

TEACHERS' IMPLEMENTATION OF A CLASSROOM RESPONSE SYSTEM FOR FORMATIVE ASSESSMENT IN SECONDARY SCIENCE AND MATHEMATICS

This study of *Technology Enhanced Formative Assessment* (TEFA) reports on how secondary school science and math teachers learn to implement TEFA pedagogy using classroom response system technology, and identifies factors that impede implementation. We found that teachers struggled with both *extrinsic factors*, which are characteristics of the teacher's context that hinder them from implementing the technology and pedagogy, and *intrinsic factors*, which are characteristics of the teacher that impede implementation. The major extrinsic factors that we found are technology malfunctions, limitations, and availability of support; time and curriculum pressure; student attitudes and abilities; and characteristics of the TEFA professional development program. We found intrinsic factors of two separate types. The first type consists of gaps in teachers' knowledge and skills needed to operate the technology, develop TEFA questions, integrate TEFA into curriculum, orchestrate classroom discussion, and practice formative assessment. The second type consists of teachers' perspectives, beliefs, philosophy, attitudes, fears, doubts, uncertainties, background and experiences, which we collectively refer to as "ways of being a teacher."

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Introduction

Teacher Learning of Technology Enhanced Formative Assessment (TLT) is a 5-year research project that has been conducted at the University of Massachusetts Amherst since 2005. The purpose of the TLT project is to understand how teachers learn to use a classroom response system (CRS) to implement *Technology Enhanced Formative Assessment* (TEFA) pedagogy. TEFA has four principles, which can be labeled *question-driven instruction*, *dialogical discourse*, *formative assessment*, and *meta-level communication* (Beatty & Gerace, 2009). TEFA uses classroom response system (CRS) technology to enact these principles in the classroom. A CRS gathers students' responses to multiple-choice or other short answer questions, and displays an immediate histogram of those results. Within TEFA, CRS technology plays an important role in

gathering formative assessment data and in encouraging students to participate in class discussion. When a question is presented, students discuss the question with their peers or think about it individually, and then report their answer choice with a CRS remote (“clicker”). After the histogram is shown, whole-class discussion generally ensues, followed by the teacher presenting or orchestrating some type of closure, in an iterative “question cycle” (Dufresne et al., 1996).

Although CRS use is becoming more common in educational settings, especially in higher education, studies about it are limited in scope and breadth, and primarily confined to post-secondary settings (Fies & Marshall, 2006). Few studies have focused on the obstacles teachers face as they attempt to implement CRS in their classes. However, much research has been reported on barriers to teachers’ use of general educational technology such as computers and the Internet (e.g., Smerdon et al. 2000; Egbert et al. 2002; Wood et al. 2005). Some well-documented factors that often discourage teachers in their practices with technology are: limited computer availability (Hope, 1997; Smerdon et al. 2000; Wood et al. 2005); limited time for planning and personal exploration (Duffield, 1997; Hope, 1997; Sheingold & Hadley, 1990; Egbert et al. 2002; Wood et al. 2005); inadequate technical and administrative support (Schrum, 1995); insufficient training and expertise (Hope, 1997; Shelton & Jones, 1996; Smerdon et al. 2000); resistance, passivity, unsupportive school cultures, and incompatible traditions of teaching (Cohen, 1987; Cuban, 1986; Ertmer, 1999; Hope, 1997); lack of vision and leadership (Ely, 1995; Hope, 1997); and curricular restrictions (Cuban, 1986; Hancock & Betts, 1994; Egbert et al. 2002). Ertmer (1999) developed a scheme for organizing this wide variety of barriers into two major categories: *first-order barriers* that are circumstantial and external to teachers, such as lack of resources; and *second-order barriers* that are internal to teachers, such as beliefs about teaching and learning.

Recently, Feldman and Capobianco (2008) reported on a study about teachers’ use of CRSs for the purpose of formative assessment. In their research, they found that teachers needed to learn four “technologies” to implement formative assessment with a CRS: 1) operating the hardware and software; 2) constructing formative assessment questions; 3) facilitating discussions; and 4) fitting the new pedagogy into their existing curriculum. Although they identified these areas as crucial to proficient implementation, further work is needed to better understand the barriers that teachers encounter as they develop (or fail to develop) proficiency in each area.

Our current study extends this work by Feldman and Capobianco. Our research questions are: 1) what factors impede implementation of TEFA using CRS technology in secondary science and mathematics classes? and 2) what does teachers’ TEFA “learning trajectory” look like as these factors change over time?

Methods

This study takes a mixed-methods approach (Johnson & Onwuegbuzie, 2004), using both qualitative and quantitative analysis to triangulate from multiple data sources. Our data sources include surveys, interviews, participant observation with field notes, video recordings of classroom observations, and document analysis. We detail these methods below.

Setting

Science and math teachers from four school districts in the northeastern US have participated in the TLT project. 10 mathematics and science teachers from the combined middle/high school in a rural, multi-town district formed our first cohort, termed “school A”; their professional development began in August 2006. 8 teachers, all science except for one in math, from the high school in a diverse college town formed our second cohort, termed “school B”; their PD began in August 2007. 12 teachers, all science except for one math, from the high school and vocational-technical high school in a large suburban city formed one site in our third cohort, termed “school C”; their PD began in August 2008. 8 science teachers from the two middle schools in the same suburban city formed a second site in our third cohort, termed “school D”; their PD also began in August 2008. Some of these teachers have left the project for a variety of reasons after one or two years of participation, and at least one new teacher has joined late.

