# ILLUMINATING TEACHER CHANGE AND PROFESSIONAL DEVELOPMENT WITH CHAT

*Technology-Enhanced Formative Assessment* (TEFA) is an innovative pedagogy for science and mathematics instruction. *Teacher Learning of TEFA* is a research project studying teacher change as in-service secondary science and mathematics teachers learn TEFA in the context of a multi-year professional development (PD) program. Applying *cultural-historical activity theory* (CHAT) to the linked activity systems of PD and teachers' classroom practice leads to a model of teacher learning and pedagogical change in which TEFA is first introduced into classrooms as an *object* of activity, and then made useful as a *tool* for instruction, and then—in rare cases—incorporated into all elements of a deeply transformed practice. Different levels of contradiction within and between activity systems drive the transitions between stages. CHAT analysis also suggests that the primary contradiction within secondary education is a dual view of students as objects of instruction versus students as willful individuals; the difficulties arising from this contradiction can either inhibit or motivate TEFA adoption.

Ian D. Beatty, University of North Carolina at Greensboro
Allan Feldman, University of Massachusetts Amherst

## Introduction

Designing and conducting effective professional development (PD) experiences for in-service secondary science teachers—especially sustained, intensive PD that addresses participants' idiosyncratic and evolving needs, and that promotes deep pedagogical change—is difficult. Although several "best practices" for teacher PD have been articulated (e.g., Loucks-Horsley, 1996; Supovitz & Turner, 2000), designing effective programs remains more art than science. We believe a major reason for this is that the dynamics of teacher learning and pedagogical change are poorly understood.

We see a need for a detailed model of how, in the context of a sustained PD program, teachers learn a new pedagogical approach and change their perceptions and practice. In order to develop such a model, we and our colleagues are conducting a five-year research project entitled *Teacher Learning of Technology-Enhanced Formative Assessment* (TLT). We have chosen to study teachers' learning of a specific pedagogical method, *Technology-Enhanced Formative Assessment* (TEFA; Beatty & Gerace, in press). TEFA is sufficiently well-defined to support a targeted PD program, sufficiently innovative and challenging to require deep teacher change in adopting it, sufficiently effective to produce motivating results for teachers that attempt it, and sufficiently multifaceted and flexible to yield research results that should generalize to teacher learning of other pedagogies.

In a previous paper (Beatty et al., 2008), we presented a preliminary model for teacher change and learning of TEFA, which we called *a model for the co-evolution of teacher*

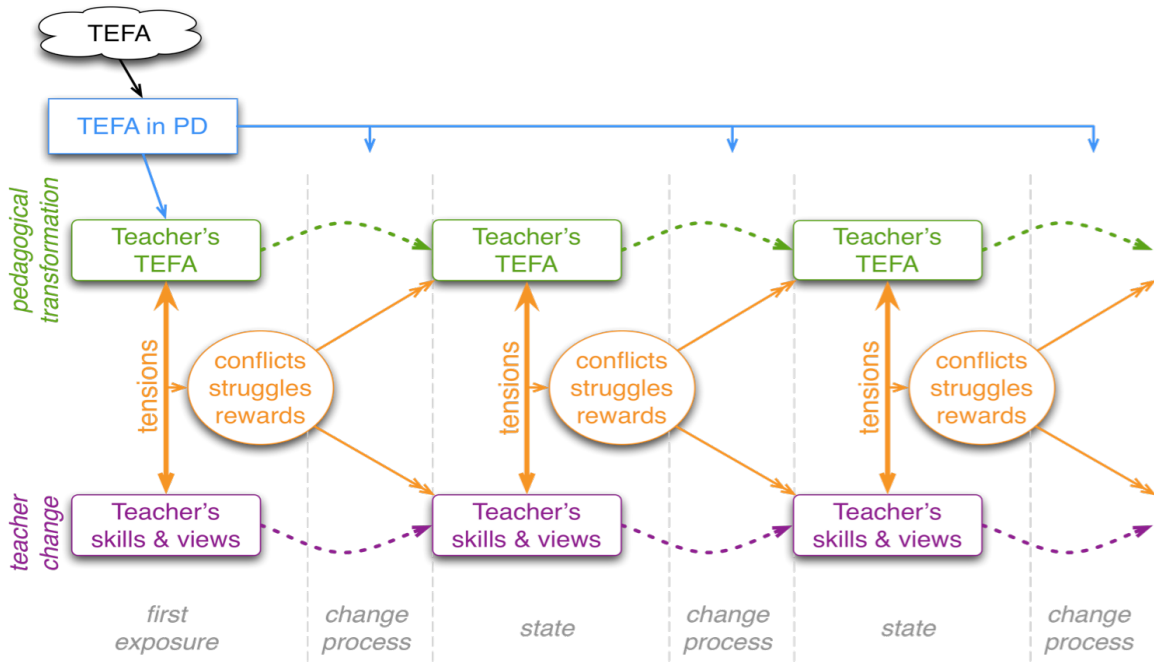


*Figure 1: A model for the co-evolution of teacher and pedagogy (Beatty et al., 2008).*

*and pedagogy* or, more concisely, the *co-evolution model* (Figure 1). It describes a teacher's learning process in terms of four general constructs:

1. the alignment or misalignment (tensions) between a teacher's skills, views, and context, and his or her conceptualization of TEFA and attempts to enact it;
2. the conflicts, struggles, and rewards he or she experiences as a result of these alignments and misalignments;
3. the changes to his or her conceptualization of the pedagogy (TEFA) and to his or her ways of attempting it that occur in response to these conflicts, struggles, and rewards; and
4. the changes to his or her skills, perspectives, and general "way of being a teacher" that also occur in response to the conflicts, struggles, and rewards.

The model represents the dynamic of a teacher's ongoing learning process as an evolving dialectic between two primary "narratives." One, labeled *teacher change*, is the story of the teacher's growth as a practitioner: acquisition of new skills, development of new perspectives, realization of new or newly emphasized values, and the like. The other, labeled *pedagogical transformation*, is the story of how the teacher perceives and interprets the pedagogy presented in PD, chooses what aspects to aspire to, consciously and unconsciously shapes it according to his or her perspectives and context, and evolves it over time. Within this model, tensions between the "teacher's TEFA" and the teacher's identity and skills at any point in time are the primary driving force of change.

The model includes a third narrative: the sustained PD experience that forms part of the teacher's context. This is another driving force for change, by challenging the teacher's personal understanding of and aspirations toward the pedagogy, suggesting alternative strategies for minimizing tensions, supporting development of new skills and perspectives, and so on.

The diagram depicts the change process as a discrete series of transitions between states, but the model is meant to include more gradual, continual change as well.

The co-evolution model has proven itself useful to us as a guide for PD and research activity, largely by focusing our attention on two key aspects of the change process: the inevitability, and even desirability, of a teacher customizing and continually re-customizing the pedagogy he or she has been presented with until it suits his or her perceived context, abilities, and orientations; and the centrality of tensions and dissonances in driving change. However, the model fails to provide much help with identifying specific tensions that promote or inhibit change. It has two weaknesses: It does not address the precise aspects of "the teacher" and "the practice of TEFA" that are relevant, and it does not adequately represent the greater context of interlocking agents and forces that constrain and influence the change process.

The first weakness can be addressed by connecting the two narrative lines in the model, "teacher change" and "pedagogical transformation," to the literature on various ways of understanding teacher change (Feldman, 2002). For example, we can connect to the literature on the *teacher knowledge* perspective, which sees the growth of expertise in teaching as the accumulation of knowledge; to the *teacher reasoning* perspective, which views teaching as a process of decision-making (e.g., Sweeney, Bula & Cornett, 2001) or reflection in- or on-practice (e.g., Schön, 1983); to the *sociocultural* perspective, in which teaching is seen as a contextualized activity in which the teacher and the sociocultural milieu interact dialectically (e.g., Roth, Lawless & Tobin, 2000); and to the *teacher as a way of being* perspective, in which the teacher's way of being a teacher results from his or her experience and the set of intentional states—dispositions, talents, interests, fears, visions, etc.—that locate the teacher and point him or her in one direction or another (Stengel, 1996). Forging such connections is not the purpose of this paper, and will not be pursued here.

The second weakness can be addressed by connecting the co-evolution model to *cultural-historical activity theory* (CHAT). The remainder of this paper is a theoretical exploration of how CHAT can be connected to the co-evolution model, and more broadly, how it can be fruitfully applied as a lens to help us understand teachers' learning of TEFA pedagogy within the context of sustained PD.

## Background: Cultural-Historical Activity Theory (CHAT)

In this section, we very briefly summarize the elements of *cultural-historical activity theory* (CHAT) that we will draw upon later in the paper. To do so, we rely on Yrjö Engeström's (2001) formulation of "third-generation activity theory" and his analysis of the history of first- and second-generation activity theory.

First-generation activity theory originated in the work of Lev Vygotsky (Vygotsky, 1978), who hypothesized that artifacts mediate all human action. These artifacts can be tools, such as hammers, ovens, or computers; cultural artifacts, including language; and theoretical artifacts, such as mathematics or feminist standpoint theory. Mediation is between the *subject* and the *object* of action, where the subject is typically an individual human being (Figure 2).

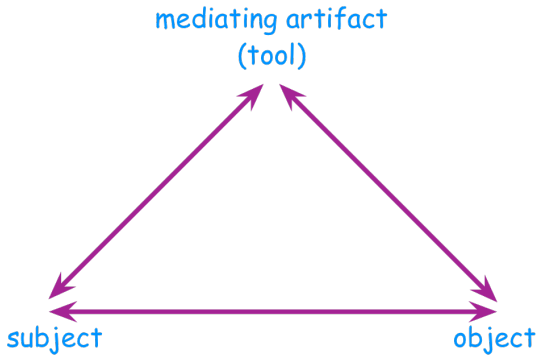


*Figure 2: Relationship between elements of first-generation activity theory (after Engeström, 1987).*

First-generation activity theory has been used to understand individual behavior by examining the ways in which a person's actions upon objects are culturally mediated. The unit of analysis is the individual, which limits researchers' ability to model collective activity and social influences upon a person. Leont'ev (1981) addressed this limitation by developing second-generation activity theory, in which the actions of an individual are seen as embedded within an *activity system* including the subject (individual), the object of action, and a *community* engaged in collective activity. Leont'ev asserts that many human actions make sense only when seen in the context of collective activity, wherein different people take on different roles according to a *division of labor*. *Rules*, including implicit norms for social behavior, mediate the interaction of subject and community. Thus, according to Leont'ev, the essential components of an activity system are the subject, object, community, tools, rules, and division of labor.

