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Factors that Affect Science and Mathematics Teachers' Initial Implementation of Technology-Enhanced Formative Assessment Using a Classroom Response System

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Abstract The purpose of this study is to uncover and understand the factors that affect secondary science and mathematics teachers' initial implementation of Technology-Enhanced Formative Assessment (TEFA), a pedagogy developed for teaching with classroom response system (CRS) technology. We sought to identify the most common and strongest factors, and to understand the general process of how teachers adopt TEFA. We identified ten main hindering factors reported by teachers, and found that *time limitations* and *question development difficulties* are reported as the most problematic. In this paper we provide five vignettes of teachers' initial implementation experiences, illustrating different courses that TEFA adoption can follow. We classify our ten factors into four groups: contextual factors that directly hinder teachers' attempts to implement TEFA (extrinsic type I); circumstances that affect teachers' teaching in general (extrinsic type 0); gaps that teachers have in the knowledge and skills they need to adopt TEFA (intrinsic type I); and *ways of being a teacher* that describe teachers' deeper perspectives and beliefs, which may be consonant or dissonant with TEFA (intrinsic type II). Finally, we identify four general categories that describe the teachers' initial TEFA implementation.

Keywords Teacher education · Classroom response system · Formative assessment

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Introduction

Learning is the result of *social interaction* (Vygotsky 1978): students learn by interacting with their peers and teachers. In traditional science classes, however, the role of a teacher is often limited to authoritatively *conveying* information to students. In such classes, teachers can have difficulty perceiving the gap between students' understanding and the scientific concepts they are teaching. Black and Wiliam (1998) argued that teaching and learning should be *interactive*, and they asserted the value of formative assessment: "Teachers need to know about their pupils' progress and difficulties with learning so that they can adapt their own work to meet pupils' needs… (p. 140)." Formative assessment is assessment of student knowledge and learning for the purpose of providing guidance to students and teachers (Bell and Cowie 2000; Black and Wiliam 1998; Bransford et al. 1999; Sadler 1989). Black and Wiliam (1998) found that the use of formative assessment by teachers can produce significant and substantial learning gains across ages, school subjects, and countries.

Although many teachers value formative assessment, they often have difficulty gathering many students' ideas and responding in an appropriate and timely manner during

whole class discussion. Fortunately, new technologies can assist with that challenge.

Classroom response systems (CRSs), often simply called *clickers*, are a technology that instantly gathers students' responses to multiple-choice or short questions. CRSs can be used for various purposes (Duncan 2006) such as for checking students' attendance or for administering quick summative quizzes. They can, however, be used to greater benefit. Dufresne et al. (1996) developed a pedagogy that used CRSs for formative assessment, and Beatty and Gerace (2009) elaborated it into *Technology-Enhanced Formative Assessment* (*TEFA*). TEFA is based on four core principles, labeled question-driven instruction, dialogical discourse, formative assessment, and meta-level communication. The principle of *question-driven instruction* implies, among other things, that teachers should pose conceptual questions within students' *zone of proximal development* (Vygotsky 1978), providing appropriate scaffolding to help students learn from the process of struggling towards an answer. In TEFA, teachers and students engage in *dialogical discourse*: teachers mediate class discussion, drawing out multiple perspectives and approaches rather than merely transmitting information to students. With the information that teachers gain from the CRS histogram and classroom discourse, they engage in *formative assessment*, helping students become more engaged and motivated (Gallagher 2000), and helping both teachers and students become aware of the limits of students' understanding and the actions they can take to facilitate progress (Ramaprasad 1983; Sadler 1989). Teachers' practice of *meta-level communication* helps students participate consciously and efficiently in course activity, by providing them with a better sense of why they are doing what they are doing.

In the TEFA pedagogy, CRS technology plays an important supporting role. When the teacher presents a question, students discuss the question with peers or think about it individually, and then report their answer choice using clickers. After the histogram of responses is displayed, whole class discussion generally ensues, followed by the teacher presenting or orchestrating some type of closure. The process then repeats with a new question, following an iterative *question cycle* (Dufresne et al. 1996). Teachers use what they learn from CRS responses and classroom discussion for the purpose of formative assessment by adjusting their teaching plan in real-time, and also by revising it for later use.

The TEFA pedagogy requires teachers to develop different skills and play different roles than in traditional instruction. In a study that focused on secondary physics teachers' use of CRS technology for formative assessment, Feldman and Capobianco (2008) found that teachers need to learn skills in four general areas to implement formative assessment with a CRS: using CRS hardware and software; creating formative assessment items; orchestrating productive class discussion; and integrating the pedagogy into their larger curricula (Feldman and Capobianco 2008).

Building on that study, our current research project—*Teacher Learning of Technology-Enhanced Formative Assessment* (*TLT*)—was designed to investigate science and mathematics teachers' adoption of TEFA pedagogy with CRS technology. During the project, we learned about the various difficulties and challenges they encountered. While few studies have specifically examined teachers' difficulties learning to use a CRS, more general research on technology adoption indicates that teachers are often discouraged by the barriers they encounter (e.g., Egbert et al. 2002; Smerdon et al. 2000; Wood et al. 2005). Well-documented barriers include: inadequate computer availability (Hope 1997; Smerdon et al. 2000; Wood et al. 2005); insufficient time for planning and personal exploration (Duffield 1997; Egbert et al. 2002; Hope 1997; Sheingold and Hadley 1990; Wood et al. 2005); inadequate technical and administrative support (Schrum 1995; Smerdon et al. 2000); insufficient training and expertise (Hope 1997; Shelton and Jones 1996; Smerdon et al. 2000); teachers' passivity and resistance to change (Ertmer 1999); schools' unsupportive cultures and incompatible traditions of teaching (Cohen 1987; Cuban 1986; Ertmer 1999); and curricular constraints (Cuban 1986; Egbert et al. 2002; Hancock and Betts 1994). 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 resource shortages; and *second-order* barriers that are internal to teachers, such as conflicts with their beliefs about teaching and learning.

Over the past decade and a half, CRS technology has become increasingly popular in higher education, and has more recently been making inroads into K-12 schools (Beatty and Gerace 2009). Abrahamson (2006) noted that "today, at almost every university in the USA, somewhere a faculty member in at least one discipline is using a response system in their teaching…(p. 2)." Abrahamson (2006) also reported that over 3,000 K-12 schools were using CRSs in early 2005, and adoption seems to have grown sharply since then. Studies about CRSs have shown that students generally like to use CRSs (Trees and Jackson 2007); that CRSs often make classroom more interactive and increase students' engagement (Fies and Marshall 2006; Penuel et al. 2007); and that CRSs can promote students' learning, used in conjunction with appropriate pedagogy (Fies and Marshall 2006; Kay and Knaack 2009; Penuel et al. 2007). The literature on CRS use, however, is still quite limited in scope and breadth (Fies and Marshall 2006), and has not clearly described what barriers teachers encounter when they try to use it to implement specific pedagogies.

Our current study investigates factors that inhibit teachers from attempting to implement TEFA pedagogy with CRSs in secondary science and mathematics class; identifies the strongest and enduring factors; and classifies types of teachers' initial implementation experiences with TEFA and CRSs.