Participation in the project involves a 3-year professional development (PD) program that includes a four-day summer workshop, weekly and then biweekly professional development meetings during the first year, and triweekly action research meetings during the second and third year. Project staff also provide teachers with CRSs and technical support. Data have been collected through various methods including classroom observation and videotaping, teacher interviews, monthly or weekly reflective online surveys, student surveys, PD journals and assignments, and daily logs of CRS usage.

Data Collection

The main data for the particular analyses we report here are drawn from the TLT *Monthly Reflection Survey* (TMRS). The TMRS is a web-based survey consisting of open-ended and multiple-choice questions. TMRS data were collected after each month of CRS use (October, November, December, February, March, April, and May, with a month’s break in January). The data from school A for ten teachers in year 1 (fall 2006 – spring 2007) and six teachers in year 2 (fall 2007 – spring 2008), and from school B for eight teachers in year 1 (fall 2007 – spring 2008),

were used in the analyses we report. Some additional data from daily logs, PD journals, and interviews were also used.

Analysis

As we noted above, this study takes a highly mixed-methods approach. For the open-ended question data, we followed a grounded theory approach (Strauss & Corbin, 1990) by performing open coding, axial coding, and selective coding with cross-case analysis. *HyperResearch* and *NVivo* software were used throughout the procedure. To better understand how the barriers teachers face evolve over time, we itemized barriers and other factors identified by teachers, counted how often each was mentioned by each teacher in each round of the survey, and constructed a matrix of frequency (number of mentions) vs. time for each teacher. To characterize multiple-choice question data, we plotted each teacher's responses to each multiple-choice question versus time, and then qualitatively interpreted the trends that these plots revealed. We triangulated the results with other data and analyses in weekly meetings of project staff, where project staff (faculty principal investigators and graduate student research assistants) discussed their analysis of data from various instruments and their first-hand knowledge of participating teachers from PD meetings.

Findings

Factors that Affect Teachers' Implementation of TEFA

In this section, we identify factors that hindered teachers' attempts to use CRS technology and implement TEFA pedagogy, based on our analysis of participants' responses to open-ended questions on the monthly reflection survey. We organize the factors into a rough taxonomy and illustrate them with direct quotes from participants' responses.

Technology Issues

This category includes all issues related to technology, including CRS clickers and receivers, computers, projectors, TV monitors, the Internet, software, human technical support, and teacher's skill and comfort operating it.

hardware & software

These are factors associated with the system or software itself.

Malfunctions and resource availability: This category includes anything associated with the technology failing to do what is supposed to do, and with the availability of the resources.

“The clickers not working with the slightest bump” “Frustration when we have to put the clickers away without finishing the procedure (because something isn’t working)” “My overhead projector was not working for a while, so I couldn’t prepare questions and multiple choice answers in advance” “At this point, I’ve been focused on the technological aspect. Broken clickers, invalid answers, frozen programs, broken monitors.” “When our computer system went down and I lost the program classes etc. then when it finally came back you could not read the TV...” “I had limited success because of the crash of the faculty server that day.”

Software limitations: This category includes anything associated with cases where the CRS being used is not capable of doing something the teacher wants it to do.

“...and too many answers had mathematical notations that cannot be entered into PRS” “I tried to create a roster, but it didn’t work the way I wanted it to.” “I think if anything, I have noticed obstacles I had never seen before, like the type font, and the fact that my tv is really small, and the fact that I have to be in the front of the room. Also, I would like to be able to put the answers in order when I feel like it, so they’re easier to read from far away, preferably with and without blank spaces.”

Technical support: This category includes the existence or the degree of human technical support that can help teachers resolve technical problems in a timely manner.

“When our computer system went down and I lost the program classes etc. then when it finally came back you could not read the TV and the tech in school was no help.” “If you have a problem there is no way to get immediate help the system is dead for whatever the reason.”

operating the technology

This category includes difficulties reported by participants due to their lack of technical skill or knowledge.

“I could not get the software out of a loop and wasted a lot of time trying to get out of it.” “I still want technical improvements.” “When I wanted to do a different type of question (mark all that apply) I hadn’t done that in a while and forgot how to see how many picked

each number and that say 123 and 321 would be the same but were different on the histogram.”

Question Development and TEFA Integration

A major obstacle reported by teachers was difficulty developing CRS questions and integrating them into a specific curriculum. This has been a serious concern for most of the teachers throughout the entire time period analyzed.

question creation

This refers to teachers’ concerns and difficulties with designing questions to achieve desired purposes.

“I want to use it more but the questions bog me down.” “I would like to develop more “introductory” questions.” “The toughest part for me is designing questions that I would want to answer.” “Question development for logical integration demands a lot of my attention.” “The ability to create questions that provide some insight and/or experience with a new topic... [is my most barrier].” “How to write good “math” questions...”

integrating TEFA into the curriculum

This refers to difficulties teachers have fitting TEFA practice into their lessons or meshing it with other instructional modes.

“Our next unit is on animation, calculator programming, and calculating rates and rate/distance equations. I’m not sure how I intend to use PRS there.” “I have used it very little. My target class is working on multiplying and factoring polynomials, translating functions, and solving quadratic equations. It has been hard to find ways to integrate TEFA/CRS other than as a means of checking understanding.” “... I’m starting a new unit for my target class and I don’t have a good overall picture in my mind of how TEFA will fit in.”

Time and Curriculum Pressure

This includes issues with time spent to plan TEFA instruction, as well as time required in class by heavily discussion-oriented TEFA pedagogy (resulting in conflicts between using TEFA and covering mandated curriculum). These were also major obstacles for many teachers.

time pressure

We found three different ways that the teachers experienced time pressure.

Planning time: Lack of time to plan and develop questions.