Engeström presented these elements and their interconnections visually in his now-famous "triangle diagram" (Figure 3). The *subject* of the activity system is the person or sub-group whose actions we seek to understand: the point of view for our analysis. The *object* motivates the actions of the subject, and can be thought of as "the 'raw material' or 'problem space' at which the activity is directed" (Center for Activity Theory and Developmental Work Research, 2003, ¶4). The subject uses *tools*, which can be physical, cognitive, or symbolic, to direct actions towards the object and to produce *outcomes*. The *community* consists of the participants engaged in collective activity with the subject, along with other individuals or groups with a stake in the object of activity; the object defines the community and distinguishes it from other communities (Engeström, 2001; Murphy & Rodriguez-Manzanares, 2008). *Division of labor* refers "to both the horizontal division of tasks between members of the community and to the vertical division of power and status" (Center for Activity Theory and Developmental Work Research, 2003, ¶4). *Rules* both implicit and explicit shape the behavior of the community members, and can be regulations, norms, conventions, or other types of beliefs.

Critics of second-generation activity theory, including Engeström (2001) and Wertsch (1991), point out its inability "to understand dialogue, multiple perspectives, and networkings of individual activity systems" (Engeström, 2001, p. 135). This led to the development of third-generation activity theory, called *cultural-historical activity theory* (CHAT). Engeström (2001) summarizes CHAT with five principles:

> *The first principle* is that a collective, artifact-mediated and object-oriented activity system, seen in its network relations to other activity systems, is taken as the prime unit of analysis. Goal-directed individual and group actions… are relatively independent but subordinate units of analysis, eventually understandable only when interpreted against the background of entire activity systems…

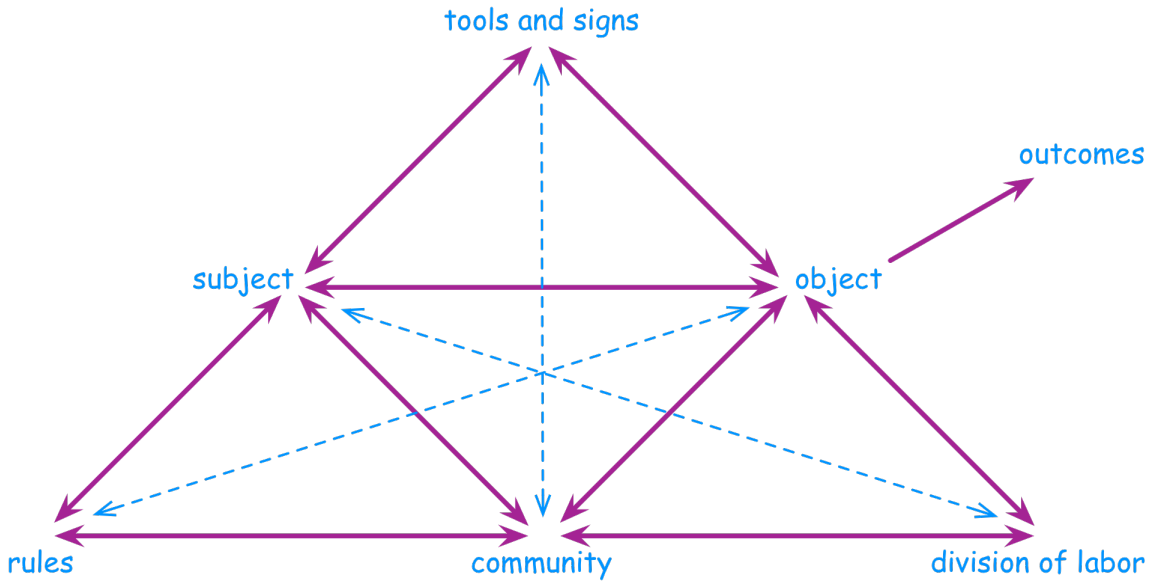


*Figure 3: Relationships between elements of second-generation activity theory (after Engeström, 1987).*

> *The second principle* is the multi-voicedness of activity systems. An activity system is always a community of multiple points of view, traditions and interests…
>
> *The third principle* is historicity. Activity systems take shape and get transformed over lengthy periods of time. Their problems and potentials can only be understood against their own history…
>
> *The fourth principle* is the central role of contradictions as sources of change and development. Contradictions are not the same as problems or conflicts. Contradictions are historically accumulating structural tensions within and between activity systems… Such contradictions generate disturbances and conflicts, but also innovative attempts to change the activity…
>
> *The fifth principle* proclaims the possibility of expansive transformations in activity systems. Activity systems move through relatively long cycles of qualitative transformations. As the contradictions of an activity system are aggravated, some individual participants begin to question and deviate from its established norms… An expansive transformation is accomplished when the object and motive of the activity are reconceptualized to embrace a radically wider horizon of possibilities than in the previous mode of the activity (pp. 136-137).

Contradictions within and between activity systems, the primary drivers of change and especially of "expansive transformations," can be divided into four categories (Engeström, 1987, p. 82): a *primary contradiction* that can be found within each constituent element of the system, *secondary contradictions* between elements of one activity system, *tertiary contradictions* between the object or motive of an activity system and the object or motive of a "culturally more advanced" form of the activity, and

*quaternary contradictions* between the activity system and other activity systems to which it is linked.

## Empirical Context: Teachers' Difficulties With TEFA

The context for our theoretical exploration is an analysis of the difficulties teachers encounter and the changes they undergo while learning, in the context of the aforementioned TLT project, to practice TEFA. Although a detailed exposition of TEFA, the TLT project's design, and our analysis and findings to date are beyond the scope of this paper, some knowledge of these is indispensable for understanding the theoretical discussion that follows. In this section, we briefly summarize TEFA and the TLT project, and then identify the major difficulties teachers encounter in their learning of TEFA as revealed by preliminary analysis of data so far collected.

### *TEFA and TLT*

*Technology-enhanced formative assessment* (TEFA) is an innovative pedagogical approach grounded on four principles: *question-driven instruction*, *dialogical discourse*, *formative assessment*, and *meta-level communication*. Each of these, independently, is of well-established value to science instruction (Beatty & Gerace, in press). TEFA integrates them into a powerful, coherent, self-reinforcing, tractable whole. It achieves this by structuring large chunks of class time around an iterative "question cycle" that consists of posing a question to the class; allowing students a few minutes to ponder it alone or in small groups; collecting students' answers; presenting a summary of the answers; eliciting students' justifications for their choices; moderating a whole-class discussion that develops, challenges, compares, contrasts, and integrates ideas voiced; and providing appropriate wrap-up or closure. A typical one-hour TEFA class might contain three or four related question cycles. The question cycle is facilitated by a *classroom response system* (CRS). Although the approach can be practiced without technological aid, using a CRS significantly improves the quality of the results (Dufresne, Gerace, Leonard, Mestre & Wenk, 1996).

*Teacher Learning of Technology-Enhanced Formative Assessment* (TLT) is a five-year project studying teacher learning and pedagogical change in the context of TEFA PD. It employs a longitudinal, staggered site, delayed intervention design, with 43 teachers from four sites participating in at least some portion of the professional development program and study. At each site, longitudinal data collection spans one baseline semester and two to three years of PD; the sites start one year apart. Across the four sites, participants include 30 high school and 13 middle school teachers; 33 teach science and 10 teach mathematics. Project staff collect data on the participants' backgrounds, outlooks, and learning of TEFA through multiple instruments and methods. Analysis is mixed-methods (Johnson & Onwuegbuzie, 2004), more qualitative than quantitative, with several distinct threads including statistical analysis of categorical survey data, qualitative coding of graphical data from quantitative sources, theory-driven and open coding of interview transcripts and open-ended questionnaire responses, and discourse analysis of classroom transcripts. From these data, project staff construct case study profiles (Yin, 2003) of each teacher's starting point and evolution, in order to understand individual "learning

trajectories" in as much detail as possible. As the profiles develop, staff proceed to cross-case analysis in an effort to identify general patterns and trends, distinct categories of experience, and central themes, with a primary focus on discerning the barriers that participants encounter and the changes to their thinking and practice that occur.

According to Feldman and Capobianco (2008), mastering TEFA requires a teacher to develop skill in four different areas: operating the CRS hardware and software; designing good questions; conducting beneficial classroom discussions; and integrating TEFA into existing curriculum[1]. TLT project staff have developed, and continue to refine, a TEFA PD program that incorporates known best practices from the in-service teacher PD literature. PD staff work on-site with eight to twelve teachers from one school, fostering a community of mutually supporting peers. The program is intensive and sustained, beginning with a four-day summer workshop, continuing with a year of weekly and then bi-weekly after-school meetings, and sustained by one or two additional years of tri-weekly *collaborative action research* meetings (Feldman, 1996). Staff model the TEFA methodology while teaching TEFA, and conduct the program in accord with the four principles of TEFA. PD remains grounded in teachers' real-world classroom experiences: At every meeting, participants discuss their current problems, insights, observations, and ideas, and design TEFA questions to use in their teaching. This helps the program stay agile and highly responsive to participants' unique and evolving needs.

## *Teachers' Difficulties Adopting TEFA*

TLT project PD, data collection, and data analysis are still in progress, so only preliminary case studies of a subset of the participating teachers are available. However, in conjunction with the experiences reported by PD staff, these profiles leave no doubt as to the dominant difficulties teachers wrestle with when learning TEFA and attempting to incorporate it into their practice. We identify and illustrate these dominant difficulties here. They are presented in approximately decreasing order of prevalence, according to the judgment of project PD staff and analysts; a rigorous quantitative frequency analysis has not yet been conducted.

### *1. Insufficient Prep Time*

By far the most common and sustained difficulty TLT participants report is finding time to create good questions for posing to students in the TEFA question cycle. Through both PD and their own experiences, teachers learn quickly that the quality and characteristics of the questions they use are crucial to success, strongly influencing both the nature and degree of students' participation and learning.

---

[1] We suspect, and at times have claimed, the existence of a fifth skill area: modeling students' knowledge and thinking based on their CRS responses and utterances in class, and making real-time decisions about how to adjust teaching accordingly—a practice we call "agile teaching" (Beatty, Leonard, Gerace & Dufresne, 2006). Anecdotal reports suggest that this skill area becomes a primary focus for highly experienced and advanced TEFA practitioners, but is not of conscious concern for the participants studied in the TLT project.

> [The barrier or limitation that has most inhibited my ability to teach with TEFA during the past month is] finding time to work on questions.
>
> *—participant b102, monthly reflection survey for year 1 round 1*

> I have felt guilty that I haven't been using the system much—it has "slipped" in the priority list because I just can't seem to find the time to write good questions.
>
> *—participant b106, monthly reflection survey for year 1 round 3*

The complaint of "not enough time," however, is not fundamental. We can unpack it to reveal a conjunction of at least three underlying factors. The first factor is that the TEFA "toolkit" presented to teachers in PD includes only a few TEFA questions scattered across subjects and topics, intended as examples. Few public question databases exist, so teachers must create their own questions.

