task that possesses shared meaning (Engeström, 1987). As a result, it is impossible to understanding teachers' learning without accounting for object-motives of their professional practice. In Study A, the preservice teachers' curriculum design for inquiry was punctuated by episodes of lesson-specificity determined by the curriculum materials they employed. While the episodic nature of their curriculum planning and enactment cycles resulted in lesson-specific tools and physical objects, their symbolic objects and motives largely remained constant – to promote students' construction of explanations from evidence through collaborative classroom inquiry. In Study B, the activity system occurs embedded in authentic teacher practice. The teachers design, enact and revise an innovative science lesson as part of their normal activity. However, active teacher learning requires collaboration with peers, as teacher knowledge development is demarked as a social process. The development of community and the role of reflection within the community are powerful elements for "expansive knowledge" (Engeström, 2007). Emerging teacher knowledge (object in Study B) is amplified through community exchange and community activity. As evidenced in both studies, to understand

teachers' learning, it is critical to identify the object-motives that orient the activities through which their learning is manifested.

CHAT also emphasizes the material basis of activity, meaning that the products of activity are not just abstract concepts or ideas, but physical, tangible objects. Here, in both studies, the teachers' learning was made manifest in the curriculum materials they produced through iterative cycles of curriculum design. As boundary objects (Wenger, 1998) between curriculum planning and curriculum enactment, the teachers' lesson plans and other curricular artifacts served a dual purpose as a working problem space for curriculum planning and an instrument to support curriculum enactment. As such, they were representations of their learning, as others have argued before (Ball & Lampert, 1999; Loughran et al., 2001; Shulman, 1986). However, they also served as vehicles and conduits for the transport and application of expertise in novel contexts. For the preservice teachers in Study A, they were not only crucial instruments for translating inquiry frameworks into classroom practice, but also the contextualization and specification of those inquiry frameworks over time. In Study B, teacher lesson designs and student artifacts, manifested as evidence for teachers and for the peer-community. The teacher could comment on their learning in practice with these artifacts, and were able to articulate their meaning and their understanding of project-based learning. Given the challenges of promoting transfer, or learning across contexts, the focus on the physical and material basis of transfer inherent to CHAT is an important element of perspectives on teacher learning.

Finally, rather than emphasizing institutional stability, CHAT assumes that activity systems are inherently contradictory, full of tensions, and always subject to change. If such dynamicism exists as an integral feature of activity systems, including science classrooms, and it demands changes in practice to respond to emergent contradictions, then teacher learning from a CHAT-based perspective is a foregone conclusion. But this does, perhaps, speak more specifically to perspectives on teachers' expertise. Teachers' expertise must not only be marked by their ability to operate within particular activity systems, but also to effectively respond to changes to those activity systems and emergent contradictions. For the preservice teachers in Study A, the introduction of inquiry as an extant framework necessitated changes in their teaching practice, though likely made less contradictory by their lack of experience and participation in a mature, preexisting form of teaching practice. What came to define their expertise for inquiry-based science, however, was the ability to respond to unpredictable schedules (rules) and curricular resources (instruments) to engage students in inquiry practices. In Study B, teachers activity systems are dynamic, fluid and in constant flux as they are dependant on the enactment of the lesson. This enactment addressed school schedules, student learning and content-discipline. The revision in lesson design (artifacts) and rules that were set up for the next iteration of enactment occurred as a response to the tensions within the original activity system. Often these shifts or changes were first recognized within the classroom (or on the fly), prompting a quick adjust during the enactment which became more formalized in the revision of lesson design for the next iteration.

Conclusion

The two studies presented here contribute to a limited but growing body of CHAT-based education research. Specifically, the two studies described in this paper illustrate how CHAT can be employed in research on science teachers' expertise, practice, and learning. As shown in the discussion of these two studies, such research can and, we believe, will continue to yield novel insights into science teachers and teaching, both empirical and theoretical, which possess the capacity to inform a multitude of design efforts focused on supporting science teachers' practice and development of expertise. 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. 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.

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