“... not enough time to create questions...” “I continue to be frustrated by the lack of time devoted to question development” “...it has “slipped” in the priority list because I just can’t seem to find the time to write good questions.” “...taking the time to find relevant questions.”

Limited class time: Difficulty devoting sufficient class time to TEFA.

“I was going to try to integrate CRS into my intro “Jump Start” activity, but I’ve been slow to do it due to time constraints.” “Time was taken out of class that might have spent in other ways that perhaps would be more beneficial.” “... and of course I had to proceed to teach the material, we are so pressed for class time so I used the questions without PRS.”

Wasted time: Wasted or inefficiently used class time while distributing CRS units or transitioning between teaching modes.

“... implementing it ate up a large amount of time.” “There is too much time wasted taking out and putting away the clickers.”

curriculum pressure

Since most teachers must obey standardized curriculum and prepare students for high-stakes tests, they struggled to cover the mandated topics within their allotted time. This was often seen to conflict with TEFA practice.

Breadth vs. depth: Many participants fear that content coverage with TEFA proceeds more slowly than with their prior modes, resulting in a perceived conflict between “doing TEFA” and covering adequate content.

“Don’t move as fast thru the various topics ...” “... as well as getting everything in this year.” I felt that I was behind in my coverage of material compared to my previous 3 years.” “We ran out of time and had to push the curriculum back a day or so.”

Standardized tests: Some teachers reported conflict between “doing TEFA” and preparing students adequately for standardized tests (which generally meant covering all the topics on a test).

“The next few weeks will be tough, as there are really only about 2.5 weeks left for introducing new material, at which point we’ll spend a day or two reviewing for the final exam.” “I’m not sure since the next few weeks unfortunately will be a push to cover topics that are on the MCAS and we haven’t had time to develop.”

Classroom Discussion

This category includes student behavior issues that affect the class atmosphere, as well as teachers’ comfort with and ability to facilitate class discussion as part of TEFA.

student issues

This category includes anything associated with students’ skill and ability to participate in discussion and use the CRS technology, along with their attitudes towards TEFA.

Students’ attitudes about TEFA and their behaviors: This includes students’ inappropriate attitudes such as turning CRS question-answering into a race, taking too much time to transition to or from TEFA, or disliking TEFA.

“some kids seemed most focused on being the ‘last one to enter a response before time ran out.’” “(students are) playing with clickers rather than participating in discussions.” “Plus, now the kids see it as a race for who can answer first!” “Students asked if they could just answer or talk about questions. I got the feeling they weren’t comfortable with clicking on a fixed choice.” “Students have expressed frustration with how I have been using PRS. they want ‘closure.’ So I’m trying to accommodate.” “Students in one class just were not able to transition from their small group discussion phases to the supposedly quieter voting and histogram follow up by the teacher.”

Students’ ability to participate in class discussion: Some students were uncomfortable with their new role within TEFA pedagogy.

“Due to the VERY limited attention span of this group of kids, when I use the PRS units I do so for approximately 10-15 minutes.” “My students and their attitude towards learning and ability to hold small group discussions is a major barrier... How I am trying to keep TEFA in my classroom even though the students do not do well with group work or small group discussions.” “Some of the weaker students are falling into the same pattern of keeping quiet during the WCD phase.”

orchestrating class discussion

This issue includes anything associated with teachers' skill at, ability with, and comfort regarding conducting class discussion and stimulating students to participate in it.

"Still trying to get the students to discuss rather than just get the right answer." "I am concerned that in my target class when we use PRS I lose the focus of many students during the question and during the discussion....Also, I was hoping the PRS system would get more students involved in class discussion - while there is good discussions, it actively involves the usual students who enter into any non-PRS discussion." "Also, I need to work more on making it flow with the discussion and all." "Noticed that the even somewhat limited whole-class discussions had fewer and fewer participants." "[My most barrier is] my lack of confidence in my ability to lead a good discussion." "how to inspire discussion without forcing them down the path I would like them to go..."

Practicing Formative Assessment

This category includes any difficulties teachers have understanding how students think based on students' CRS responses and discussion participation, and deciding what to do in response—essential elements of using a CRS for *formative* assessment.

Understanding students' thinking

"Looking at the 'wrong' answers to understand student misconceptions..." "I like to use it to get the students thoughts and what avenues they are going in. Also, at times it allows me to see where they might be making errors or clarify some of their past knowledge..."

Agility and teaching practice

"I am not comfortable with this initial integration to feel comfortable to add it in other places. I would love to be able to do it on the fly if the students bring up a good question and get the students to discuss their ideas and see if it will sway students thoughts." "I have been looking at how students learn best and trying to use "the system" in such a way that it enhances student learning..."

Revising lessons

"Revising/elaborating on questions used last semester [was my most concern]." "Revising CRS questions for future use based on the outcome after first-time use."

Teacher Training Program

This refers to dissatisfactions with the TLT project's professional development program.

PD program: Some teachers experienced a gap between their expectation for PD and what PD actually provided them.

“Although we learned question styles, we are not given enough time with “colleagues” to develop age-appropriate content questions.”

Ways of Being a Teacher

This includes individual teachers' beliefs, perspectives, and philosophy about teaching and learning; doubts and uncertainties about the value of TEFA and resistance to change; attitudes about TEFA; personality characteristics and confidence; and background and personal experiences (Stengel, 1996).

“... and also not being convinced that it's worth the time it takes to plan for and use.”

“...not being sure the class time used for TEFA is ‘worth it’ in terms of my educational goals for my students.” “I think my major barrier is still myself, but that's just going to be the way it is.” “I think it [the most barrier] is my own fears...” “I am pleased in general with my students' willingness to discuss and explain concepts/questions. I don't, however, have a sense of whether or not there is an improvement since January, or if there was, whether or not it was due to CRS/TEFA.”