> I just think it would be nice to have that resource [a collection of ready-made TEFA questions] available so like, when you say that you're short on time, you know, um, you know 'cause a lot of times I can imagine that you *know* exactly where you want to go with a particular kind of topic, or what you want to touch on. And you can see that this question is drawing it out as soon as you look at it, you know? Um, you just don't have the time to sit there and come up, out of the *blue*, with your own.
>
> *—participant quote from transcript of site C PD meeting 04 of year 1*

Over time this factor usually decreases in severity, as teachers build up their own repertoire of questions that they can re-use in future terms. However, a teacher's dissatisfaction with his or her early question attempts, and changes to teaching assignments, can decrease the utility of such a repertoire.

> [During the last month, I've been most focused on] trying to organize what I've done this year so that when I'm ready next year to try again that I can find what I've done.
>
> *—participant b103, monthly reflection survey for year 1 round 7*

> Using questions for the second time, it is much easier to lead the discussion, and to weed out bad questions.
>
> *—participant b103, weekly reflection survey for year 2 round 1a*

> [The aspects of using TEFA I have found most difficult, limiting, or discouraging during the past two weeks are] finding time with three preps to write good questions.
>
> *—participant b103, weekly reflection survey for year 2 round 9a*

The second factor is that teachers, at least initially, have insufficient skill at question design to be efficient and reliably successful.

> [The barriers or limitations that most inhibited my ability to teach with TEFA this past month are] coming up with those questions. I don't want it to be poll the audience. I want good discussion I think this will come with time!
>
> *—participant a105, monthly reflection survey for year 1 round 1*

> [The barriers or limitations that most inhibited my ability to teach with TEFA this past month are] the ability to craft questions geared to a specific goal.
>
> *—participant a109, monthly reflection survey for year 1 round 1*
>
> [The barriers or limitations that most inhibited my ability to teach with TEFA this past month are] feeling that I was not writing good questions on my own.
>
> *—participant b101, monthly reflection survey for year 1 round 1*

Like the first, this factor can decrease with time, in part due to the trial-and-error experience teachers get if they persevere, and in part due to much PD time devoted to helping participants learn to fashion effective questions.

> Feel more comfortable with question writing.
>
> *—participant b101, monthly reflection survey for year 1 round 2*
>
> I am starting to feel comfortable with creating quick questions.
>
> *—participant b103, monthly reflection survey for year 1 round 3*
>
> I am getting faster at writing; slowly faster!
>
> *—participant b105, monthly reflection survey for year 1 round 2*

The third factor is that most secondary school teachers are allotted very limited prep time during their working hours, and must do significant grading, lesson planning, and other preparatory and administrative work in their personal time. The problem is exacerbated for science teachers that must find time to set up, take down, and maintain laboratory equipment. We find it telling that two of the eight participants at TLT site B quit teaching after project year 1 in order to take a less stressful job.

> I am enjoying having a life again—time for sleep, exercise, family and reading! I do miss the energy of the students, sometimes.
>
> *—participant b102, email after having quit teaching at the end of project year 1*
>
> I have indeed resigned and will be returning to [a local hospital] to work 3 days a week in the hematology department. I'm looking forward to reading some fiction again and playing lots of music!
>
> *—participant b106, email after having quit teaching after the end of project year 1*

We note that "not enough time" can also be an excuse used to whitewash or soften some other barrier that the participant is unwilling to share with project staff. It can, for example, mean "I'm not impressed enough by TEFA to prioritize it above the things that I currently spend my time on."

> Experience with great discussion (based on a good question) started the ball rolling and then I was willing to soak up ideas and advice and work harder to create good questions.
>
> *—participant a113, monthly reflection survey for year 1 round 6*

### *2. Disappointing Student Participation*

Another common difficulty identified by TLT participants is coaxing satisfactory student participation in the whole-class discussion portions of TEFA instruction. The number of students participating (much of the class or just a few "usual suspects"), the extent of student utterances (extended or monosyllabic), and the depth of thought articulated (reasoned arguments, simple assertions, or just guesses) are all points of concern.

> I wouldn't say I am "uncomfortable" with "stimulating and steering good whole-class discussion" but it doesn't happen very often without my constant steering and too-often leading.
>
> *—participant a102, monthly reflection survey for year 2 round 1*

> Because this group is an honors group, the "lower-achieving" students can be very intimidated socially to participate in discussions.
>
> *—participant a109, monthly reflection survey for year 2 round 1*

> The students seem more and more distracted as the end of the year approaches and as good weather arrives. It's been harder in general to motivate, let alone get them to participate in good discussion.
>
> *—participant a113, monthly reflection survey for year 1 round 7*

> I want them to say more, and I want me to say less… You know I wish and or think that they would have been more engaged… I feel like they're not always with me.
>
> *—participant b101, post-videotaping interview for year 1 round 2*

Interestingly, some teachers experience apparently insurmountable difficulty in eliciting quality student participation, some struggle but find ways to improve it over time, and some have difficulty getting students to *stop* talking at the end of a whole-class discussion interval.

### *3. Insufficient Class Time*

A difficulty that presents less of an immediate barrier to teachers learning TEFA, but that poses a more serious long-term threat to their willingness to adopt it for more than occasional use, is a perceived conflict between the fact that doing TEFA takes significant class time and the fact that many teachers feel themselves pressured to cover a broad swath of mandated curriculum within a term. TEFA demands time primarily due to the extended whole-class discussion that it entails, with additional "inefficiency" caused by the overhead of distributing and collecting student response devices, starting up the software, and so on. Teachers' sense of pressure to cover topics at a rapid pace generally stem from state frameworks and standardized high-stakes exams.

> I've run out of class time a few days due to adding TEFA-time that didn't substitute a similar amount of time in teaching in a different modality.
>
> *—participant a102, monthly reflection survey for year 2 round 3*

> [Day-to-day, I have been most concerned about] fitting [TEFA] in with the rush to cover material for the Biology MCAS [state-wide high stakes exam].
>
> *—participant b102, monthly reflection survey for year 1 round 7*
>
> [The barrier or limitation that has most inhibited my ability to teach with TEFA this past month is] trying to squeeze stuff in before the AP exam.
>
> *—participant b103, monthly reflection survey for year 1 round 7*
>
> [Day-to-day, I have been most concerned about] lack of time due to snow days to keep up with the curriculum… I've needed to drop one activity and one lab activity in order to keep up with the curriculum.
>
> *—participant b106, monthly reflection survey for year 1 round 4*

This difficulty is, of course, an incarnation of the classic "depth vs. breadth" conundrum, and is not unique to TEFA. It has been identified as the "mile wide, inch deep" problem of US education (Schmidt, 1997, cited in Bransford, Brown & Cocking, 1999, Ch. 2). Most teachers in the TLT project acknowledge that the rich, dialogical whole-class discourse espoused by TEFA—in which students' various perceptions, ideas, and understandings are elicited, examined, and interrelated—are effective at developing robust student understanding of the content being taught. However, most are also under pressure to "cover" a specific list of topics in order to obey state standards and prepare students for standardized tests, and do not think they can afford to cover many of those topics so deeply. To put it bluntly, they would like to teach for understanding, but feel forced to teach for exposure.

The difficulty may also be more a matter of perception than reality, or a problem that can be eliminated by skillful use of TEFA. Some participants report that despite their initial expectations and the way that TEFA instruction "felt" in class, they actually ended up covering material in *less* time than they would have without TEFA. They attribute this to two factors: TEFA provides them with detailed feedback about students' understanding and thinking, which helps them tune their instruction for maximal efficiency; and taking the time to build solid foundational understanding and root out misconceptions in early material helps students learn later material much more efficiently.

> b104: Last semester [my first using TEFA] was the first year that I had days where I can just take days off to talk about where the students are at… I mean, we've had so much extra time and I still covered everything… Because I used TEFA [indecipherable] was such a deeper understanding for the students… And so when I get to, you know, um, new units where I have to build upon what they learned before, it doesn't take me as much time, to go back and fill in the holes, fill in the holes, fill in the holes.
>
> Facilitator: So that's where your time savings is coming from.
>
> b104: Yes, I really, truly think that it's because of TEFA. That's my feeling.
>
> Facilitator: Other folks, do you have, I mean, do you perceive a pace problem? That coverage versus depth kind of problem, or—?
>
> …[nine turns of tangential banter omitted]…

b105: I *did* get further this semester than I ever have. And I'm gonna get one more chapter in, and next year I'm gonna get one more. I'm gonna get to acids and bases…

b101: You know, it's interesting, I found the same thing. I had like, four days at the end of the semester I didn't know what to do with…

*—transcript excerpt from focus group discussion during year 1 PD meeting 18*

Whether the difficulty is real or perceived, inevitable or avoidable, it presents a very real stumbling block to teachers that perceive it.

### *4. Technical Difficulties*

For almost all project participants, learning to operate the CRS technology and finding solutions to various bugs and problems was a major obstacle and distraction for the first month or two of the project, largely due to school-wide problems with the CRS installation at each site (and idiosyncratic to each school district involved). Thereafter, a few participants wrestled with nagging or new problems, but most reached a comfortable level of skill and resolved their difficulties, shifting their attention to other concerns such as designing questions and eliciting improved student participation. Inadequate school technical support remained a problem at all project sites, for reasons sometimes beyond the control of technical support staff, and hardware or software upgrades frequently introduced new problems to be solved or worked around.

At this point, I've been focused on the technological aspect. Broken clickers, invalid answers, frozen programs, broken monitors. I know there is light at the end of the tunnel, as long as we dodge the pieces of concrete falling from the tunnel's ceiling due to poor construction!

*—participant a102, monthly reflection survey for year 1 round 1*

[Day-to-day I've been most focused on] just getting kids used to the normal log in process so that we eliminate errors and delays so that we can get smoothly into the Q&A phase of the lesson.

*—participant a106, monthly reflection survey for year 1 round 1*

[I didn't try anything new with TEFA this past month because it would involve] more use of the technology. I am afraid of the bugs.

*—participant a108, monthly reflection survey for year 1 round 1*

The [CRS] was not functioning for a couple of weeks. Technical support here is unreliable, and I abandoned question development.

*—participant b106, monthly reflection survey for year 1 round 1*

Although technical issues ceased to be a major obstacle for most project participants after a month or two, a few found the barrier of operating the technology sufficiently intimidating that they never developed comfort with TEFA. Two of the ten participants completing the first year of PD at TLT project site A dropped out of the project before the second year, citing unwillingness and/or inability to learn the technology.

### *5. Student Behavior Problems*

Another difficulty that project participants contend with is preventing or controlling undesirable student behavior in the context of TEFA activity.