Methods

Setting

This study was conducted as a part of the *Teacher Learning of Technology-Enhanced Formative Assessment* (TLT) project, a six-year research project studying teacher learning and pedagogical change. During the project, our group has worked with 38 science and mathematics teachers from six different secondary schools in three school districts in the northeastern US, grouped into four cohorts. The intervention began at the first cohort's school in August 2006, at the second cohort's school in August 2007, and at the third and the fourth cohorts' schools in August 2008. Teachers' participation was voluntary. Our research group provided each cohort with a 3-year (cohorts A and B) or a 2-year (cohorts C and D) professional development (PD) program. The PD program began with a 3- or 4-day summer workshop, followed by weekly and then biweekly after-school meetings during the first year, and then action research meetings every 3–4 weeks during the second and third years. CRS technology and TEFA pedagogy were introduced to the teachers at the summer workshops. After-school PD meetings during the first year were focused on helping participants develop skill in each of the four skill areas necessary for effective practice of TEFA. At action research meetings, teachers chose aspects of their TEFA practice to focus upon and improve through experimentation, reflection, and discussion. At all PD meetings, teachers reflected on their use of the CRS technology and performance of TEFA pedagogy, and shared their experiences with other participants. Project staff provided the CRS systems and offered technical support related to the CRS software and hardware, with schools providing technical support related to the teachers' computers, network, and similar infrastructure.

TLT project staff collected data through classroom video-recordings, teacher interviews, regular online surveys, logs of teachers' daily TEFA usage, student surveys, audio-recordings of PD meetings, and PD artifacts such as teachers' journals. Each participant's class was visited and videotaped twice per semester, with brief interviews before and after the visit to provide context. Each participant was interviewed once per year about his or her perspectives on and use of TEFA. Monthly, participants completed a web-based questionnaire about their recent use of and experiences with TEFA; this questionnaire consisted of both Likert-type items and free response questions. Daily, they completed a simple 2-page paper log form to record their use of TEFA, including the number of TEFA questions they posed, their degree of their satisfaction, level of student participation, fraction of class time spent on TEFA, and any technical problems they might have encountered. To understand the impact of TEFA on the learning environment, we administered a questionnaire to each participant's students once per semester or year. Finally, all PD meetings were audio-recorded, and some teachers kept reflective journals about their experiences learning TEFA.

Because getting teachers to complete the questionnaire in a timely manner turned out to be a major challenge, coupled with the fact that the number of teachers participating in the project increased dramatically in fall 2008 with the addition of Schools C and D, we altered the survey's frequency and content significantly after the spring 2008 semester concluded. This paper reports on analysis of data collected from fall 2006 through spring 2008, before that change occurred.

Participants

Project staff visited schools in the geographic region to meet with teachers and administrators, in order to identify promising candidate schools for the project. The first school that we worked with, School A (also called "cohort A"), is a combined middle and high school in a rural district. School B, started one year later, is a high school in a small, diverse college town. The goal of this article is to report on factors that affect teachers' initial implementation of TEFA, based on data from fall 2006 through spring 2008, encompassing two years of intervention at School A and one year at School B.

The School A cohort consisted of ten teachers during year 1, six teaching high school classes and four teaching middle school. Four taught science and six taught mathematics. At the end of year 1, four teachers left the project due to various reasons, some personal and connected to the project (discussed later in this article). Two of those leaving showed interest in continuing to use TEFA, but without participating in data collection activities or professional development. At School B there were eight teachers participating, including all seven science teachers from the science department and one math teacher.

Data Collection

In this article, we report on one strand of project analysis, aimed at uncovering and understanding factors that impede participants' initial attempts to use CRSs and implement

TEFA. The data analyzed for this come primarily from one specific project instrument, called the *TLT Monthly Reflection Survey* (TMRS). This questionnaire was designed to provide us with data about the difficulties and barriers each teacher encountered (among other things not relevant to this article). It is a web-based questionnaire consisting of both open-ended and Likert-type questions. It has 17 questions, four of which specifically ask the respondent about his or her difficulties and concerns while using a CRS and implementing TEFA (Table 1). Two of the open-ended questions ask for concerns and barriers. One of the Likert-type questions provides a list of TEFA component practices and asks how comfortable the respondent is with each. The other Likert-type question provides a list of possible barriers to implementation, and asks to what degree each had been encountered. The Likert-type items were based on researchers' prior experiences with TEFA-based professional development, including findings reported in Feldman and Capobianco (2008). The TMRS also included an open-ended item that teachers could use to comment upon any aspects of their experiences with TEFA and CRS not addressed by other items. The remainder of the TMRS instrument, not directly relevant to this paper, asked about the instructional purposes of CRS questions, student participation, positive and negative effects of TEFA use, and plans for the upcoming interval.

During the time period we focus upon for this analysis, TMRS data were collected approximately monthly, in October (round 1), November (round 2), December (round 3), February (round 4), March (round 5), April (round 6), and May (round 7). January was skipped in response to the disruption of the holidays, the disruption of the transition from the fall to spring semesters occurring mid-January (these were both long-block schools with single-semester courses), and a consequent hiatus in professional development activities. For each survey round, each participant logged onto a web site to complete the survey.

During the 2006–2007 academic year, data were collected from ten participants at school A. During the 2007–2008 academic year, data were collected from the six

Table 1 TMRS questions specifically asking about TEFA implementation barriers

3. (O)	Day-to-day, what aspect(s) of using CRS + TEFA have you been most focused on or concerned about during the last month? That is, which most demand your attention?				
6. (L)	How comfortable are you with each of the following aspects of practicing TEFA?	Very uncomfortable	Somewhat uncomfortable	Somewhat comfortable	Very comfortable
	6.1 Operating the technology				
	6.2 Creating (or borrowing/finding, choosing, and adapting) CRS questions				
	6.3 Implementing the "question cycle" (pose, think/talk, answer, histogram, share, discuss)				
	6.4 Stimulating and steering good whole-class discussion				
	6.5 Figuring out what students think and why they think it				
	6.6 Adapting teaching based on info from CRS and discussion				
	(O) Other aspects (if necessary):				
7. (L)	To what degree have each of the following possible barriers hindered your ability to practice TEFA the way you would have liked to this past month?	Not a barrier (no issue)	Small barrier (inconvenience)	Moderate barrier (limitation)	Large barrier (prevents)
	7.1 Insufficient technology or equipment available				
	7.2 Insufficient technical support available				
	7.3 Technology-related problems or bugs				
	7.4 Your ability to operate CRS reliably				
	7.5 Lack of prep time to plan curriculum/lessons integrating TEFA				
	7.6 Lack of class time to use TEFA				
	7.7 Difficulty creating or finding suitable TEFA questions				
	7.8 Difficulty reconciling TEFA with the rest of your teaching				
	7.9 Students' ability to use CRS clickers reliably and responsibly				
	7.10 Students' attitudes towards TEFA				
	7.11 School administrators' attitudes towards CRS, TEFA, and "the project"				
	7.12 Parents' attitudes towards CRS, TEFA, and "the project"				
8. (O)	What barriers or limitations, if any, most inhibited your ability to teach with CRS + TEFA this past month?				

Questions 3 and 8 are open-ended (O), and questions 6 and 7 are Likert-type (L) questions. The last sub-question of question 6 is open-ended

remaining School A participants, and from eight participants at school B. Since project involvement at School B began and ended one year later than at School A, we label these data subsets as "School A Year 1," "School A Year 2," and "School B Year 1."

Analysis

We took a grounded theory approach to analyzing responses to the questionnaire's relevant open-ended questions (Strauss and Corbin 1990) by performing open coding, axial coding, and selective coding with cross-case analysis. First, we *conceptualized* by coding all participants' responses. Second, we *categorized* those codes into sets of similar concepts by making connections between them. As we iterated these first and second steps and revisited the data, we revised the codes and the categories and made them more sophisticated. Third, when we or other project staff encountered mention of participants' difficulties or concerns in data from other instruments—such as teacher interviews, journals, or PD meeting transcripts—we examined our developing core concepts and categories to see if they were supported by this other data. Finally, based on these procedures, we developed a theoretical model and applied it to our accumulating profile of each participant. We used *HyperResearch* and *NVivo* software to support these analysis procedures.