Other Contextual Factors

These are factors that are not explicitly part of teaching with TEFA, but could affect teachers' practice in general. Teachers are human beings who have their own personal lives. When a family member is sick or when some other family issue arises, trying new things in school can become more difficult and less important. Similarly, when teachers participate in other PD programs or projects or have other priorities and burdens, their attention to TEFA can diminish. If they have a student teacher, they have less opportunity to do TEFA. Frequent school events (whether planned or unplanned) reduce available class time, and weather, time of the day, and progression of the semester also affects students' behavior in class.

“Unfortunately, with [my son's] adoption coming quickly and then his baptism my personal life has taken priority.” “Things going on outside of school that have affected me and my ability to focus on new things.” (*Personal life*)

“I’m too busy with other professional development requirements.” “Graduate classes, teaching practices, lot’s of things going on...” (*Other priorities*)

“Remembering to incorporate PRS in lesson planning with my student teacher [is my most concern].” (*Having a student teacher*)

“... as we have had several field trips and other things that have taken class time in general.” (*School Events*)

“Also, one barrier that wasn’t mentioned has to do with the time of day I have my target class. They are freshmen and at the end of the day they are less reflective (in general -- especially now that the weather is getting nicer) and harder to get to settle down for a good discussion. It’s often easier to use an alternate mode of teaching than to use TEFA.” (*Weather*)

We have listed factors that teachers report having impeded their attempts to implement TEFA pedagogy with the use of CRSs. Those factors, and our taxonomy for organizing them, are summarized in Appendix A. Some factors are more of a hindrance than others. Some can be resolved quickly, and others persist. In the following section, we will present some results from analysis of TMRS multiple-choice question responses in order to better understand the chronology of these factors, including when and in what order they typically arise, and on what time scale they are resolved.

Factor Strength and Change over Time

In the TMRS, multiple-choice questions specifically asked teachers about their degree of comfort with various aspects of CRS and TEFA, and about the degree of difficulty they encountered with various potential barriers; these questions spanned factors related to hardware and software, time, available support, student behavior, question creation, classroom discussion, and formative assessment. The survey instrument was developed before some of our categories were identified, so some, such as dissatisfaction with professional development, were not probed. Other categories, such as parental and administrative support, were probed but turned to be non-issues. Figure 1 breaks down the aggregated school A year 1 responses to each category of factor by year and round of survey, showing the percentage of teachers who chose each of the four multiple-choice options. Although the particular factors that most strongly affect TEFA adoption may vary from teacher to teacher, some specific factors appear to be most troublesome to many project participants. As can be seen in the graph, “time” and “question development” issues hindered teachers the most.

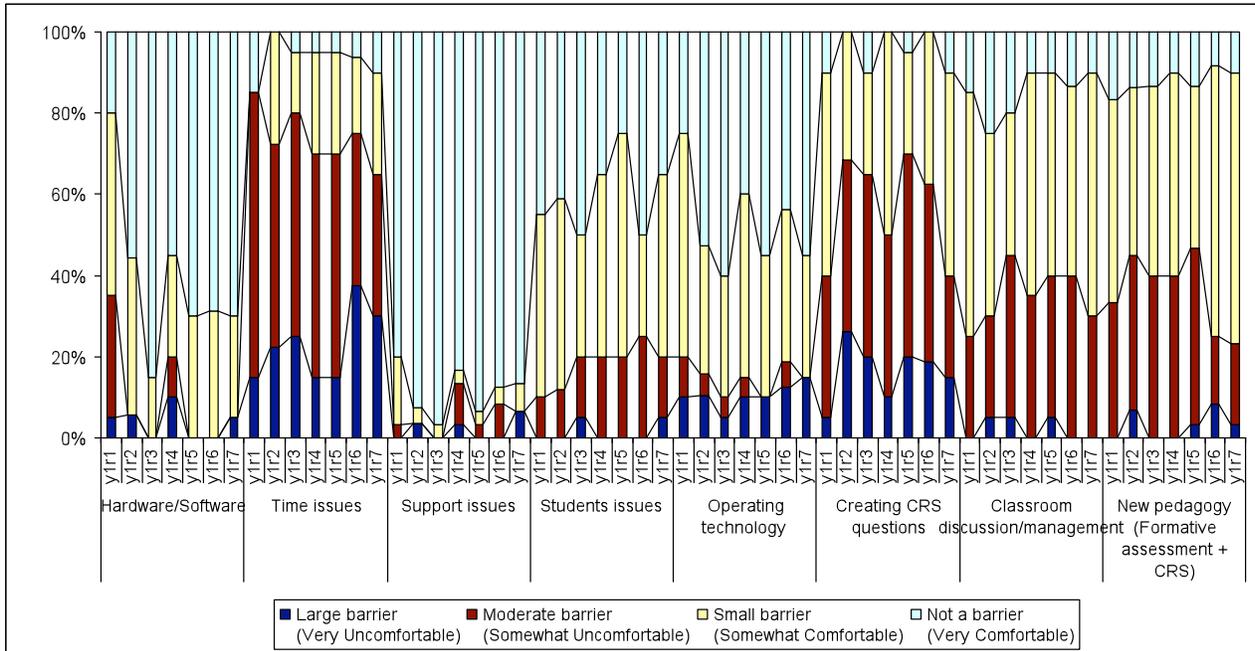


Figure 1: Percentage of teachers choosing each multiple-choice “significance of barrier” rating for each barrier category, for each TLT Monthly Reflection Survey round in year 1 at school A (10 teachers).