> When the kids behave it [TEFA] works so well… and when they're naughty it's soooo frustrating.
>
> *—participant b103, monthly reflection survey for year 1 round 3*
>
> I haven't been using it in the target class since they've been so naughty.
>
> *— same participant, same survey, four months later (year 1 round 6)*

To many teachers, practicing TEFA in the highly student-centered manner modeled in PD feels like a dangerous relaxation of control, inviting misbehavior of many kinds. Some specific forms of misbehavior reported are disrespectful conversation during whole-class discussion, inattention, back-chatter, excessive playing with the CRS student units, physically damaging the CRS student units, and turning CRS use into a race or other game that distracts from the intended learning.

> After initial introduction of PRS, some kids seemed most focused on being the "last one to enter a response before time ran out." Discussion that followed required obvious re-direction. Turning off TV monitor during response-entering phase all but eliminated this "game." I haven't determined an appropriate length of time to use the PRS units each week. This particular group of twelve year olds have a limited attention span.
>
> *—participant a103, monthly reflection survey for year 1 round 1*

We find concern about "back-chatter" during whole-class discussion—small side conversations between students—to be particularly interesting. Some teachers seem to have a very high tolerance for it, while others cannot tolerate any and want all students to be sitting quietly with their eyes on the teacher or the one student currently holding the floor.

> The teacher kept interrupting the discussion to verbally call out and discipline students for back-chatter, even though the talk was so quiet that I rarely noticed it. These frequent interruptions struck me as far more disruptive to the discussion than the back-chatter would have been, and they certainly cast a negative pall over the class. I'm not surprised the discussion was anemic, with poor participation.
>
> *—field note by project staffer visiting participant a113's classroom for year 1 round 1 videotaping*
>
> When *I* think learning is happening is usually when it's most chaotic.
>
> *—participant b104, pedagogical perspectives interview, year 1 (emphasis by speaker)*

We find this issue interesting because far from being detrimental, a nonzero level of back-chatter may in fact be essential to good whole-class discussion in a classroom. Mortimer and Scott (2003) argue that quashing back-chatter kills such discussion, because the back-chatter is frequently on-topic and helps students get up their nerve to speak out to the whole class. For example, they claim that students are often checking

with a peer to see whether the question they are about to ask has already been answered—perhaps they missed it—or are testing whether their comment sounds foolish.

As with poor student participation, the problem of student misbehavior plagues some teachers far more than others.

### *6. Clash with Teaching Style*

All teachers have a personal "style" of teaching, which we loosely define to include beliefs and preferences, orientations towards or against certain kinds of practices, areas of comfort and discomfort, and habits. TEFA may be more or less aligned with any individual's style. One point of stylistic conflict reported by some teachers is discomfort with the whole-class discussion phase of the question cycle.

> I don't find it very beneficial to sort of ask a question, present it to the whole class and then sort of wait for the response—that's not all that effective.
>
> *—participant a103, pedagogical perspectives interview, baseline*

> I mean, kind of politically, I've pushed [TEFA whole-class discussion] aside, because it doesn't really agree with my educational philosophy. So, I'm kind of getting over that, and *trying* to get over that. And, um, look at it's value.
>
> *—participant b101, focus group discussion at year 1 PD meeting 18*

> I am trying to figure out why I don't do [TEFA] more—I really need to get away from the self expectation that this HAS to be whole class based. That still makes me uncomfortable.
>
> *—participant b101, monthly reflection survey for year 1 round 6*

> I am not uncomfortable steering a whole class discussion, I just don't think I do it as [PD staff] would like where it is so totally student centered.
>
> *—participant b105, monthly reflection survey for year 1 round 6*

Another, somewhat less common point of stylistic conflict involves the degree and nature of pre-class preparation required by TEFA. Some teachers prefer a more spontaneous, ad-libbing style of instruction, whereas others dislike the surprises that TEFA can produce.

> [My ability to teach with TEFA is inhibited by] the fact that I don't spend large amounts of time thinking of "perfect" questions… I think the fact that I am a relative novice at this means that there are limited returns on spending a large amount of time thinking about what questions to ask my class, so basically I don't spend my time this way. I wait for things to occur to me… I often teach very off the cuff.
>
> *—participant a111, monthly reflection survey for year 1 round 1*

> [The barrier or limitation that most inhibited my ability to teach with TEFA this past month was] reconciling TEFA with my style of teaching. I like to discuss students' questions at the moment. I still find it hard to imagine how to set up questions ahead of time without knowing what the students want to ask.
>
> *—participant b106, monthly reflection survey for year 1 round 3*

> When [participant a102] said he'd had one question that produced a 50-minute discussion, I said 'Great! Wonderful!' He didn't look happy, and when I probed, he said that it had thrown off his plan for the day, and he'd had to reschedule the homework that evening.
>
> *—field note by facilitator from PD meeting at site A, year 2, round 6*

This type of difficulty can be difficult to identify with confidence, because complaints about other obstacles sometimes seem to be rationalizations covering an unvoiced, perhaps unrealized style conflict, and sometimes apparent style conflicts are rooted in other difficulties (e.g., a teacher who's dislike of the whole-class discussion "style" is due to difficulty controlling student behavior).

### *7. Incompatibility with Subject or Curriculum*

Some teachers report difficulty fitting the TEFA approach into specific subjects or harmonizing it with specific curricula. One teacher at site B uses a *layered curriculum*, which is based on highly asynchronous student seat-work and does not lend itself to the whole-class mode of instruction in TEFA.

> b101: Um, you know with the layered curriculum it's hard to say that. Everybody's doing something different. It's not like I teach a lesson everyday…
>
> Interviewer: So with the layered curriculum, you go in and you expect different groups of students to be involved in different activities at different points of the lesson?
>
> b101: Always.
>
> *—pedagogical perspectives interview with participant b101, baseline round*

Other teachers avoid using TEFA within laboratory-heavy units and courses, sometimes because of difficulty figuring out how to fit it in, sometimes out of a simple fear of having CRS student units in close proximity to liquids or other potentially damaging items. At other times, "incompatibility with this course" simply means that the course is under so much content-coverage pressure that difficulty 3 above, "insufficient class time," seems prohibitive.

## Theory: Applying CHAT to TLT and TEFA

As "an accommodating framework… rather than a neat set of propositions" (Roth & Lee, 2007, p. 191), CHAT can be applied to secondary science and mathematics education, the TLT project, and teachers' learning of the TEFA pedagogy in many conceivable ways. Although different possible applications might be more or less consonant with how other authors understand and use CHAT, we believe that no one application is "right." Rather, applications should be judged by their utility and self-consistency.

In the following subsections, we first apply CHAT to the "activity system" of TLT project professional development, with the teacher as subject. We then apply it to the activity system of an individual teacher's class. Building on those two analyses, we suggest a model for a teacher's process of TEFA adoption.

## *Co-Evolution and CHAT for Professional Development*

After an initial multi-day workshop, TLT professional development consists of regular after-school meetings between (typically) two PD facilitators and the participating teachers from one "site." A site is either one school, or two closely linked schools of the same level from one district. The number of participants from a site tends to start at eight to twelve for the first year, and then dwindle to six and then four (or so) over the second and third years. During the first year, staff play a strong role in conducting lessons, introducing provocative ideas, modeling pedagogy, and stimulating discussion on particular topics, although teachers' own concerns and agendas are also continually solicited and addressed. During the second and third years, participants are encouraged to formulate and pursue their own action research agendas either individually or collectively, with PD staff support. The staff's goal throughout is to help participants understand TEFA as it was designed, develop the skills to practice TEFA with success, adapt TEFA to their idiosyncratic situations and orientations, and solve problems that arise.

### *TLT Professional Development as an Activity System*

The first activity system we consider consists of the PD staff and participating teachers, engaged in the activity of "TEFA professional development" with the motive of helping the teachers learn to use TEFA successfully in their classes. Within the CHAT "activity triangle," we identify the collection of staff and participating teachers as the *community*, and choose to focus on the viewpoint of an individual teacher as *subject* (Figure 4). The *object* of this system is the teacher's instructional practice, and the desired *objective* is successful implementation of TEFA to help students learn what they are supposed to learn from the class.

Within this system, the *division of labor* specifies the roles and responsibilities of the staff and teachers. These are somewhat complicated by the fact that project staff are also part of a linked activity system of researchers conducting research with the teachers as subjects, so they have additional and possibly conflicting roles. The situation is further muddied by the fact that participants have the option of receiving graduate credit for the program by registering for it as a university-offered course and paying a small fee. For participants who opt for this, PD facilitators take on the additional roles typical of instructors, including "setter of standards" and "determiner of grades," which may not be entirely compatible with their facilitation and research roles. Staff tried very hard to minimize the impact of such conflicts, prioritizing facilitator responsibilities over others.

The *rules* element of the system was a source of some tension, as many teachers revealed feeling that they were "supposed" or "obligated" to use TEFA with a greater frequency or in a different manner than they would choose purely for their own instructional reasons. Staff tried to find a balance between reassuring participants that their instructional judgment was paramount and encouraging them to push beyond their comfort zone, and as a result may have sent mixed messages about the *rules*. Also important were emergent rules (unspoken agreements) about what PD "assignments" participants would or would not complete; generally, participants would play along with in-meeting tasks of various sorts, but felt little obligation to complete between-meeting tasks.

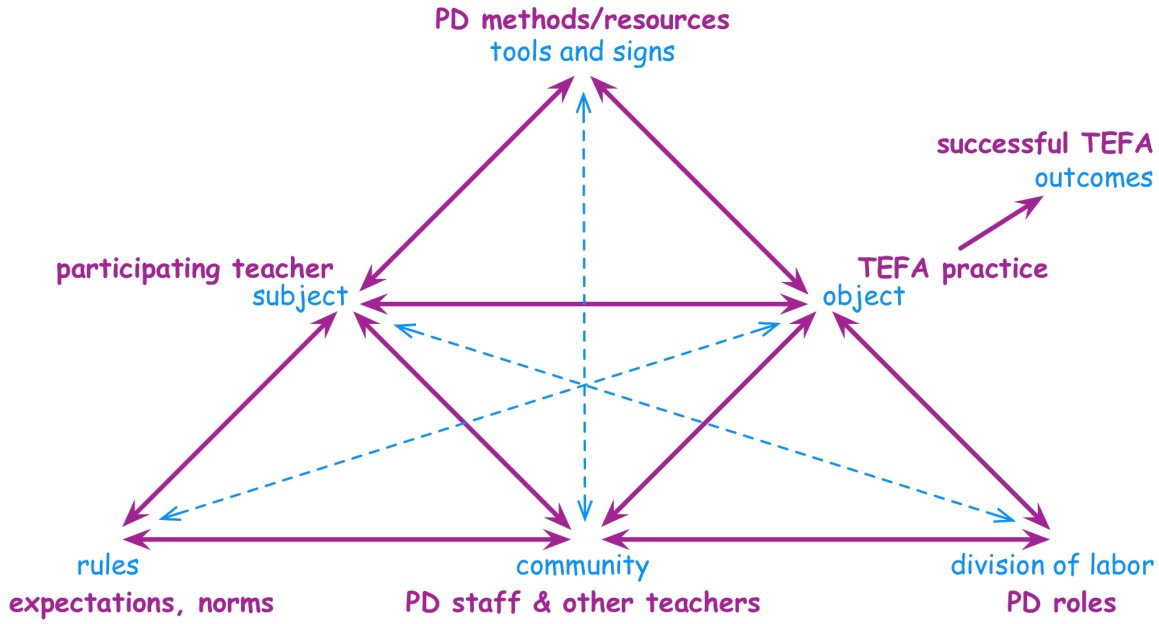


*Figure 4: TLT professional development as an activity system, focusing on the participating teacher's point of view.*

Finally, the *tools* of the system include the many different PD tactics and resources employed to help teachers reflect upon their practice and improve their skills, such as discussions of various natures, model TEFA lessons by staff (thus making TEFA a tool as well as an outcome), mock TEFA lessons by participants, viewing and discussing of videotape of participants' teaching, literature readings, journaling, and formative feedback surveys used to inform future PD design.