To better understand how the set of factors affecting each teacher evolved over time, we tallied the number of code applications in each category for each teacher, in each round of the survey, and constructed a matrix of frequency (number of code applications) versus time (survey round) (Miles and Huberman 1994). We compared this matrix with our results from the Likert-type items to assign a "strength" to each factor.

We analyzed the data from the Likert-type items descriptively in two ways. First, we graphed each teacher's response to each TMRS Likert-type item versus survey round, to see how the strength of that factor varied over time. Then, we collected all the graphs for an individual teacher for all TMRS questions and developed a qualitative, global narrative for them, in order to understand each teacher's overall profile of implementing TEFA and the difficulties that he or she had through the year(s). We discussed these individual teacher narratives/profiles with other staff at weekly project meetings, triangulating with other data sources and analyses and with the experiences of the professional development facilitators. Based on the understanding that we developed in these weekly meetings, we constructed vignettes of the teachers.

Second, to understand the overall pattern among the teachers, the Likert-type items were grouped into categories developed from the open-ended responses. In the process of categorizing the Likert-type items, we calculated Cronbach alpha values to determine the internal consistency of the two to three Likert-type items combined to form each category (Table 4). The Likert-type items asked participants to indicate their degree of comfort or discomfort by selecting one of four options (Table 1): *large barrier* (or *very uncomfortable*), *moderate barrier* (or *somewhat uncomfortable*), *small barrier* (or *somewhat comfortable*), and *not a barrier* (or *very comfortable*). We counted the number of teachers selecting each option for each Likert-type item, averaged these counts over the two or three Likert-type items constituting each category, and graphed the averages against time (round) for each category in order to represent the time evolution of the relative difficulties of the categories (Fig. 1). We used this graph to identify common difficulties, and to reveal general patterns of how participants' perceptions evolved during the study.

The results of this analysis were triangulated with the results from analyses of other TLT project data such as field notes of classroom observations, interviews, daily logs, PD journals and PD meeting transcripts by other project staff during weekly meetings, where faculty principal investigators and graduate student research assistants discussed their analyses of data from the various data collection instruments employed by the project. The findings reported in this study are consonant with the findings of other project analyses (Beatty et al. 2008).

Findings

We divide our findings into three sections. First, we report the factors that affected the teachers' use of TEFA and CRSs, found from their TMRS open-ended responses. Second, we show the relative "strength" of these factors and how they vary over time, based on both open-ended and Likert-type responses. Third, we present selected vignettes to illustrate general patterns of teachers' initial implementation of the TEFA pedagogy and CRS technology.

Factors that Affect Teachers' Implementation of TEFA and CRS

We identified ten major factors that affected teachers' initial implementation of CRS technology and TEFA pedagogy. In this section we present those factors, along with examples from the data to illustrate them.

Hardware and Software

As we studied participants' open-ended responses, we found that their ability to use the CRS hardware and

software was affected by malfunctions in the hardware, limitations of the software, and inadequate technical support. For example, teachers reported that they had problems with equipment malfunctioning: "At this point, I've been focused on the technological aspect. Broken clickers, invalid answers, frozen programs, broken monitors (a102, y1r1, TMRS),[1]" "I had limited success because of the crash of the faculty server that day (a106, y1r4, TMRS)."

The teachers also reported limitations of the CRS software. For example, the software did not support collecting or displaying student input in the ways that some teachers believed would work best. Some teachers noted that the small font size used by the software was difficult for students in the back of the classroom to see, or that operating the CRS required them to remain close to the front of the classroom.

In general, most participants felt that they lacked adequate support to help them resolve technical problems in a timely manner: "If you have a problem there is no way to get immediate help…(a108, y1r4, TMRS)" Although both schools provided technical support personnel, these personnel were overworked and had little knowledge of the CRS hardware and software. In addition, while the TLT staff provided some additional technical support, they were not on site at the schools.

Operating Technology

The previous factor focused on aspects inherent to the hardware and software. We also found that teachers reported difficulties due to their lack of technical skill with or knowledge about the CRS technology. These ranged from difficulties in the basic use of the software to difficulties in using more sophisticated software options: "When I wanted to do a different type of question [choose 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 (a104, y1r6, TMRS)."

Time and Curriculum Pressure

Participants' open-ended responses indicated that time-related factors had some of the largest effects on their use of CRS and their implementation of TEFA. Teachers reported three ways that time had an impact on their TEFA practice: preparation time needed to plan TEFA instruction and to develop questions; class time required for the discussion-oriented TEFA pedagogy; and additional class time consumed by transitions between TEFA and non-TEFA instructional modes, for example, "There is too much time wasted taking out and putting away the clickers (a112, y1r1, TMRS)."

Time was also a factor because of teachers' beliefs about content coverage and preparation for standardized exams. For example, one teacher reported, "I'm not sure [if I'm going to do TEFA] since the next few weeks unfortunately will be a push to cover topics that are on the MCAS [Massachusetts Comprehensive Assessment System exam] (a104, y1r6, TMRS)." Many participants in our study reported that content coverage with TEFA seems to proceed more slowly than with their prior modes, resulting in a perceived conflict between using TEFA and covering adequate content, for example, "I am finding it difficult to cover material FASTER while using it and have chosen to use it less this spring (b102, y1r6, TMRS)."

Question Development

Another major factor reported by teachers was the difficulty that they had crafting effective TEFA questions. For some teachers, simply getting started was a problem. Others were concerned with writing questions that would be interesting or motivating, for example, "The toughest part for me is designing questions that I would want to answer (a111, y1r1, TMRS)." Some had difficulty developing questions that fit logically with their lessons, for example, "[My biggest concern][2] continues to be developing meaningful questions that integrate seamlessly into the current unit of study in a timely fashion (a103, y1r5, TMRS)." Finally, there were those who were hindered by their need to develop questions that would provide them with insight about student understanding, or would foster class discussion to target higher-order thinking skills, for example, "[My biggest concern is] designing questions to foster good discussions to enhance understanding and promote deeper thinking (b104, y1r1, TMRS)."

Integrating TEFA into the Curriculum

According to Feldman and Capobianco (2008), teachers must learn how to integrate the new pedagogy with their existing curricula. Some teachers reported difficulty in doing this because they did not see how TEFA could be used for the topic that they were teaching. For example, one teacher reported, "I'm starting a new unit for my class

[1] (a102, y1r1, TMRS) refers to the source of the quotation. a102 is teacher 102 from school A. The data source is the first round (r1) of TMRS data from year 1 for school A.

[2] "My biggest concern", "My biggest barrier is", "I've been concerned", "I have been most concerned about how to", "I have been most concerned about how to" are stems used in the open-ended questions on the TMRS.

and I don't have a good overall picture in my mind of how TEFA will fit in (a113, y1r5, TMRS)." Another teacher wrote more specifically, "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 (a109, y1r4, TMRS)."

Classroom Discussion

This factor refers to anything associated with teachers' skill at, ability with, or comfort regarding conducting class discussions and stimulating students to participate in them. A major component of the TEFA question cycle is the whole class discussion (WCD) following the display of the histogram. We found that teachers' use and facilitation of WCD was affected by the knowledge and skills that they have about orchestrating WCD. Some of our participants' open-ended responses suggest that they were aware of their lack of ability to hold worthwhile discussions. For example, they wrote, "[My biggest barrier is] my lack of confidence in my ability to lead a good discussion (a113, y1r5, TMRS)," and "[I don't know] how to inspire discussion without forcing them down the path I would like them to go (a109, y1r6, TMRS)."