To better understand how the importance of various factors changes over time, we performed a paired-sample *t*-test for the ten year 1 teachers at school A, noting that results for $N=10$ should be interpreted with skepticism. The pairs that we used were Oct. 2006 (y1r1) vs. Dec. 2006 (y1r3) and Feb. 2007 (y1r4) vs. May 2007 (y1r7) to check for increase or decrease over one semester; and Oct. 2006 (y1r1) vs. May 2007 (y1r7) to check for changes over one school year; and Dec. 2006 (y1r3) vs. Feb. 2007 (y1r4) to check for changes over the winter break and accompanying six-week hiatus in PD. We used Holm’s sequential procedure to control the family-wise error rate.

The statistically significant results are summarized in Table 1. “Hardware/software” issues, including technical support and operating the technology, decreased significantly ($p < 0.05$) during the first semester (y1r1-y1r3), but increased significantly ($p < 0.05$) across the winter break (y1r3-y1r4). Over the whole year (y1r1-y1r7), “hardware/software” issues decreased significantly ($p < 0.05$). In contrast with the decrease in importance of technology-related issues, difficulties with question development increased significantly ($p < 0.05$) during the first semester (y1r1-y1r3). We can infer, with appropriate qualifications and caveats, a pattern from these results: Teachers initially wrestled with technological issues, and as these were overcome, they shifted their attention to question development. The technology-related issues were resolved quickly for many

teachers—within 3 months—but question development difficulties increased during the first semester and then stayed high for the remainder of the year.

The trend is more obvious when looking at Figures 2 and 3. After one year, four teachers dropped from the project for various reasons, leaving six participating teachers at school A. Figure 2 shows the mean for the degree of barrier significance reported by the six remaining teachers for six major barrier factors, and Figure 3 shows the mean for the four teachers who dropped after year 1. On the y-axis, a larger number represents a more significant barrier. In Figure 2, the mean values for technology-related issues (hardware/software and operating technology) and for question development in y1r1 are comparable. After one month, technology issues rapidly declined and then stayed low, but question development issues increased and stayed high. Although technology issues occasionally reappeared in later months (e.g., y2r2 and y2r3), they were resolved within a month or two. In addition, teachers' comfort with and ability to operate the technology remained relatively constant. For most teachers, time and question development issues were the most severe and persistent factors hindering their TEFA implementation. Although these issues seem to decrease slightly in year 2, it is hard to say whether the decrease is significant.

For the four teachers who left the project after one year (see Figure 3), the reported factors of highest severity were also time and question development. When we compare Figure 3 to Figure 2, however, we see evidence that some of the teachers who dropped out were struggling more with time and technology issues than the six who continued.

Categories	Pairs	t	df	p (1-tailed)
Hardware/Software	y1r1 - y1r3	4.16316	9	0.00122
	y1r1 - y1r7	2.75299	9	0.01118
	y1r3 - y1r4	-2.71360	9	0.01193
Support Issues	y1r1 - y1r3	2.70114	9	0.01217
	y1r3 - y1r4	-2.58922	9	0.01463
Operating Technology	y1r1 - y1r3	3.35410	9	0.00423
	y1r3 - y1r4	-2.71360	9	0.01193
Q development	y1r1 - y1r3	-2.75299	9	0.01118

Table 1. Paired-samples t-test results for year1 at school A, testing for change in teacher's ratings of the significance of various barrier categories over various time intervals (1-tailed, Holm's, $\alpha = .05$, $N=10$).

Discussion

Extrinsic and Intrinsic Factors

As Ertmer (1999) suggested, we have taken the factors identified above and grouped them into two major divisions: *extrinsic* and *intrinsic*. Extrinsic factors are external to the teacher: aspects of his other context and situation that hinder attempts to use CRS technology and implement the TEFA pedagogy. Intrinsic factors are internal to the teacher: skills, proclivities, perceptions, preferences, and the like.

Extrinsic Factors

Extrinsic factors can be divided into two subsets: “type I,” in which the difficulty is directly associated with some element of implementing TEFA; and “type 0,” in which the difficulty is associated with something outside of TEFA but affects TEFA practice circumstantially. Issues with hardware or software (technical malfunctions, resource availability, software limitations inadequate technical support), time shortages (planning time, class time) and curriculum pressures