### *The Co-Evolution Model and CHAT*

It seems to us that the CHAT activity system just described maps very neatly onto the co-evolution model summarized earlier, complementing it. The *subject* element of the system, the teacher, obviously corresponds to the "teacher" box of the co-evolution model. The *object* element, the teacher's practice, corresponds to the "teacher's TEFA" box. The influence of PD on the teacher and his or her practice, left fairly vague in the co-evolution model, is expressed via CHAT as the influence of the PD community on the teacher, as mediated by *rules* and shaped by the *distribution of labor* and the supplied *tools*.

While CHAT provides more structure to understand the influence of PD on teachers and their practice, the co-evolution model makes explicit two propositions that are only implicit in the CHAT activity system: that the subject and object (and, for that matter, all other elements of the system) are in constant and interlinked evolution, and that tensions between elements of the system are drivers of this change. We see the co-evolution model as illustrating the temporal dimension of a subset of the CHAT activity system.

We can also view the co-evolution model as a way of understanding the process of *expansive learning* discussed by Engeström (2001). Within the TLT project, teachers are not simply learning a set of pre-defined skills or acquiring "stable knowledge." They are

also exploring and pushing back the horizon of the space of pedagogical possibilities open to them, participating in an ongoing re-conceptualization of what TEFA practice means to them and what teaching can look like. We suspect that a dialectical interaction of two narratives, analogous to the co-evolution model's "teacher change" and "pedagogical transformation" arcs, may be essential to any process of expansive learning.

## *CHAT for Classroom Instruction*

The activity system just described is rather pointless in isolation. It only has value, and can only be properly understood, in the context of each participating teacher's classroom instruction. Thus, we turn the lens of CHAT to the activity system consisting of a secondary school teacher and his or her students, engaged in the activity of "teaching a subject." (Other activity systems are also related and relevant, describing the activity of educational research by project staff, for example, and the administrative activity of a school, and the outside-school lives of students, but we do not explore those here.)

### *The Classroom as an Activity System*

Again, we begin by mapping the CHAT activity triangle to our system. Continuing to adopt the teacher's perspective for analysis, we identify the teacher as *subject* (Figure 5). The *object* of the teaching/learning activity is the set of *students*. More precisely, it is the students' content knowledge that is the "raw material" (Center for Activity Theory and Developmental Work Research, 2003, ¶4) for producing the desired *outcomes* of subject comprehension and student readiness for standardized tests and subsequent schooling. Some teachers also hold students' personal growth and social development among their desired outcomes. The *community* includes other members of the school, such as support staff, counselors, administrators with disciplinary roles, and student teachers. The students can arguably be included in the community as well, giving them an ambiguous member/object status. We discuss this ambiguity below. We could, if we wish, expand our definition of community to include the larger social matrix encompassing the classroom and school. This would allow us to model the roles of parents, civic and religious leaders, and others.

The *distribution of labor* in the classroom specifies the power structure, including the teacher's authority to designate learning goals for students, select and design learning activities, establish performance criteria and measures, and dictate behavior standards. *Rules*, explicit and implicit, specify norms and expectations for behavior by teacher and students. In particular, the "rules" of the classroom include the teacher's and students' deep-seated, often unconscious models of what school teaching and learning "should look like," as well as implicitly negotiated (and often tested) thresholds of acceptability for borderline behavior such as back-chatter. In observing various teachers' classrooms, we have seen that many of these rules vary from classroom to classroom, meaning that students learn a different set for different teachers, and adjust their behavior accordingly. This creates the likelihood of interactions and conflicts between the activity systems of different classrooms that have students in common.

The activity system's *tools* include a wide array of teaching/learning resources, ranging from concrete items like whiteboards, computers, and textbooks to abstract patterns of action such as types of learning activity, teacher questioning strategies, and recourses for

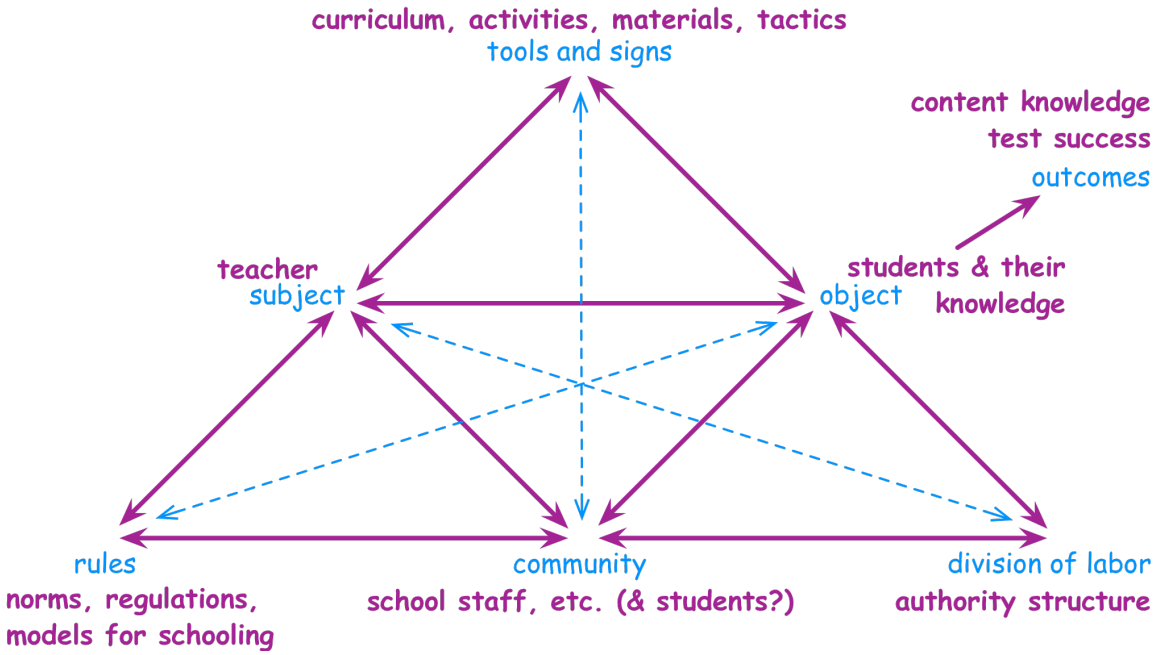


*Figure 5: The classroom as an activity system, focusing on the teacher's point of view.*

disciplinary action. Most experienced teachers seem strongly attached to their toolkit: It forms a set of survival strategies and resources that they have painstakingly collected to cope with the trying environment of the classroom, and they are cautious about tinkering with it for fear of the possible consequences (Cuban, 1993).

### *The Primary Contradiction*

"The primary contradiction [of an activity system] can be found by focusing on any of the elements" of the activity system (Center for Activity Theory and Developmental Work Research, 2003, ¶16). They define this as a "primary inner contradiction (double nature) within each constituent component of the central activity" (Center for Activity Theory and Developmental Work Research, 2003, caption accompanying Figure 6) at each of the six elements of the triangle diagram. We take this to mean that any activity system has a deep, fundamental dichotomy or dialogical tension that manifests itself in every component of the system[2].

We contend that the *primary contradiction* within secondary education is obvious to anyone who has spent time in a classroom: the clash between the teacher's goal of teaching subject material and his or her need to almost continually manage student behavior and keep students "on task." That is, the activity system's *division of labor* has assigned to the teacher two conflicting roles: teacher of subject content, and maintainer of order. We label this contradiction "instructor | warden" as it is manifest within the *subject* element of the system, the teacher. The vertical bar between "instructor" and "warden" indicates a dialectical category constructed from two mutually exclusive, reciprocal terms

[2] It is unclear to us whether they mean that any activity system has *at least* one or *exactly* one such primary contradiction.

and encompassing a built-in contradiction (Roth & Lee, 2007). Although this metaphor may seem extreme to many readers, we believe it is an accurate representation of the situation in many secondary science and mathematics classrooms. Continuing the metaphor, we label the corresponding manifestation within the *object* element, the student, as "trainee | inmate." And from this, we believe the base cause of the contradiction becomes clear: The activity system treats students as the *object* of activity, as if they were "raw material… at which activity is directed" (Center for Activity Theory and Developmental Work Research, 2003), despite the unavoidable fact that they are willful individuals making a transition to adulthood. To put it another way, students' dual status as *object* and member of the *community* in this activity system lies at the root of the contradiction. The issue is *sovereignty* and whether students act or are acted upon.

This primary contradiction echoes throughout our system (Figure 6). It manifests itself in the *community* and the school that encompasses it as an "academy | prison" dual nature. We label the subject-to-object link (termed *production* by activity theorists) as "instructing | controlling." The teacher's tools, which mediate the subject-object relationship, thus must serve the dual purpose of "informing | holding responsible." We find it telling that the two general questions prospective TLT participants most often ask about TEFA are "Will it help students learn the content better?" and "Will it get the students to participate and behave?"

Two of the seven teacher-reported difficulties listed in the previous section can be seen as straightforward manifestations of this primary contradiction. "Disappointing student participation" and "student behavior problems" both mean "students are choosing to do what *they* want to do, rather than what *I* want them to."

We suggest that the resolution to this primary contradiction is not to pull for one alternative or the other, but to transcend it by escaping from the "student as trainee | student as inmate" dichotomy to a system where the student might be described as "explorer and seeker of knowledge." This would require that the production dynamic of "instructing | controlling" transform to one of "engaging," the teacher transform from "instructor | warden" to "guide," the classroom and school transform from "academy | prison" to "environment and resource," and the tools transform from "means of informing | means of holding accountable" to "means of challenging and tools for exploring" (Figure 7). To put it another way, the escape from the dichotomy is to have students become *invested* in their learning and take the responsibility and initiative for it.