Students

Teachers' use of a CRS and facilitation of WCD is affected by their students' behavior. Teachers reported that students' inappropriate behavior affected their ability to engage the class in discussions. At times, students would race to see who could enter the first response, for example, "now the kids see it as a race for who can answer first! (a105, y1r4, TMRS)," or would send silly responses and profanities. Some participants also reported that when they used the CRS they lost students' focus, or that the students who participated in the TEFA WCD were the same few who normally spoke up in class: "Some of the weaker students are falling into the same pattern of keeping quiet during the WCD phase (a104, y1r6, TMRS)."

Some teachers reported that they believed their students were not capable of participating in lengthy WCD. Others had little confidence in their students' ability to work in small groups. In both types of situations, teachers noted that students were frustrated by ambiguity and the lack of a clearly identifiable correct answer in some questions (a deliberate question design tactic advocated by project professional development facilitators).

Practicing Formative Assessment

Some teachers mentioned difficulty in being able to understand students' thinking based on students' CRS responses and their participation in discussions, for example, "[My biggest concern is] looking at the 'wrong' answers to understand student misconceptions (a109, y1r1, TMRS)," and how to revise their lessons accordingly, for example, "[I have been most concerned about how to] revising CRS questions for future use based on the outcome after first-time use (b104, y1r2, TMRS)." Some also noted that they wanted to improve their teaching agility, for example, "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… (a105, y1r2, TMRS)." Although the data do not indicate these responses as a major factor, they represent the teachers' concerns and awareness of the necessity of improving their skill of practicing formative assessment.

Contextual Factors

All of the factors so far identified are specifically about implementing TEFA. However, some aspects of teachers' educational situations and lives transcend TEFA. Participants wrote of some difficulties connected to the nature of school, such as the intricacies of the school schedule and disruptions due to class trips, sports, or fire drills. Weather was even reported as an occasional hindrance: snowstorms disrupt the schedule, and signs of spring's approach led to student restlessness. We also found that many of the participating teachers have other professional development commitments, including some needed for certification and re-certification. In addition, teachers are human beings with their own personal lives; when a family member is sick or some other family issue arises, trying new things in school can become more difficult, and teachers can become less focused. Various participants adopted children, took care of elderly parents, or had their own health problems during the course of the project. Some quotes from teachers are:

> Unfortunately, with [my son's] adoption coming quickly and then his baptism my personal life has taken priority (a105, y2r2, TMRS).
> I'm too busy with other professional development requirements (b106, y1r6, TMRS).
> … several field trips and other things that have taken class time in general (a105, y2r4, TMRS).
> 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 (a113, y2r5, TMRS).

Ways of Being a Teacher

We call the last emergent category of factors "ways of being a teacher" (Feldman 1997; Stengel 1996). This includes individual teachers' beliefs, perspectives, and philosophy about teaching and learning; attitudes about TEFA, including doubts and uncertainties about its value; teaching habits and resistance to change; personality characteristics and confidence; and background and personal experiences. Some exemplary quotes are:

> I think it [the biggest barrier] is my own fears… (a105, y1r4, TMRS),
> I think my major barrier is still myself, but that's just going to be the way it is (a111, y1r5, TMRS),
> I keep forgetting to use it. Transition from first to second semester… need to get back in rhythm (a110, y2r4, TMRS),
> [My biggest barrier is] overcoming inertia, seriously (a109, y2r6, TMRS),
> I'm not convinced that the clickers always provide the best vehicle for me to accomplish what I want (a113, y2r7, TMRS).

All the categories and subcategories found from open-ended responses are summarized in Table 2. As we analyzed the data, we found that some factors were frequently or emphatically mentioned by many teachers. In the next section, we present our findings regarding factor *strength*—the relative importance and degree of hindrance posed by a factor—and how that strength changes over time.

Factor Strength

In order to better understand which factors were the most important and prevalent, we counted the frequencies of appearances of each code, for each category and survey round (month). Table 3 shows the number of TMRS open-ended response codes for teachers at School A in year 1 (fall 2006–spring 2007) and year 2 (fall 2007–spring 2008), and School B in year 1 (fall 2007–spring 2008). When a teacher mentioned a specific category more than once within a single round, we only counted the number of mentions with distinct subcategories.

As can be seen from the table, the factor *time and curriculum pressure* is overwhelmingly the most prevalent for these participants and project years, followed by *question development*. Analysis of responses from Likert-type items show similar results. Figure 1 shows responses for each category by survey round (month), showing the average number of teachers who chose either "*large barrier*" or "*moderate barrier (uncomfortable)*" versus those who chose either "*small barrier*" or "*not a barrier (comfortable).*" Table 4 summarizes Cronbach alpha values for the groupings we defined to categorize Likert-type items; the categories are reliable ($\alpha > 0.7$) except for the category *practicing formative assessment*. The category *integrating TEFA into curriculum* only contained one item.

Although the particular factors that most strongly affected participants' initial implementation of TEFA varied from individual to individual, some specific factors appear to have been most troublesome to many project participants. As can be seen in the three plots in Fig. 1, *time* was the factor that participants at both schools generally struggled with the most. The next most prevalent factor was *question development*; analysis of open-ended responses corroborates this. These factors remained persistently strong across the entire time period analyzed.

Adoption Experiences with TEFA and CRSs

Many of the project participants overcame the factors discussed above and developed satisfaction with their TEFA practice, but others failed in early stages of implementation of TEFA or showed little growth in their practice of the new pedagogy. In this section, we present vignettes of five teachers to illustrate how the different factors affecting teachers can shape their eventual failure, partial success, or full success with TEFA.

Henry: I Can't Get Used to this Software Ever!

Henry was in his late 50s and had more than 20 years of teaching experience. When he first heard that his school would be involved in the TLT project, he was interested in using a CRS in his science class. However, he found the hardware and software to be much more complicated to learn than he had expected. For example, he wrote in the TMRS survey, "I could not get the software out of a loop and wasted a lot of time trying to get out of it (TMRS y1r2)." The CRS software froze during class; his students waited patiently, looking at him, while he struggled to make it work again. When he was finally able to restart the software, he was relieved. He displayed a question with an overhead projector, and students started to enter responses into their clickers. Everything seemed to be working, but after a few seconds, one student raised her hand and said that her clicker did not work. Although Henry checked the clicker, he could not find anything wrong with it. He gave the student a different clicker, apparently resolving the difficulty. The CRS collected the students' responses and displayed a histogram. When Henry looked at the histogram, however, he saw that all the students' responses were categorized as "invalid." He thought he might have done something incorrectly, but he could not figure out what. The class became chaotic as he floundered. Henry often reported finding himself in this kind of situation. One day,