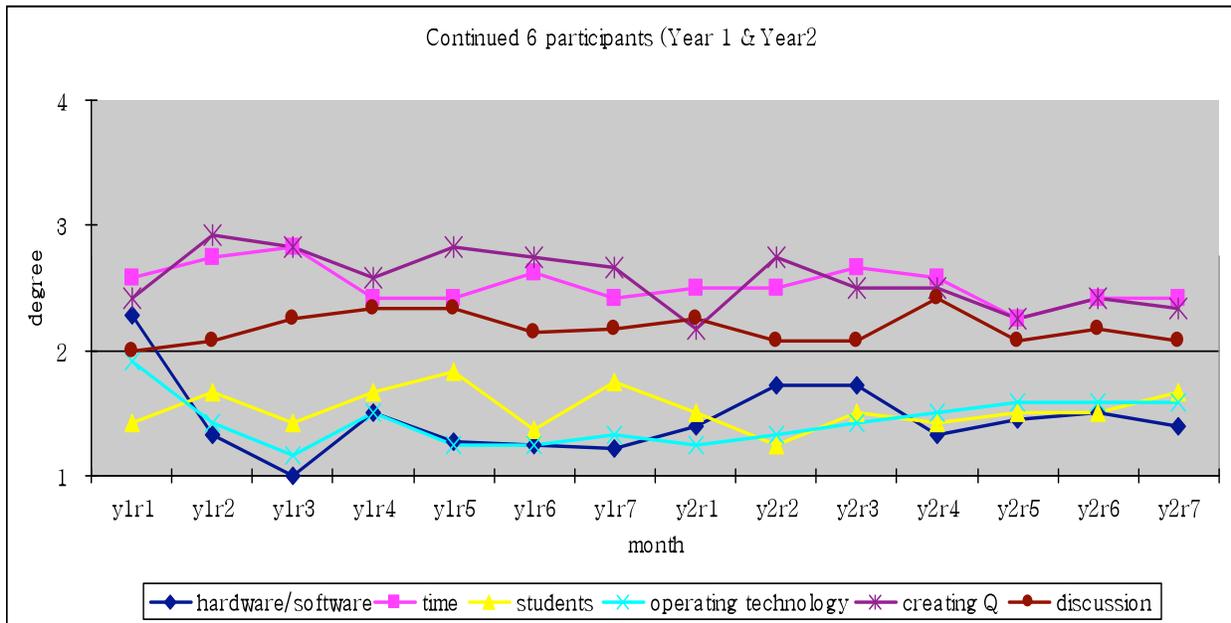


Figure 2. Mean barrier severity rating for six teachers who participated in years 1 and 2 at school A. Scale on y-axis: 1—not a barrier (or very comfortable); 2—a small barrier (or somewhat comfortable); 3—a moderate barrier (or somewhat uncomfortable); 4—a large barrier (or very uncomfortable). [Cronbach’s alpha (number of Qs): Hardware/Software 0.833 (n=3), Time 0.669 (n=2), Students 0.725 (n=2), Operating technology 0.806 (n=2), Q creation 0.744 (n=2), Facilitating discussion 0.768 (n=2)]

(breadth vs. depth of coverage, standardized tests), student issues (behavior, attitudes, ability) and difficulties with the TEFA PD program are extrinsic type I factors that teachers must deal with when they are trying to “do TEFA.”

When teachers lack basic facilities such as hardware or software, or when these facilities do not work properly, it reduces their willingness or ability to attempt TEFA. We found that malfunctions, absent resources, and software limitations often impeded teachers’ early attempts to perform TEFA. Prompt technical support, which could have helped resolve such issues, was frequently unavailable.

Lack of preparation and planning time for developing TEFA questions inhibited teachers’ ability to practice TEFA. Without good TEFA questions prepared in advance, TEFA pedagogy tends to be far less successful. However, most teachers require considerable time to develop good questions, and many had difficulty finding enough time to do so. In addition, many teachers expressed concern about their rate of curriculum coverage due to the time-intensive discussion-oriented nature of TEFA. Many struggled with conflict between the depth of understanding that TEFA could provide and the breadth of material they felt obligated to cover.

Student behavioral issues were also found to be an important extrinsic factor that affected teachers’ teaching practice with TEFA. Teachers often reported that some students used the CRS to play games with their peers (such as who can get the first or last response in), or had difficulties

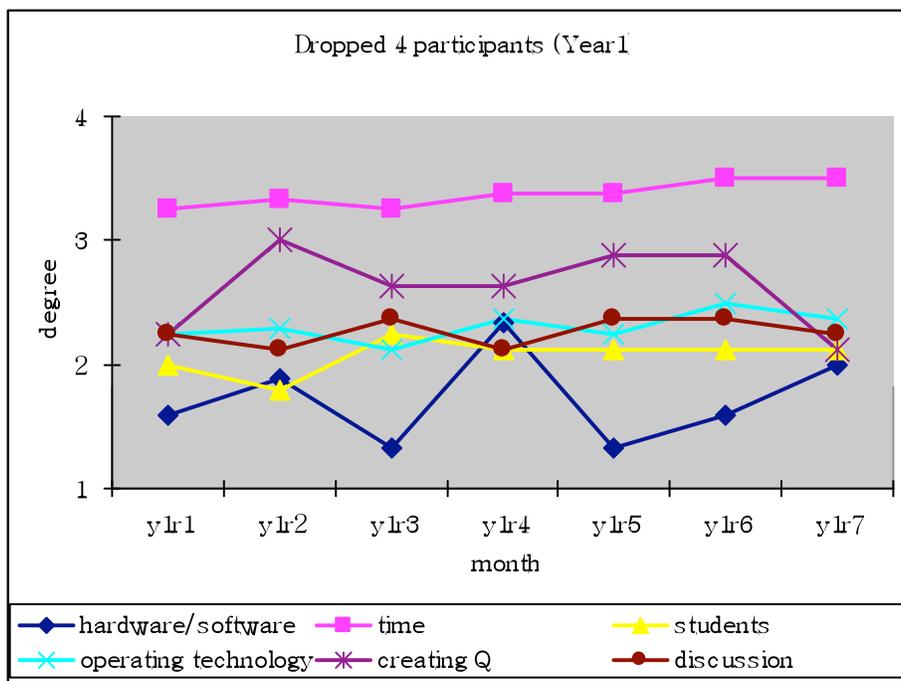


Figure 3. As Figure 2, but for the four teachers who left the project after one year.

learning to operate their CRS units. Most students enjoyed using the CRS, but some remained passive and reluctant to participate in whole-class discussion. At school A, this phenomenon was more problematic in middle school classes than in high school ones.

Another extrinsic type I factor represents difficulties with the TLT project's professional development program. Some teachers experienced frustration with a discrepancy between their expectations and hopes for PD and what actually transpired, and reported this as a barrier to their learning of TEFA.