Such a transformation may seem utopian and unrealizable, requiring a drastic re-visioning and overhaul of the entire activity system and many coupled systems including teacher preparation programs, all public education from K-12, and parental and societal perceptions. However, one of the participants in the TLT project demonstrated that a single teacher can, with the support of project PD, achieve this transition on a scale of one class of students.

> I mean you come into my classroom, it looks chaotic from the onset. You don't see a teacher that is standing, and all of the students sitting behind a desk and quietly, you know, staring at the teacher. You see some students at one whiteboard, students at a SmartBoard, students in little groups, you know, and all working on the same problem, and then all coming back together, and then

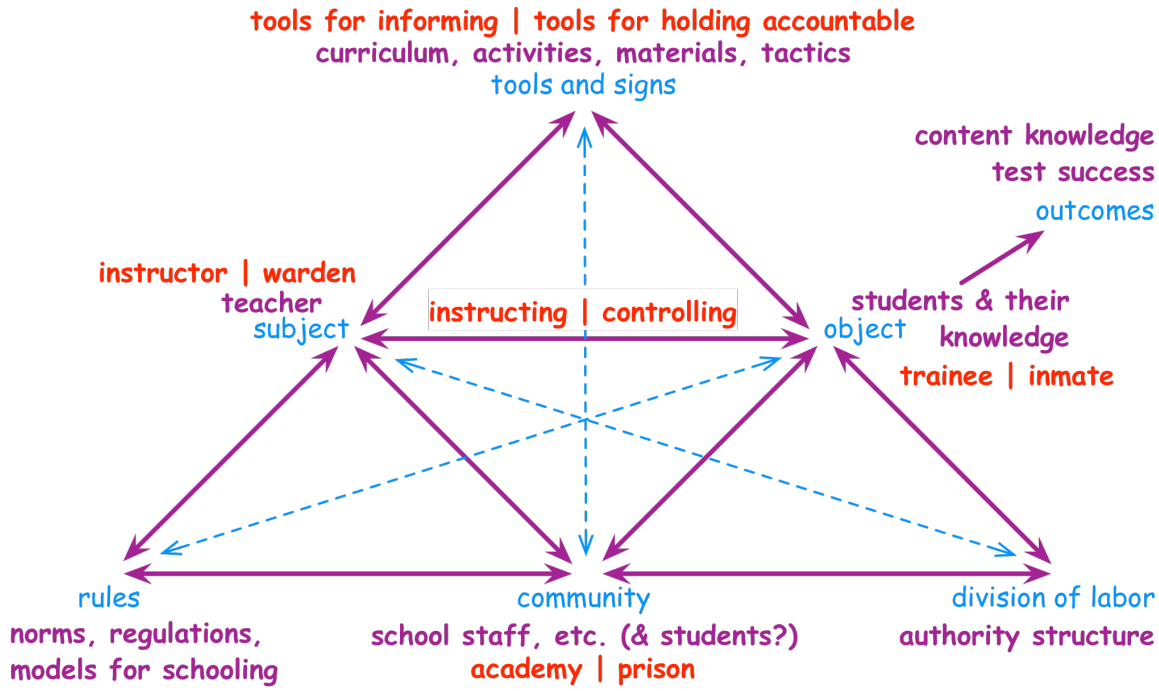


*Figure 6: The primary contradiction of secondary education, as it is manifest within different elements of the classroom activity system.*

> students arguing. It seems kind of chaotic, but it's, it was so much learning happening that I think it was a risk worth taking… I tried to get [the school administration] in there to see that, and see what a real learning classroom looks like. Because it was new for me, and it was exciting for me…
>
> Sometimes as teachers we *get* in the way of our students' learning. Um, I think, that's why I think this back-of-the-classroom approach works…
>
> I mean, the [CRS] clickers are just a tool we use to see where we're at at any given moment. Um, and for good or bad, I don't necessarily think "Well, we're gonna include the [CRS]." There are times when I *don't* include the [CRS], it's not a part of my plan. And the students say "Let's poll this!" And they'll get up, they'll grab their clickers. I'll, you know, turn it up, and they turn and they all vote. And then they'll say "Well, okay, um, most of us choose *this*, so we're gonna go with this." And that happens a lot when the students can't come to any particular consensus on a particular thing. They all just decide different things and so they use it. They poll each other for just, you know, just to see where they stand. And then before they turn it over to me, they'll say "Well, fifty-five percent of us says this, so we're gonna go with this." And then I look at it and we talk about it…
>
> I had one student that said to me "I never liked math before, but this feels good."
>
> —*participant b104, excerpts from pedagogical perspectives interview, year 1 (emphasis by speaker)*

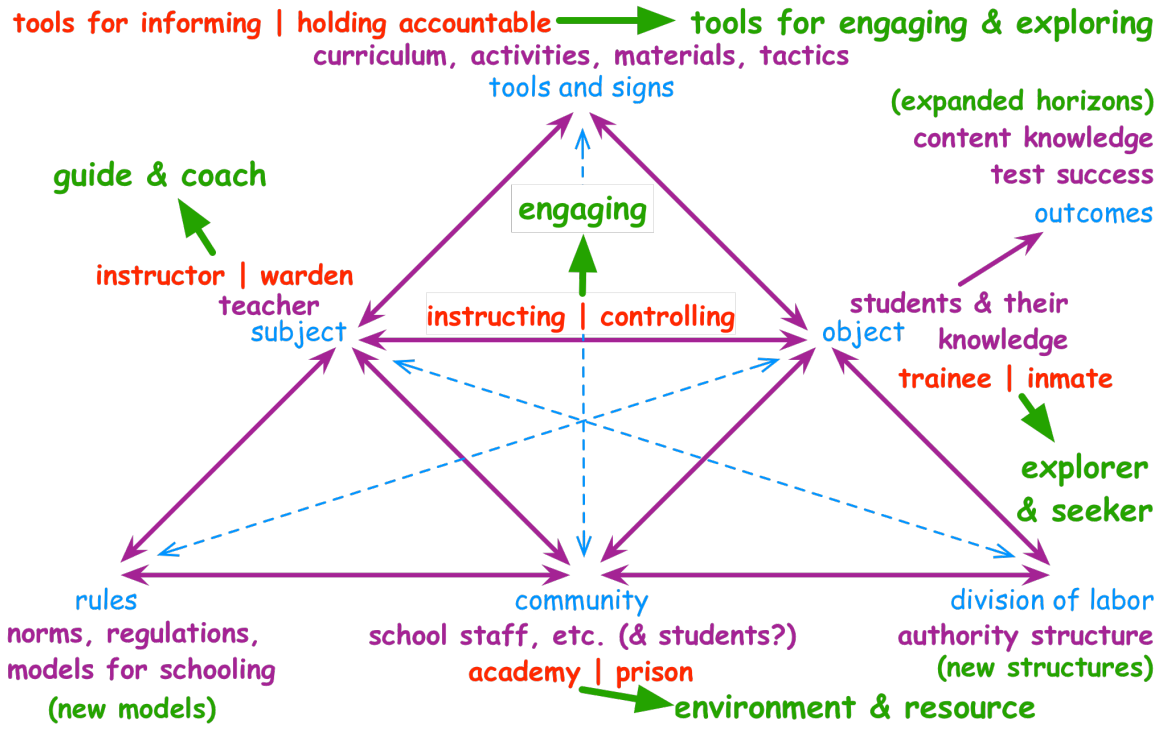


*Figure 7: Transcending the primary contradiction with a dynamic of engaging.*

Aside from the teacher, the class in question was not particularly special in any way. It was a 9th grade algebra class, heterogeneous in ability level, in a relatively high-performing public high school serving a diverse population in a large college town. To us, this suggests that teachers have far more control over the dynamics of their classrooms than most believe. It also provides us with hope that our suggestion for transcending the "informing | controlling" contradiction by escaping to a dynamic of "engaging" is realistic and worth pursuing.

### *Depth vs. Breadth: Echo of the Primary Contradiction*

Not surprisingly, this primary contradiction of informing | controlling pervades all the coupled activity systems of the public education complex, and echoes of it rebound from other systems to impact the classroom system we are examining. We believe that the classic "depth vs. breadth" conundrum—"students learn better when I use TEFA, but I don't have time because I have to get through so much content"—is one such echo. Its TEFA-specific manifestation, the reported TEFA difficulty of "insufficient class time," is therefore traceable to the primary contradiction.

Teaching students to understand content has always been the leading goal of education, to the point that "schooling" is largely synonymous with "teaching stuff." However, other linked activity systems within the "secondary education" complex have developed their own tools for carrying out the control side of the instructing | controlling dialectic (and for controlling teachers as well as students). These tools include curriculum standards, high-stakes testing, and rules regarding them that teachers and schools must obey. In other words, we interpret pressure to cover curriculum as a result of the primary training | controlling contradiction, reflected upon the classroom activity system through its

interaction with other, coupled activity systems and their influence on its rules and desired outcomes.

### *Illuminating TEFA Adoption with CHAT*

We have just presented a CHAT-based description of the two linked activity systems central to a teacher's adoption of TEFA: TLT project PD and his or her classroom. Now, we build on these to suggest a model for how TEFA is—or can be—adopted into a teacher's practice, with transformative results. Although this description is consistent with our findings and observations to date, further analysis is necessary before we can claim empirical support for the model.

#### *Stage 1: TEFA as Another Object*

When a teacher in the TLT project initially encounters TEFA, it is not immediately useful for their instructional goals. Rather, it is something new, unfamiliar, awkward, perhaps intimidating, and frequently troublesome. Participants make an effort to try it out in their classes because they hope that it will prove to be of value, and also because they feel obligated to through their participation in the project. In the early stages, however, using TEFA is "one more thing" to try to accomplish in class. We call this stage "TEFA as object," since their implementation of TEFA has become an additional *object* for them to focus activity upon.

> [Day-to-day, the aspect of using TEFA I've been most focused on or concerned about is] trying to work with it and include it into my class as an important part.
>
> *—participant a105, monthly reflection survey for year 1 round 2*

> [Day-to-day, the aspect of using TEFA I've been most focused on or concerned about is] remembering to use [it] in my planning.
>
> *—participant a110, monthly reflection survey for year 1 round 3*

> Ever even doing it consumes most of my attention, because it means I had some time to think about it, or that I just decided to fit it in.
>
> *—participant a111, monthly reflection survey for year 1 round 2*

This creates a new tension in the classroom activity system, as multiple objects (students and their knowledge, TEFA practice) and multiple outcomes (student learning, doing TEFA "right") vie for scarce resources (class time, student attention span, teacher energy). To use the language of CHAT, we would say that the linked activity system of TLT PD has injected an additional *object* and desired *outcome* into the classroom activity system, creating a *quaternary contradiction* between the two systems.

For some teachers, this uncomfortable state of affairs can protract for more than a year.