Table 2 Factors that affect teachers' implementation of TEFA

Factors	Description
Hardware/software	Anything associated with limitations or failures of technology
Malfunctions	Technology failing to do what is supposed to do
Software limitation	CRS software does not to do what the teacher wants it to do, even when working properly
Resource availability	Not provided a hardware/software resource which is necessary for TEFA
Technical support	Human support for the technology
Operating technology	Teacher's skill and comfort using the technology
Basic usage	Basic use during the class
Sophisticated usage	More advanced level of use
Time/curriculum pressure	Difficulty finding enough time to do TEFA and covering mandated curriculum adequately quickly with TEFA
Planning time	Lack of time to prepare, plan, and develop TEFA lessons and questions
Limited class time	Difficulty allocating class time for TEFA
Wasted time	Inefficient use of class time associated with TEFA
Breadth vs. depth	Slow pace of coverage with TEFA
Standardized tests	Pressures from externally mandated topic frameworks and/or exams (that are perceived to be in conflict with doing TEFA)
Question development	Concern with or difficulty designing questions to achieve desired purposes
Integrating TEFA into curriculum	Difficulty fitting TEFA practice into existing curricula and/or other classroom instructional modes
Classroom discussion	Teachers' skill and comfort stimulating student participation and conducting class discussion
Students	Difficulties associated with students' abilities, behaviors, cooperation, and attitudes
Distractedness and disruptive behavior	Students being disruptive or inappropriately focused
Ability	Students' abilities to use a CRS productively and participate in class discussion
Practicing formative assessment	Difficulty performing formative assessment based on students' CRS responses and their participation in discussions
Understanding students' thinking	Interpreting students' statements and actions, and understanding what students know and think
Agility and teaching practice	Making real-time teaching decisions based on students' CRS responses and discussion statements
Revising lessons	Revising or altering future lessons and questions based on class experiences
Contextual factors	Affecting teachers' teaching in general, and giving indirect influence on teachers' implementing TEFA, e.g. personal life, other priorities & demands, school events, weather, time of day, time of the semester
Ways of being a teacher	Perspectives and views of the individual teacher, e.g. fears & doubts, pedagogical philosophy, confidence, background & prior experiences, affinities

one of his students asked, "Why don't you just ask the questions? Forget the clickers! (TMRS, y1r7)."

Experiences like this are probably common among teachers trying new classroom technology. Although most of the teachers in our study encountered initial difficulties operating the CRS technology, they typically overcame them within a month and became comfortable with it. Henry, however, continued to have major issues with the technology and never developed comfort or facility. His responses to the TMRS Likert-type items showed that he was continuously struggling with this issue through the year (Fig. 2). He quit the project near the beginning of year 2.

Kim: Is TEFA Really Worth the Time it Requires?

Although Kim was new to School A in year 1, she had taught for seven years at a previous school. The technology

Table 3 Number of TMRS open-ended responses in each category

		Fall 2006–Spring 2007								Fall 2007–Spring 2008							
		r1	r2	r3	r4	r5	r6	r7	Total	r1	r2	r3	r4	r5	r6	r7	Total
Hardware and software	School A	5	2	0	7	3	2	3	22	1	1	4	0	1	0	2	9
	School B	–	–	–	–	–	–	–	–	4	0	0	2	0	0	0	6
Operating technology	School A	2	0	2	1	1	1	0	7	0	0	0	0	0	1	0	1
	School B	–	–	–	–	–	–	–	–	0	0	0	0	0	0	0	0
Time and curriculum pressure	School A	8	7	10	5	8	2	8	48	7	5	9	5	6	4	2	38
	School B	–	–	–	–	–	–	–	–	9	8	10	9	10	11	7	64
Question development	School A	6	7	6	6	5	8	4	42	1	4	3	0	4	1	1	14
	School B	–	–	–	–	–	–	–	–	2	4	6	6	4	2	4	28
Integrating TEFA into curriculum	School A	1	4	1	2	2	0	3	13	0	0	0	1	0	0	0	1
	School B	–	–	–	–	–	–	–	–	0	1	2	2	1	1	1	8
Classroom discussion	School A	1	0	1	2	0	7	0	11	1	0	1	0	1	1	4	8
	School B	–	–	–	–	–	–	–	–	0	2	4	1	0	1	2	10
Students	School A	1	1	4	1	4	0	1	12	1	0	0	0	1	1	1	4
	School B	–	–	–	–	–	–	–	–	0	0	0	1	0	1	0	2
Practicing formative assessment	School A	1	0	1	1	1	1	0	5	1	0	0	2	0	1	3	7
	School B	–	–	–	–	–	–	–	–	1	2	1	0	1	2	1	8
Contextual factors	School A	1	0	0	2	1	0	1	5	0	1	1	2	2	1	1	8
	School B	–	–	–	–	–	–	–	–	0	2	0	1	1	1	0	5
Way of being a teacher	School A	2	1	1	2	3	1	3	13	2	0	2	2	0	1	3	10
	School B	–	–	–	–	–	–	–	–	0	1	0	0	0	1	2	4

The number of participating teachers is ten in school A year 1, six in school A in year 2, and eight in school B in year 1

Rounds (r1–r7) represents the month that the survey was taken: October (r1), November (r2), December (r3), February (r4), March (r5), April (r6), and May (r7)

was a challenge for her at first, but she became comfortable with it after a month. However, she frequently asked herself whether TEFA was a sufficiently worthwhile way to spend class time. For example, she wrote, "…and my difficulty in making sure the integration of TEFA is good use of class time (TMRS, y1r1)," "…and also not being convinced that it's worth the time it takes to plan for and use (TMRS, y1r2)," and "…not being sure the class time used for TEFA is *worth it* in terms of my educational goals for my students (TMRS, y1r3)." She thought using the clickers would be most valuable when it led to good class discussion: "Although the system can have multiple uses, I believe the time allotted to its use gives the biggest benefit when a good question provokes thoughtful discussion (TMRS, y1r4)." However, she needed considerable preparation time to develop questions that she felt would stimulate adequate discussion: "[I've been concerned about] finding the time to create really good questions that will elicit the kind of discussion that I feel makes this system worth using (TMRS, y1r5)", and "Designing good questions is time consuming (TMRS, y2r5)." She felt pressure to cover a broad curriculum within a limited time, and thought that the discussion-oriented TEFA pedagogy would prevent her from covering all the necessary topics: "I've been most concerned about how the time taken up by using CRS + TEFA is affecting coverage of material (TMRS, y1r1)", and "…the feeling that time is running out and I don't have unlimited class time (TMRS, y2r3)." In addition, she thought setting up the CRS system and distributing clickers consumed valuable class time. After a few months, however, Kim adopted a suggestion made during project professional development: "I now have the students pick up a clicker when they walk into the room, even if I have not planned a clicker question. This makes it more convenient to be spontaneous about adding a question in. I also start the program every day, again, whether or not CRS is in the plan (TMRS, y1r4)."

By the middle of year 1, Kim had her first major success with TEFA. She put a question to her class that she had developed during the professional development program, and saw that her students were actively participating in the discussion by arguing and debating. She described this experience in her journal: "The result was amazing. Students boldly shared opinions and gave sound reasoning and examples to support their ideas… For the first time ever I experienced with my students what I would consider to be the *beauty* of using