Extrinsic type 0 factors are constraints on how teachers do teaching in general, and are not directly part of learning and doing TEFA. Such factors include issues in teachers' personal lives, competing priorities at school, school events and disruptions, mentoring of student teachers, and factors that affect students' (and teachers') mood, energy, and focus, such as weather, season, time of day, and progression of the semester. Although these issues are not directly related to TEFA, they shape the context in which teachers learn and do TEFA and can exert a very real influence on TEFA practice.

Intrinsic Factors

Intrinsic factors can also be grouped into two subsets. Type I addresses teachers' skills and knowledge relevant to practicing TEFA. These skills can be divided into five sub-areas: operating the technology reliably, developing TEFA questions, integrating TEFA into a curriculum, facilitating classroom discussion, and practicing formative assessment (Beatty et al., 2008; Feldman & Capobianco, 2008).

In contrast, type II intrinsic factors involve teachers' general "way of being a teacher" (Feldman, 1997; Stengel, 1996) such as: doubts and uncertainties about the value of TEFA; resistance to changes in teaching; perspectives, beliefs, and philosophies about teaching, learning, pedagogy, and students; attitudes and interests about TEFA; personality characteristics and confidence; satisfaction with TEFA; and personal biography. For example, if a teacher's character is reflective, she would be inclined to look back upon her TEFA experiences frequently in order to figure out what does and doesn't work. In the process of reflection, her TEFA practice would tend to improve. If a teacher has a strong orientation towards traditional teaching practices, she might have higher resistance than others to changing her teaching style. A teacher's way of being a teacher cannot be separated cleanly from other intrinsic and extrinsic factors; rather it is deeply interwoven with them. (We acknowledge that more nuanced models of this "way of being" are possible, but identifying this one category is adequate for our present purposes.)

Table 2 summarizes the extrinsic and intrinsic factors identified this study.

Association Between Extrinsic and Intrinsic Factors

Extrinsic and intrinsic factors do not exist separately; rather, they are closely interrelated. The figure in Appendix 2 represents some of the relationships we have tentatively inferred between extrinsic and intrinsic factors. Hardware and software issues are related to a teacher’s skill with the technology. Teachers must learn how to develop questions for various purposes, but do not have enough time to ponder and design those questions. Due to curriculum pressures, teachers have uncertainties, doubts and resistance about whether using TEFA furthers their instructional goals sufficiently to justify the time it requires. Student behavior and attitudes affect teachers’ facilitation of class discussion. Dissatisfaction with the PD program affected willingness and ability to implement TEFA.

Intrinsic type II factors are closely related to intrinsic type I and extrinsic type I, and affect what teachers decide and how they behave in class. Therefore, although the teachers identified similar extrinsic factors with similar severity ratings at the inception of the project, their ongoing learning trajectories could differ depending on intrinsic factors, which shaped how they dealt with the extrinsic factors (e.g., Beatty et al., 2008).

Extrinsic Factors		Intrinsic Factors	
Type 0	Type I	Type I	Type II
Contextual factors circumstantially affecting TEFA	Contextual factors directly part of TEFA	Teachers’ skill, knowledge and ability to do TEFA	General “way of being a teacher”
<ul style="list-style-type: none"> · Teachers’ personal life · Conflicting priorities · School events · Student teacher · Weather, season, time of day, progression of semester 	<ul style="list-style-type: none"> · Hardware/software (malfunctions, resource availability, software limitations, technical support) · Time (planning, in-class) and curriculum pressure (breadth vs. depth, standardized tests) · Student issues (behavior, attitudes, ability) · PD program 	<ul style="list-style-type: none"> · Operating technology reliably · Developing TEFA questions · Integrating TEFA into curriculum · Facilitating classroom discussion · Practicing formative assessment 	<ul style="list-style-type: none"> · Doubts about the value of TEFA · Resistance to change · Perspectives, beliefs, and philosophies about teaching, learning, and students · Attitudes towards TEFA · Personality · Confidence · Satisfaction with TEFA · Relevant biography

Table 2. Extrinsic and intrinsic factors affecting teachers’ implementation of TEFA pedagogy with CRS technology.

Learning Trajectory of TEFA

Intrinsic type I factors seem, at least on the surface to be those that teachers must resolve in order to successfully implement TEFA. Teachers require skill operating the CRS reliably; creating good questions to further instructional goals; integrating those questions into lessons and managing the potentially slow pace of TEFA pedagogy; orchestrating student-centered whole-class discussion; and understanding students' thinking based on CRS histogram results and class discussion, and using that understanding to make teaching decisions.

In our study, we have observed that these five intrinsic type I factors generally arise in a specific sequence over time (Figure 4). This doesn't mean that one factor must be completely resolved before the next arises; a prior one may have been partially addressed, or may continue with the same or even greater degree of severity. Here, "arises" means that the next factor surfaces enough to be reported by teachers. The time interval between the arising of these factors can be different for different teachers. Some may wrestle with operating the technology for a semester, and difficulties with question creation may not appear during the time. Others may experience difficulties with technology in the first week, and report struggling with question creation almost simultaneously. In general, technology-related barriers decreased quickly within 1 to 3 months, and question creation and TEFA integration issues arose almost simultaneously with each other and lasted beyond the first year. Reports of difficulty facilitating classroom discussion arose shortly after difficulties with question creation and TEFA integration for some teachers, and a few months later for others. Few teachers dealt with barriers related to formative assessment (interpreting student responses and deciding how to respond) during the first year.

As time goes on, we find fluctuations in barriers' degree of severity. Some teacher may experience moments of epiphany or insight, but these may not immediately resolve the tension. Even if a factor is "resolved" at some point, it can subsequently reappear.