> [Day-to-day, the aspect of using TEFA I've been most focused on or concerned about is] doing it at all.
>
> *—participant a111, monthly reflection survey for year 2 round 2*

For most, however, the tension motivates change. Two forms of resolution are possible: abandoning TEFA and withdrawing from the project, or finding a way to make TEFA aid, rather than conflict with, the teacher's primary instructional goals.

### *Stage 2: TEFA as Tool*

Fortunately for the TLT project, few participants select the first path, at least within their first year. (Reasons for withdrawing later on are generally more complicated.) In our model of TEFA adoption, we posit a second stage that we call "TEFA as tool." The stage is characterized by a teacher's belief that TEFA use is productive for him or her in teaching students, and that the gains achieved are worth any additional effort required.

> When I use TEFA regularly I can tell that the students are much more comfortable with their conceptual understanding of the material, and are not just "plugging and chugging."
>
> *—participant b103, monthly reflection survey for year 1, round 2*

> "I would." "Absolutely, I would." "Oh my God, yes."
>
> *—responses from three participants to the focus group question "If the project folded now and you got to keep your equipment, would you continue to use TEFA?" in site B year 1 PD meeting 18*

In practice, the transition from stage 1 to stage 2 is not sharp. Most participants find that TEFA becomes gradually more useful and less onerous, and they become gradually more convinced that persevering is worthwhile. Some teachers fluctuate, apparently backsliding on their degree of conviction. Some have dramatic moments of epiphany, where a specific insight or occurrence alters their perception of TEFA's value.

> I think having one really amazing experience using TEFA—because I had a great question and it really worked—has restored my view that it's worth trying to find the time to design good questions and use TEFA… I was able to use PD class time to think about a question and it just "clicked."
>
> *—participant a113, monthly reflection survey for year 1, round 4*

As TEFA transitions from *object* to *tool* in the classroom activity system, the quaternary contradiction identified above subsides. However, as mediator of the subject-object interaction, tools influence the activity of the system in fundamental ways. The incorporation of TEFA as a tool rather than object may resolve the quaternary contradiction mentioned above, but it introduces *secondary contradictions* between TEFA and other elements of the system.

#### *Insufficient prep time.*

We believe that teachers' reported difficulty finding time to create good TEFA questions is a manifestation of such secondary contradictions. As discussed earlier, this difficulty can be unpacked into three overlapping factors: the fact that TEFA includes no accompanying curriculum materials, so teachers must manufacture their own; the fact that question design requires skills that teachers do not initially possess; and the fact that the structure of schooling provides teachers with very limited preparation time and many responsibilities to fulfill during that time. The first factor can be considered an

incompleteness of the TEFA toolkit itself. By failing to provide curriculum materials alongside the technologies of TEFA, we require teachers to adopt the role of curriculum designer in addition to all the roles they must already fulfill. Thus, a flaw in the tool leads to a conflict between *tools* and what the system's *distribution of labor* allots to the teacher: a secondary contradiction between elements of the system. We consider this contradiction "transient" because if and when TEFA practice becomes commonplace, we expect appropriate curriculum to be developed and disseminated. Additionally, as any individual teacher continues to practice TEFA, he or she will amass a personal collection of questions that can be re-used each time a given topic is taught.

The second factor, teachers' insufficient skill at question design, can be viewed as a secondary contradiction between the *subject* (teacher) and the new *tools* (TEFA). Such a difficulty is inevitable any time new and nontrivial tools are introduced to an activity system. We also consider this transient, since teachers can develop skill over time due to experience and PD assistance.

The third factor, insufficient preparation time, strikes us as a structural flaw in the system. By providing teachers with very limited prep time, schools hinder teachers from investing significant time in pedagogic or curricular improvement. Any major change in teaching practice will require additional time and energy to plan, explore, and become efficient with. In the schools associated with the TLT project, teachers must devote their personal evening and weekend hours to such things. This serves as a strong deterrent and retardant to change. The structural flaw is not transient, but its effect on TEFA learning is transient in the sense that if and when TEFA practice becomes the norm for a teacher, the flaw's retardant effect on change ceases to be relevant.

Interestingly, most but not all participants in the TLT project report difficulty finding enough time to create TEFA questions. This suggests that the details of a specific classroom activity system, with a specific teacher, can affect how severe and how amenable to resolution this set of secondary contradictions is.

#### *Technical difficulties.*

We see teachers' difficulties with the technology—including learning to operate it, teaching the students to work with it, and overcoming problems—as attributable to fairly straightforward secondary contradictions between the new *tool* (the classroom response system) and either the *subject* (the teacher's comfort and facility with the tool), the *community* (school technical support staff's knowledge and availability), the *distribution of labor* (tech staff's perception that supporting CRS use was not part of their mandate) or, occasionally, the *object* (students' interest in finding creative ways to misuse and abuse the technology). For most teachers, most of these contradictions were resolved in relatively short order. Those that weren't, such as unresponsive school technical support staff, should largely disappear if and when CRS technology becomes standard and familiar. Thus, we view this set of difficulties as transient.

#### *Clash with teaching style.*

If a teacher's "style" is their internalized and perhaps unconscious patterns of behavior for functioning within the activity system they are accustomed to—their comfort zone—then anything that perturbs that system is likely to cause them feelings of discomfort and

disequilibrium. The introduction of TEFA into their classroom system, first as an object and then as a tool, has altered the system's dynamic, causing a secondary contradiction between the tool and subject (teacher). As other elements of the system adjust, such as the object (if students' behavior changes in response to the use of TEFA), the rules (if TEFA's activity patterns alter perceptions of what teaching and learning should "look like"), and the distribution of labor (if the teacher's role comes to be seen as more of a facilitator and less of an authority), a cascade of second-order contradictions between these elements and the subject may arise.

### *Incompatibility with subject or curriculum.*

Within this CHAT-based description, incompatibilities between TEFA and a specific subject, versus incompatibilities between TEFA and a specific curriculum, must be handled separately. An incompatibility between TEFA and a curriculum would seem to be a straightforward conflict between discordant tools in the teacher's toolkit: a secondary contradiction. (We don't call it a primary contradiction because it is not a dialectical "dual nature" within one tool, but simply a clash between two different components of the system, even if they both fall on the same portion of the triangle diagram.) The teacher must discard one, modify one, or find a way to harmonize them.

An incompatibility between TEFA and the subject of a class (not to be confused with the *subject* of an activity system) is harder to analyze. If TEFA really were fundamentally incompatible with what students are intended to learn, then we would have a secondary conflict between tool and object, and TEFA would have to be rejected or altered to suit. An example might be a highly skills-based class such as keyboarding, with little conceptual content to be pondered and discussed. We suspect, however, that most such reported incompatibilities are not with the content itself, but with the ways that that content is traditionally taught: the curriculum, methods, activities, apparatus, assessments, etc. If that is true, we again have a secondary conflict between tools.

### *Resolving the secondary contradictions.*

Just as the quaternary contradiction of the "TEFA as object" stage—the competing object injected into the system by the linked activity system of TLT project PD—provided an impetus to either abandon TEFA or turn it into a useful tool, the collection of secondary contradictions that result from TEFA as a newly-adopted tool drive further change. Within the TLT project, we have seen four different possible outcomes: rejection, accommodation, transformation, and provisional use.

These have blurry boundaries, and the first three form a sort of continuum. *Rejection* means that the teacher finds the difficulties caused by the secondary contradictions to be intolerable, or finds TEFA insufficiently beneficial to justify them, and so abandons TEFA or relegates it to a very minor role within his or her teaching. In other words, the teacher experiences too little gain for the pain. *Accommodation* means that the teacher incorporates TEFA into his or her existing patterns of practice, enhancing but not deeply changing that practice. We believe this occurs when the perceived drawbacks are minor and the perceived benefits are moderate. *Transformation* means that the introduction of TEFA precipitates a dramatic and sweeping alteration of the teacher's practice and the entire classroom activity system. We conjecture that this occurs when the perceived

drawbacks are moderate or perhaps even major, but the perceived benefits (e.g., resolution of some disliked pre-TEFA contradictions) are even more significant.

The fourth outcome, *provisional use*, is a transient rather than stable state. It means that the teacher's long-term relationship with TEFA has not yet been resolved, and the teacher continues to use TEFA at some level while seeking solutions to difficulties and gauging its value. He or she continues to explore the pain to gain ratio. This non-outcome "outcome" is unfortunately common in the context of a project like TLT, in which the teacher may feel socially obligated to continue "exploring" TEFA for the duration of the project.

### *Stage 3: TEFA as Transformed System*

Of the three stable outcomes, rejection means that TEFA is no longer part of the classroom activity system in any meaningful way. Accommodation means that it remains a *tool*, with the resulting secondary contradictions either tolerated or gradually reduced through small adjustments to TEFA practice and other elements of the system. Transformation, on the other hand, means that TEFA becomes more than just a tool: it expands to permeate the system, becoming deeply embedded in the rules, division of labor (roles), perceptions and behaviors of community members, identification of objects, and envisioning of outcomes.

To understand this, one must realize that TEFA is more than a collection of instructional tactics for using a classroom response system. TEFA is, in fact, triple-layered (Beatty & Gerace, in press). The first layer is a statement of pedagogic objectives: "to help students grow contextually robust, transferable conceptual ecologies that are thoroughly reconciled with their experiences, perceptions, and prior understandings… by engaging students in extensive dialogical discourse about scientific ideas and their applications, set within the context of rich and challenging questions and problems… [and] to explicitly confront students' beliefs and attitudes, communicate high teacher expectations, and scaffold self-directed, self-regulated learning habits" (Beatty & Gerace, in press, p. 7). The second layer is a set of core pedagogic principles, summarized as *question-driven instruction*, *dialogical discourse*, *formative assessment*, and *meta-level communication*. The third level is a complex of instructional tools and tactics, including CRS technology, the design and use of "TEFA questions" for a variety of teaching purposes, student-centered whole-class discussion, meta-level communication, and the "question cycle." Although the majority of TLT project PD time is devoted to helping teachers develop skill with the tools level, PD exposes teachers to the other two levels as well through both explicit and implicit paths, seeking to impact them at all three levels.[3]

From what we have seen so far of the TLT project data, the "instructing | controlling" primary contradiction discussed above can either dissuade or motivate teacher's adoption of TEFA. The first case is obvious: Teachers fear that students will misbehave within the apparently tolerant, inviting atmosphere of TEFA, or will cause TEFA to fail by refusing to participate meaningfully. The second is less obvious: TEFA has been designed with

[3] We could argue that TEFA has a fourth—or perhaps "zeroth"—layer, consisting of the research-based models of cognition and learning upon which it is founded (Beatty & Gerace, in press). This layer, however, has not featured prominently in TLT project PD.

the ideal of a classroom dynamic of student engagement and investment, with the student as "explorer and seeker of knowledge." It encourages and scaffolds the emergence of such a dynamic in many ways both overt and implicit, and in fact aims to subvert the instructing | controlling dichotomy. If we are correct in recognizing the primary contradiction of secondary education and in identifying the solution as transcending the dichotomy, then TEFA provides a tool for achieving such a transcendence. Teachers that chafe under the dichotomy may perceive this and be encouraged to make a "leap of faith" in making wholesale changes to their practice.