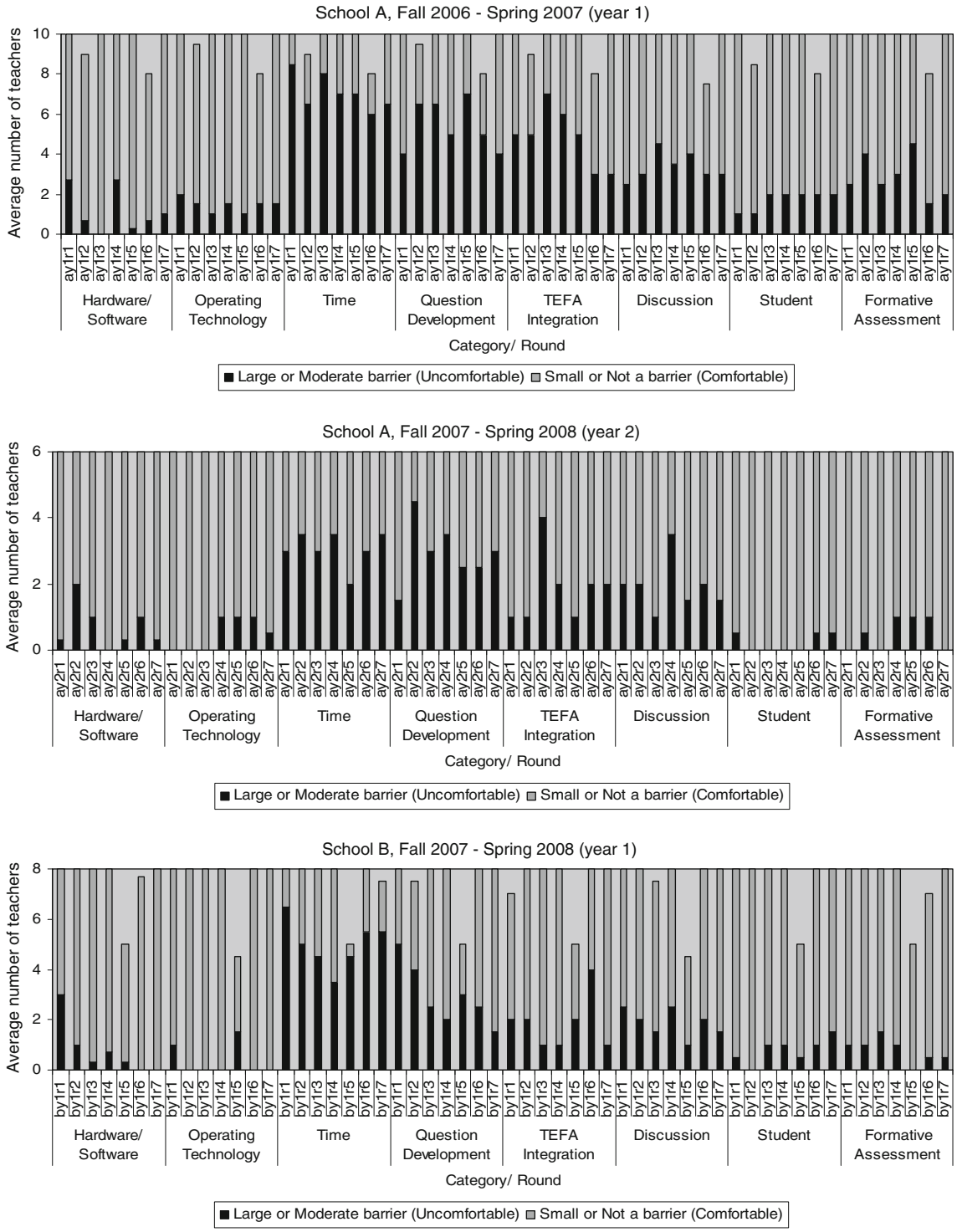

Fig. 1 Average number of teachers selecting each option (either *large barrier/moderate barrier* or *small barrier/not a barrier*) for each category of Likert-type items. *Note*: The number of participating teachers is ten in school A year 1, six in school A in year 2, and eight in school B in year 1. In some rounds, one or more teachers failed to complete the survey

TEFA/CRS. It really worked! (PD journal, February, y1)," Similarly, in the TMRS she wrote, "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/[CRS] (TMRS, y1r4)."

Table 4 Cronbach alpha values for the categories of TMRS Likert-type items

Categories	(question number) TMRS Likert-type items	Cronbach α
Hardware/software	(7.1) Insufficient technology or equipment available	0.847
	(7.2) Insufficient technical support available	
	(7.3) Technology-related problems or bugs	
Operating technology	(6.1) Comfort operating the technology	0.798
	(7.4) Ability to operate CRS reliably	
Time	(7.5) Lack of prep time to plan curriculum/lessons integrating TEFA	0.707
	(7.6) Lack of class time to use TEFA	
Students	(7.9) Students' ability to use CRS clickers reliably and responsibly	0.758
	(7.10) Students' attitudes towards TEFA	
Question development	(6.2) Comfort creating (or finding, choosing, and adapting) CRS questions	0.717
	(7.7) Difficulty creating or finding suitable TEFA questions	
Integrating TEFA into curriculum	(7.8) Difficulty reconciling TEFA with the rest of teaching	–
Classroom discussion	(6.3) Comfort implementing the TEFA question cycle (pose, think/talk, answer, histogram, share, discuss)	0.704
	(6.4) Comfort stimulating and steering good whole–class discussion	
Practicing formative assessment	(6.5) Comfort figuring out what students think and why they think it	0.558
	(6.6) Comfort adapting teaching based on info from CRS and discussion	

Data is from school A years 1–2 and school B year 1, with 182 total questionnaires submitted

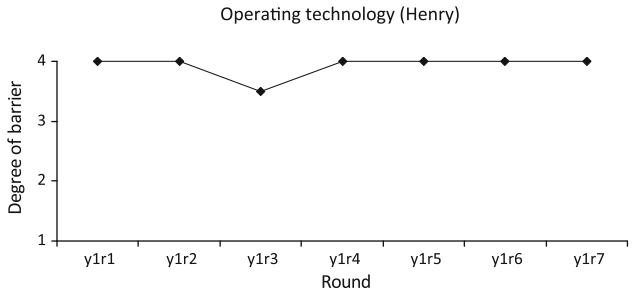

Fig. 2 Henry's average response to the TMRS Likert-type items addressing the barrier presented by operating technology. He continuously responded throughout the year that operating technology was a large barrier. *Note*: 1 = not a barrier, 2 = small barrier, 3 = moderate barrier, 4 = large barrier

During that first school year, Kim's views about teaching changed. In a baseline interview on pedagogical perspectives, she said, "my responsibility as a math teacher is to convey information in such a way that it is easy to learn by as many students as possible." One year later, with the same interview protocol, she said, "I realized that I was planning it from the standpoint of what I need instead of what the students need." Kim came to believe that TEFA pedagogy helps students to develop deep thinking and reasoning, but still wrestled with whether TEFA was worth the preparation time required to develop good questions and the class time to practice it: "Planning time will always be an issue, and I'm not convinced that the clickers always provide the best vehicle for me to accomplish what I want (TMRS, y2r7)." Consequently, her TEFA practice remained intermittent, restrained, and cautious.

James: I Like to Use CRS Mainly for Checking Students' Answers

James is a high school mathematics teacher with more than 10 years of teaching experience. He always began class with pop music playing and a few math questions written on the board. As students came into the class, they would set about solving the math problems. He called this the *jump-start* activity. After about 15 min, he would solve the problems for the students and checked on how they had answered. When he was introduced to TEFA, he decided to use it for his jump-start activity. Although he had some technical difficulties at the outset, he became comfortable with the technology after about a month. Like Kim, he expressed concern about the time required by TEFA and struggled to find sufficient value to justify its use:

> This month I would have to say the time devoted to [TEFA] questions and discussions was perhaps not 'worth' the time taken out of different aspects of the lessons. The discussions generally did not add much worth to the lessons proportionally to the time spent on them. (TMRS y1r7)

He also wrote, "I plan to use it more for checking-in. When I use it I tend to use it for five questions in a row, rather than for one question that is broader and may reveal a misconception (TMRS y2r1)."

After two years of participation in the TLT project, his classes remain quite similar to the baseline classes we observed, although now he incorporates the CRS into his jump-start. He still begins with music and math questions on the board. As students enter, they try to solve the math problems, and then he collects their responses with the CRS and solves the problems for them. The process includes little discussion. He uses the CRS primarily for checking students' answers, rather than for revealing their ideas and misconceptions.

Gina: Middle School Kids Cannot Handle Discussion!