Summary

We have identified and categorized extrinsic and intrinsic factors that inhibit a teacher's ability to implement *technology-enhanced formative assessment* (TEFA) with a classroom response system



Figure 4. *Trajectory of implementing TEFA pedagogy.*

(CRS). “Technology” issues are the first that teachers typically face. For most teachers, these are resolved within 3 months; however, some few may wrestle with them for far longer. Most teachers need considerable time to create TEFA questions, and factors related to question creation typically present the largest barrier to implementation of the pedagogy. Time and curriculum pressures are also severe barriers for most teachers, and these tend to remain severe and change little over time. Intrinsic type I factors—issues of teacher’s skill with the elements of TEFA—seem to arise in a particular order, with a typical but not universal timeline. Extrinsic and intrinsic factors are intertwined. Some factors can be easily resolved, while others cannot.

Acknowledgement

This material is based upon work supported by the National Science Foundation under Grant No. TPC-0456124. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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Appendix A

Categories and Dimensions for each category developed in this study

Factors that impede teachers to attempt to implement TEFA

Category	Subcategory	Properties	Description	Dimensions
Technology Issues	Hardware / Software - Malfunctions and Resource Availability - Software Limitations - Technical support	Extrinsic	Anything associated with the technology failing or having limitations Human support for the technology	Deficient ↔ Sufficient
	Operating technology	Intrinsic	Teacher's skill, ability and comfort using the technology	1) Skill & Ability: Unskillful ↔ Skillful 2) Comfort: Uncomfortable ↔ Comfortable
Question Development and TEFA Integration	Question Creation	Intrinsic	Concerns or difficulties with designing questions to achieve desired purposes. Such as: to reveal students' thinking or knowledge, to stimulate discussion, to target higher-order thinking or misconceptions, to introduce new topics, to review previous topics, to prepare for exams, etc.	1) Question Type: Exam-type ↔ Reasoning-type 2) T's perception: Difficult ↔ Easy
	TEFA Integrating into the Curriculum	Intrinsic	Difficulty making questions and TEFA practice fit the lessons and/or other classroom instructional modes. T's ability & skill to reconcile it with TEFA	1) Teaching Goal: Content goal ↔ Process goal 2) T's perception: Difficult ↔ Easy
Time and Curriculum Pressure	Time Pressure - Planning Time - Limited class time - Wasted time	Extrinsic	Lack of time to plan, create, and develop questions. Difficulty dealing with the class time required to do TEFA, or Wasted and inefficient class time associated with TEFA	Deficient ↔ Sufficient
	Curriculum Pressure - Breadth vs. Depth of curriculum - Standardized tests	Extrinsic Intrinsic	The slow pace of TEFA resulting conflicts between TEFA and covering curriculum, and pressures from mandated topic frameworks and/or standardized exams. T's perceptions to curriculum pressure.	1) Curriculum: Conflict ↔ Non-conflict 2) T's perception: Stressful ↔ Manageable

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Classroom Discussion	Students' aspect	Extrinsic	Students' attitudes, behavior and skill toward CRS uses and class discussion	1) Attitudes & Behavior: Negative ↔ Positive 2) Skill & Ability Unskillful ↔ Skillful
	Teacher's aspect	Intrinsic	Teachers' skill, ability, and comfort conducting good class discussion and stimulating students to participate in the discussion	1) T's pedagogy: Teacher-centered ↔ Student-centered 2) Skill & Ability: Unskillful ↔ Skillful 3) Comfort: Uncomfortable ↔ Comfortable
Formative Assessment	Understanding Students Thinking	Intrinsic	Anything having to do with understanding what students know, think, and why they say what they do	1) Interests to do: Low ↔ High 2) Skill & Ability: Unskillful ↔ Skillful 3) Comfort: Uncomfortable ↔ Comfortable
	Agility and Teaching Practice	Intrinsic	What to do next, based on understanding of students responses	1) On-the-fly: Unskillful ↔ Skillful 2) Lesson plan: Non-flexibility ↔ Flexibility 3) Meta-cognition: Not-performing ↔ Encouraging
	Revising the Lessons	Intrinsic	Revising or altering lessons or Qs based on what T learned from class discussion	Non-reflective ↔ Reflective
Teacher Training Program	Professional Development Program	Extrinsic	Gap between what Ts expect to learn from PD and what PD provides	1) Goals and Structure: Confused ↔ Clear 2) T's expectation to PD: Non-matched ↔ Well-matched

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<p>Ways of Being a Teacher</p>	<ul style="list-style-type: none"> - Fears, Doubts, Uncertainties & Resistance - Perspectives, Beliefs, Philosophy & Attitudes - Characteristics & Confidence - Background & Experience 	<p>Intrinsic</p>	<p>Nature of individual teacher relevant to TEFA+CRS</p>	<p>1) Fears, Doubts, Uncertainties, Resistance: Low ↔ High</p> <p>2) Perspectives, Beliefs, Philosophy & Attitudes: Negative ↔ Positive</p> <p>3) Teaching Pedagogy: Traditional, frontal, T-centered ↔ Constructivist, Ss-centered</p> <p>4) Characteristics: Non-reflective ↔ Reflective</p> <p>5) Confidence : Low ↔ High</p> <p>6) Satisfaction: Premature Satisfaction ↔ Non-Satisfaction</p> <p>7) Teaching Experiences: Novice ↔ Experienced</p>
<p>Other Contextual Factors</p>	<ul style="list-style-type: none"> - Personal life - Other priorities (ex. other PD) - Having a student teacher - School Events - Weather, time of day, or time of the semester 	<p>Extrinsic</p>	<p>These are contextual factors that are not directly related to TEFA, but could affect teachers to do teaching in general.</p>	<p>Not-helpful ↔ Helpful</p>

Appendix 2

A diagram of possible associations between extrinsic and intrinsic factors.