> This semester, I did a lot of risk taking, *a lot*, that paid off for me in the end. But for a long time it was, I was scared. "Was this gonna work?" You know?… I decided that maybe the teacher's role is at the back of the classroom, and not at the front. Maybe the students are to be the drivers, and not the teacher. And I tried that this year and it worked… There's the whole idea of having students struggle through and sort of finding their own way, and *by their own path*. Um, I just thought that *maybe* we should try that. You know?… [The students] are able to come up with their own problem sets, um, they go to the front of the board. If I am not there, they take over the entire class. I mean, I've had subs saying to me "Wow, what a class you have!"… They hooked up the SmartBoard and *they*, as a class, they had their classroom discussion.
>
> —*participant b104, pedagogical perspectives interview, year 1 (emphasis by speaker)*

When TEFA so thoroughly transforms the activity system of one teacher's classroom, it can cause *tertiary contradictions* between that system and the linked systems of other teachers' classrooms, with the PD activity system mediating the linkage between systems. TLT project PD staff report the beginnings of such tertiary contradictions at site B, where in the second semester of year 2, other teachers are expressing great curiosity about the changes participant b104 has reported in her practice. They have been interrogating her during PD meetings, asking questions about how she changed the dynamic in her classroom and how she avoids or handles the various problems they fear would occur if they tried to do the same thing. One teacher even took the initiative to set up a video camera and record b104 teaching the first class of a new term, in order to find out how b104 taught her students to participate in such a completely student-driven, engaged, responsible way.

Participant b104 perceives the tertiary contradiction between other classes and her "culturally more advanced" (Engeström, 1987, p. 82)activity system, although not, of course, in those terms. Rather than seeing this as a difficulty, however, she interprets it as a challenge and opportunity to foment change in other classes.

## Summary and Discussion

In this paper, we have explored the utility of *cultural-historical activity theory* (CHAT) as a lens for understanding the difficulties teachers face and the sequences of changes their practice undergoes when learning a novel and challenging pedagogy, *technology-enhanced formative assessment* (TEFA), in the context of a three-year professional development program. After describing the most common difficulties reported by

teachers learning TEFA, we applied CHAT to the problem by describing the TEFA professional development program and teachers' classroom teaching as two linked activity systems, with the individual teacher as the *subject* of both.

Applying CHAT to TEFA PD allowed us to connect it to our previously developed *co-evolution model*. We found that the two fit together well and complement each other. CHAT helps explicate how PD and other circumstantial factors feature in the teacher change process described by the co-evolution model. The co-evolution model makes explicit the processes that are implicit in the standard "triangle diagram" representation of a CHAT activity system, such as the ways that tensions within a system drive change, and the fact that subject and object (teacher and practice) necessarily co-evolve in an ongoing dialectical narrative. The conjunction of the two models suggests that teacher learning of TEFA, as described by the co-evolution model, can be an example of the *expansive learning* described in CHAT literature.

Applying CHAT to a teacher's classroom helped us identify the *primary contradiction* within secondary education: Students have a dual status as both objects of instruction and willful individuals. This contradiction reverberates through the activity system, and can be understood as the root cause of three of the seven difficulties most often reported by teachers learning TEFA. Fears of exacerbating these difficulties can be a barrier to teachers' adoption of TEFA, but hopes of transcending the contradiction can be a motivator.

Building on these two applications of CHAT, we then suggested an activity-theoretic model for how a teacher's adoption of TEFA can proceed through up to three stages: *TEFA as object*, *TEFA as tool*, and *TEFA as transformed system*. In the first stage, the linked activity system of TEFA PD "injects" TEFA into the classroom activity system as an additional object, causing a quaternary contradiction between the systems. To resolve this contradiction, the teacher either rejects TEFA or finds a way to make it useful, thus shifting it from object to tool. In the second stage, secondary contradictions between this new tool and other elements of the system (and, as changes propagate, between pairs of other elements) drive a teacher towards one of three possible resolutions: *rejection*, *accommodation*, or *transformation*. A fourth, non-final state of *provisional use* may persist for a long time, especially under the influence of ongoing PD. If the classroom activity system moves to transformation, tertiary contradictions between it and the classroom activity systems of other teachers in the school, mediated by PD, can drive change in those other systems.

Although we have illustrated many of our assertions with quotes from project data, we must stress that the project within which we are operating is still in progress. Data are still being collected, and analysis is still preliminary. This paper should be interpreted as a theoretical exploration. Our three-stage model for teacher change and adoption of TEFA must be considered suggestive only, to be substantiated or contradicted by more rigorous testing against empirical data. The results of such testing will be published in a future work.

If these theoretical explorations bear fruit, we see various implications. One implication is that we may be able to help teachers surmount the difficulties they face at each stage of TEFA adoption by familiarizing them with the primary contradiction and the sequence of

other contradictions they are likely to encounter, thus aiding them to resolve the contradictions rather than chasing symptoms. Another implication is that TEFA may be able to help teachers escape the primary contradiction, but may require assistance from systemic reform efforts throughout the educational complex to deal effectively with the many ways in which the primary contradiction manifests itself.

We hope that others more knowledgeable than us about CHAT will critique our use of activity theory, perhaps suggesting more fecund ways of applying it. We also hope that researchers having experience with different, but analogous, teacher change (or other expansive learning) contexts will explore how well our ideas generalize. For our part, we will be confronting these ideas with the cold hard reality of data.

## Acknowledgements

We are grateful to our colleagues in the *Teacher Learning of Technology-Enhanced Formative Assessment* project, including William Leonard, William Gerace, Hyun Ju Lee, Robby Harris, Karen Tallman, and Karen St. Cyr, for many productive discussions and for their part in all the components of the TLT project that are not directly represented in this paper but are nevertheless essential for creating a context in which this paper is possible.

Preparation of this manuscript and development of the ideas described have been supported in part by US National Science Foundation grant TPC-0456124. Any opinions, findings, conclusions, or recommendations expressed are those of the authors and do not necessarily reflect the views of the NSF.

## References

Beatty, I. D., & Gerace, W. J. (In press). Technology-Enhanced formative assessment: A research-based pedagogy for teaching science with classroom response technology. *Journal of Science Education and Technology.*

Beatty, I. D., Feldman, A., Leonard, W. J., Gerace, W. J., St. Cyr, K., Lee, H., et al. (2008, April 1). *Teacher learning of technology-enhanced formative assessment.* Paper presented at the Annual Conference of the National Association for Research in Science Teaching, Baltimore, MD.

Beatty, I. D., Leonard, W. J., Gerace, W. J., & Dufresne, R. J. (2006). Question driven instruction: Teaching science (well) with an audience response system. In D. A. Banks (Ed.), *Audience Response Systems in Higher Education: Applications and Cases* (pp. 96-115). Hershey, PA: Idea Group Inc.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How People Learn: Brain, Mind, Experience, and School*. Washington, DC: National Academy Press.

Center for Activity Theory and Developmental Work Research (2003). The activity system. Retrieved February 23, 2009, from the University of Helsinki: http://www.edu.helsinki.fi/activity/pages/chatanddwr/activitysystem/

Cuban, L. (1993). *How teachers taught: Constancy and change in American clasrooms, 1890-1990*. New York: Teachers College Press.

Dufresne, R. J., Gerace, W. J., Leonard, W. J., Mestre, J. P., & Wenk, L. (1996). Classtalk: A classroom communication system for active learning. *Journal of Computing in Higher Education*, *7*(2), 3-47.

Engeström, Y. (1987). Learning by expanding: An activity-theoretical approach to developmental research. Retrieved March 1, 2009, from http://lchc.ucsd.edu/MCA/Paper/Engestrom/expanding/toc.htm

Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*(1), 133-156.

Feldman, A. (1996). Enhancing the practice of physics teachers: Mechanisms for the generation and sharing of knowledge and understanding in collaborative action research. *Journal of Research in Science Teaching*, *33*(5), 513-540.

Feldman, A. (2002). Multiple perspectives for the study of teaching: Knowledge, reason, social context and being. *Journal of Research in Science Teaching*, *39*(10), 1032-1055.

Feldman, A., & Capobianco, B. M. (2008). Teacher learning of technology enhanced formative assessment. *Journal of Science Education and Technology*, *17*(1), 82-99.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. *Educational Researcher*, *33*(7), 14-26.

Leont'ev, A. N. (1981). *The Development of Mind: Selected Works of Aleksei Nikolaevich Leontyev*. Pacifica, CA: Marxists Internet Archive.

Loucks-Horsley, S. (1996). Professional development for science education: A critical and immediate challenge. In R. Bybee (Ed.), *National Standards & the Science Curriculum*. Kendall/Hunt.

Mortimer, E. F., & Scott, P. H. (2003). *Meaning Making in Secondary Science Classrooms*. Maidenhead, UK: Open University Press.

Murphy, E., & Rodriguez-Manzanares, M. A. (2008). Using activity theory and its principle of contradictions to guide research in educational technology. *Australasian Journal of Educational Technology*, *24*(4), 442-457.

Roth, W. M., & Lee, Y. J. (2007). Vygotsky's neglected legacy: Cultural-historical activity theory. *Review of Educational Research*, *77*(2), 186-232.

Roth, W. M., Lawless, D., & Tobin, K. (2000). Towards a praxeology of teaching. *Canadian Journal of Education*, *25*(1), 1-15.

Schmidt, W. H., McKnight, C. C., & Raizen, S. (1997). *A Splintered Vision: An Investigation of U.S. Science and Mathematics Education*. Dordrecht: Kluwer Academic.

Schön, D. (1983). *The Reflective Practitioner: How professionals think in practice*. New York: Basic Books.

Stengel, B. (1996, April). *Teaching epistemology through cell reproduction: A narrative exploration.* Paper presented at the Annual Meeting of the American Educational Research Association, New York.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching*, *37*(9), 963-980.

Sweeney, A. E., Bula, O. A., & Cornett, J. W. (2001). The role of personal practice theories in the professional development of a beginning high school chemistry teacher. *Journal of Research in Science Teaching*, *38*(4), 408-441.

Vygotsky, L. S. (1978). *The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Wertsch, J. V. (1991). *Voices of the Mind: A Sociocultural Approach to Mediated Action*. Cambridge, MA: Harvard University Press.

Yin, R. (2003). *Case Study Research: Design and Methods (3rd ed.)*. Newbury Park, CA: Sage Publications.