When the project began, Gina was a new middle school math teacher, with only one year of teaching experience. She became comfortable with the technology fairly quickly. However, she had difficulties with her students' behavior. She wrote, for example, "this group of students is tough to teach as they are not really self-motivating (TMRS, y1r4)"; "my biggest problem is the maturity of the students… my students and their attitude towards learning and ability to hold small group discussions is a major barrier (TMRS, y1r5)."

In the middle of the school year, she started to believe that young middle school students may not be ready to participate in lengthy discussions, and she decided to alter her way of using TEFA. She began focusing on checking students' answers with sets of questions, reducing the discussion time for each question, and she regularly revised her lessons by reflecting on her students' responses. She wrote:

> I have been using TEFA a lot more. I am trying to incorporate it into my regular class lessons. I am using it to check on MCAS [Massachusetts Comprehensive Assessment System] questions as well on a daily basis. This enables me to see what I might need to cover that I haven't planned to cover as it was covered in past years. (TMRS, y1r5)

Later in year 2, she wrote, "[I've been] looking at what topics need to be emphasized more or re-taught (TMRS, y2r1)." Although her teaching practice is quite different from what project staff originally modeled for teachers during professional development meetings, the change she made helped her to practice formative assessment.

Tracy: I Want to Tell My Students the Right Answer Right Away!

Tracy was a highly experienced high school science teacher who described herself in a baseline interview as having "confidence with technology." Like Kim and James, Tracy struggled to find time to use TEFA and to prepare good questions: "[I've been concerned about] finding time to use the system (TMRS, y1r2)" and "finding time to write questions (TMRS, y1r3)," but she became more efficient with practice and professional development. As she did, she experimented with various styles of questions, including some more complex than had been modeled in project PD. She came to believe that spending class time on TEFA helped her to understand her students' thinking and modify her lessons accordingly. For example, she wrote, "I have been hearing more from students and subsequently changing or tweaking my lesson plan for the day or week. It's really helpful. (TMRS, y1r1)", and "I have heard more of what students are thinking (TMRS, y1r2)."

By the end of the first year, although she had difficulty covering all the curriculum topics, she was certain about the value of spending time on TEFA. She wrote in her journal,

> [TEFA] is most useful when I want to generate class discussions. However, using CRS in this manner takes time. Currently, I am wrestling with the time issue in the context of understanding versus breadth of content. I'm leaning toward depth… The goal of teaching for me has shifted gradually from a very content oriented process to a mission that still focuses on content but puts increasing emphasis on the importance of learning how to be a good learner. (PD Journal, April y1)

In the interview at the end of the school year, she said,

> The whole class discussion piece of it, I plan to keep using. It's convinced me that it's worth the time more often than not, because in a funny way I've had to double back because I didn't know that kids have misconceptions, or people did poorly and I didn't know why. And I think it was because I never asked… I never really gave them a chance to say "Well, yeah, I think that, you know, electrons are like this". (pedagogical perspectives interview, May y1)

For Tracy, another strong factor affecting her use of TEFA was the conflict between her previous teaching style and the new pedagogy. She was inclined to quickly reveal correct answers to students, but the TEFA pedagogy discourages teachers from revealing the correct answer

immediately. After a few months, she began to grasp the importance of not telling students the correct answers too quickly. Instead, she tried to give students more time to think and to elicit their ideas. She changed her practice so that after allowing enough class time for extended discussion, she clarified students' thinking and summarized the key points of the discussion. She also developed a tactic for keeping discussions focused by writing key words from students' arguments on the white-board as they were speaking. This served to keep track of their various ideas and to expand their understanding, and encouraged students' engagement and participation in discussion. Overall, Tracy dealt successfully with the difficulties that she faced and integrated TEFA pedagogy deeply into her teaching practice (St. Cyr 2009).

These five vignettes provide examples of the different types of factors that affected project participants while they learned to use the CRS technology and to implement the TEFA pedagogy, and of how these factors and the ways individuals responded to them shaped their practice of TEFA. In the next section, we develop a scheme for categorizing our various identified factors, as well as a way of categorizing teachers' different trajectories of TEFA implementation.

Discussion

Extrinsic and Intrinsic Factors

Following Ertmer (1999), we can group the factors that inhibited project participants from implementing the new pedagogy and technology into two major divisions, *extrinsic* and *intrinsic*. Extrinsic factors are external to the teacher: aspects of his or her context and situation that hinder attempts to use CRS technology and implement TEFA pedagogy. Intrinsic factors are internal to the teacher: skills, tendencies, perceptions, preferences, and the like.

Extrinsic Factors

The extrinsic factors that we identified can be divided into two subsets: *type I*, in which the factor is directly associated with some element of implementing TEFA; and *type 0*, in which the factor is associated with something not specific to TEFA, and that circumstantially affects TEFA practice. Difficulties with hardware and software (technical malfunctions, resource availability, software limitations, and inadequate technical support), time shortages (planning time, class time), curriculum pressures (breadth vs. depth of coverage, standardized tests), and students' behavior, attitudes, and abilities are extrinsic type I factors that teachers must deal with when they are trying to practice TEFA.

Extrinsic type 0 factors are these that affect the teachers' practice in general, and are not directly part of learning and doing TEFA. Such factors include distractions and demands in teachers' personal lives, competing priorities at school, school events and disruptions, and factors that affect students' and teachers' mood, energy, and focus, such as weather, season, time of the day, and progression of the semester. Although these issues are not directly related to TEFA, they shape the context in which the 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* factors address a teacher's skills and knowledge relevant to practicing TEFA. These skills can be divided into five sub-areas: operating the technology, developing TEFA questions, integrating TEFA into a curriculum, facilitating classroom discussion, and practicing formative assessment (Feldman and Capobianco 2008; Lee et al. 2009). In contrast, *type II* intrinsic factors involve teachers' deeper *ways 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, and students; personality, characteristics and confidence; satisfaction with TEFA; and personal biography, etc. For example, if a teacher were habitually reflective, she would be inclined to look back upon her TEFA experiences frequently in order to figure out what does or does not 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 be more reluctant than others to change her teaching style.

Figure 3 summarizes our proposed categorization scheme. Note that although we identified no *extrinsic type II* factors in this study, such might exist: these might include educational and administrative policies or social and cultural issues.

Spectrum of TEFA Implementation

All project participants encountered similar factors, yet different ones affected different teachers to different degrees. How each teacher dealt with the factors encountered shaped the development of his or her practice. Figure 4 presents a spectrum of "TEFA pedagogical implementation with CRS technology integration" that serves to categorize various participants' implementation

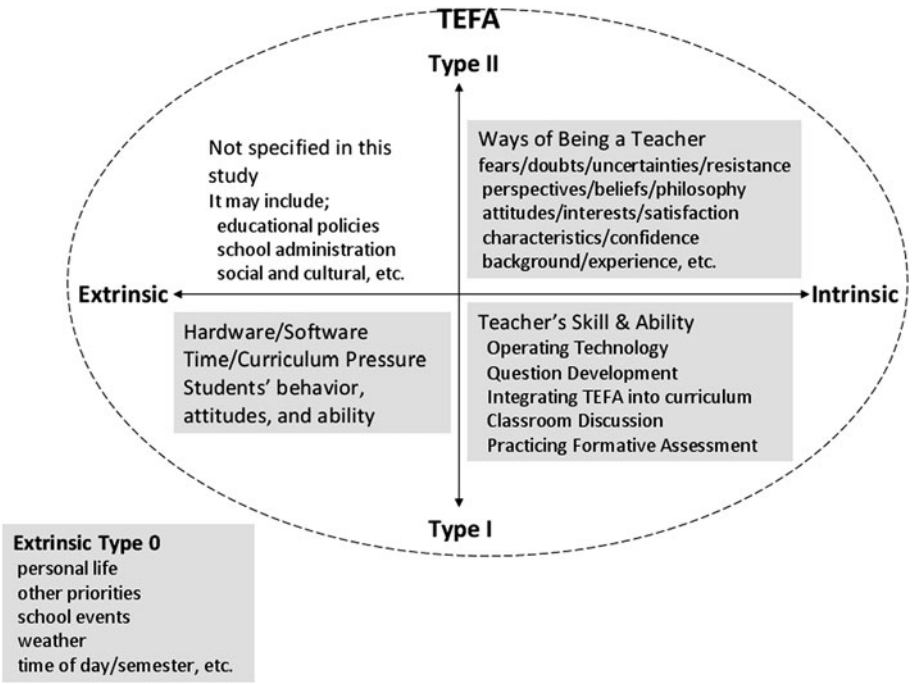

Fig. 3 Extrinsic and intrinsic factors

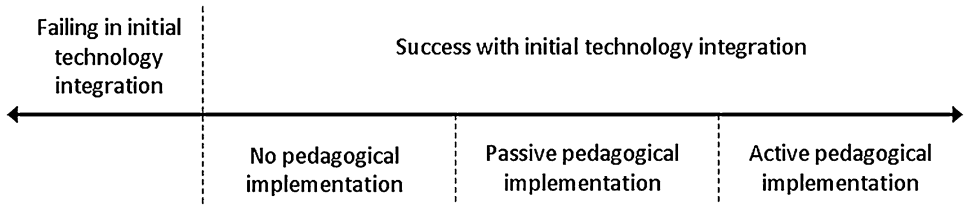

Fig. 4 Spectrum of teachers' TEFA pedagogical adoption with CRS technology integration

trajectories. Hardware and software problems hindered most teachers in the first stage of technology integration. Henry, as shown in his vignette, did not become comfortable with the technology and did not achieve any pedagogical change. He abandoned the use of the CRS technology and, consequently, of the TEFA pedagogy. We identify this as the first category of adoption, *failing in initial technology integration.* In other words, extrinsic and intrinsic type I factors blocked him from experiencing any success whatsoever with technology integration.

Many teachers did learn to use the technology reliably. Some, however, did not show any pedagogical change. James became comfortable with technology quickly, as portrayed in his vignette, but struggled to find sufficient value in TEFA (intrinsic type II) to justify the time (extrinsic type I) required. Although he used the CRS technology regularly, he rarely did so to support classroom discussion or formative assessment; rather, he saw the technology as a tool to help him check students' answers. As a result, his teaching looked fundamentally the same with a CRS as without one. We think of this as a second adoption category: successful with initial technology integration but *no pedagogical implementation*.

Kim's vignette demonstrates a third category, *passive pedagogical implementation*. The strongest factor that hindered her attempts to implement the new pedagogy was lack of time (extrinsic type I) and her uncertainty (intrinsic type II) about whether practicing TEFA was worth the class time required. Unlike James, however, Kim saw value in the pedagogy, and therefore she was willing to accept it and to practice it to the extent that she felt she could dedicate class time to it. Gina also illustrates this third category: she had difficulties with her students (extrinsic type I) when she attempted to elicit their participation in classroom discussion (intrinsic type I). She began to fear that her students were not mature enough to participate in lengthy discussions (intrinsic type II), and decided not to use the CRS in that way. Both Kim and Gina recognized value in the new pedagogy, but tried to adapt it to their original teaching style. Their perspectives about teaching and learning changed to some extent, from teacher-centered during the baseline year to more student-centered

subsequently. However, both of their teaching practices were still rather cautious and conservative.

Tracy's vignette, on the other hand, shows an example of a fourth adoption category: *active pedagogical implementation* of TEFA. Although she struggled like the other participants with various extrinsic and intrinsic factors, she overcame the difficulties and was able to develop ways of implementing TEFA richly. When she was able to overcome intrinsic type II factors (for example, the conflict between her previous teaching style and the new pedagogy), her pedagogical views evolved to become more aligned with TEFA. As a result, she was able to engage her students deeply in classroom discussion, practicing high-fidelity TEFA pedagogy.

From the examples given above, we can see that extrinsic type I factors are basic to a teacher's practice: hardware and software, time and curriculum pressure, and students' behavior, attitudes, and ability. We can also see that a teacher's ability to overcome extrinsic type I factors is related to intrinsic factors. Intrinsic type I factors seem, at least on the surface, to be those that a teacher must resolve in order to successfully implement TEFA. He or she requires skills to operate the CRS reliably; to create good questions to further instructional goals; to integrate those questions into lessons and manage the potentially slow pace of TEFA pedagogy; to facilitate student-centered whole-class discussion; to understand students' thinking based on CRS histogram results and class discussion; and to use that understanding to make teaching decisions. However, the more fundamental factors affecting a teacher's initial implementation of TEFA pedagogy may be intrinsic type II. Although teachers may have good TEFA and CRS skills, they may remain in passive pedagogical implementation as long as they struggle with intrinsic type II factors. Understanding in more detail the web of relationships between extrinsic and intrinsic factors, and between type I and type II factors, remains a task for future study.

Conclusion and Implications of the Study

We have identified various factors that affect teachers' attempts to adopt CRS technology and TEFA pedagogy, integrating them into their practice. First, they must operate within specific contexts that directly hinder their attempts to implement the new technology and pedagogy, which we label *extrinsic type I*: for example, *hardware and software* difficulties, *time and curriculum pressure*, and problems with *students' behavior*, *attitudes and ability*. Second, they must learn specific knowledge and skills (*intrinsic type I*), such as *operating technology* reliably and flexibly, *developing CRS questions* to achieve desired purposes, *integrating TEFA into curriculum*, *facilitating classroom discussion* in a student-centered way, and *practicing formative assessment* by eliciting students' thinking and adjusting teaching. Third, they must reconcile with TEFA their *ways of being a teacher* (*intrinsic type II*), such as perspectives and philosophies about teaching, learning and students; attitudes and confidence; fears and uncertainties; and resistance to change. Fourth, they must adapt to circumstantial factors that affect their teaching in general, beyond just TEFA (*extrinsic type 0*), including personal life and health issues, other priorities, school events, and weather. Depending on how a particular teacher deals with these various factors, he or she can be placed on a continuum of TEFA implementation: *failing in initial technology integration*, *no pedagogical implementation*, *passive pedagogical implementation*, or *active pedagogical implementation*.

The history of technology integration in schools is filled with examples of purchased equipment being left idle in classrooms (Cuban 2001). Even when teachers have adopted new technology, they often continue to teach using traditional methods. Many factors can frustrate teachers learning to use a new technology, including ones beyond the actual use of the technology itself. In our study, technology-related issues (*hardware/software* and *operating technology* categories) were the first that teachers faced, but these were predominantly resolved within one or a few months. Rather, we found that *time and curriculum pressures* were the strongest and most enduring factors for most teachers. *Question development* presented the second most daunting long-term factor to implementation of the pedagogy.

Our study shows that teachers need more than technology and training in its use. We, as science educators, must try to alter educational contexts so that extrinsic type I factors are diminished, by reforming educational policies and arranging better administrative support. Science teacher professional development programs may need to focus on developing teachers' knowledge and skills (intrinsic type I factors) for practicing discussion-oriented pedagogy. Continuous encouragement through long-term professional development may help to decrease the impact of intrinsic type II factors.

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