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Teacher Learning of Technology Enhanced Formative Assessment

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Abstract This study examined the integration of technology enhanced formative assessment (FA) into teachers' practice. Participants were high school physics teachers interested in improving their use of a classroom response system (CRS) to promote FA. Data were collected using interviews, direct classroom observations, and collaborative discussions. The physics teachers engaged in collaborative action research (AR) to learn how to use FA and CRS to promote student and teacher learning. Data were analyzed using open coding, cross-case analysis, and content analysis. Results from data analysis allowed researchers to construct a model for knowledge skills necessary for the integration of technology enhanced FA into teachers' practice. The model is as a set of four technologies: hardware and software; methods for constructing FA items; pedagogical methods; and curriculum integration. The model is grounded in the idea that teachers must develop these respective technologies as they interact with the CRS (i.e., hardware and software, item construction) and their existing practice (i.e., pedagogical methods, curriculum). Implications are that for teachers to make FA an integral part of their practice using CRS, they must: 1) engage in the four technologies; 2) understand the nature of FA; and 3) collaborate with other interested teachers through AR.

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Introduction

The context of the study is an NSF-funded project titled, "Assessing to Learn [A2L]" (See http://umperg.physics.umass.edu/projects/a2l). The major goal of this project is to develop formative assessment [FA] items that would be used by high school physics teachers with a classroom communication system. The principal investigators [PIs] of this project have studied conceptual learning in physics for the past 20 years (e.g., Mestre et al. 1993, 1988). Beginning in 1993, the PIs turned their attention to the development of curricular materials and teaching methods for high school physics. Their first effort resulted in the publication of *Minds on Physics* (Leonard et al. 1999), which has as its goal, the development of deep conceptual understanding that leads to expert-like problem solving. One of the outcomes of the PIs' work with physics teachers in the *Minds on Physics* project was the realization that for teachers to implement successfully a curriculum like *Minds on Physics* they need to make significant changes in their teaching methods. In the A2L project the PIs sought to do this by creating FA items to be used with a classroom response system (CRS). The CRS in use by A2L teachers is called "Personal Response System [PRS]"(see http://www.interwritelearning.com/ for more information).

PRS consists of hardware and software including remotes that students use to send answers to a computer that then displays the results in a histogram. The PIs designed the assessment items to be "consistent with constructivist and active-learning pedagogies" and to "target many of the cognitive difficulties identified by physics education research and will employ a variety of techniques, such as having students use multiple representations, work in cooperative groups and carry out hands-on activities" (Gerace et al. 1997, p. 3). In addition, the PIs hypothesized that "the feedback obtained from teachers' ability to probe students' understanding on a continuing basis will result in a more responsive instructional style and make teachers receptive to the adoption of alternative pedagogical strategies" (Gerace et al. 1997, p. 3).

The PIs see the use of PRS and their assessment items as *technology enhanced formative assessment*. Recently there has been increased interest in encouraging science teachers to use FA to guide their practice (Atkin et al. 2001; Bell and Cowie 2001; Black and Wiliam 1998b; James et al. 2006). Black and Wiliam (1998a) define FA as "all those activities undertaken by teachers and by their students [that] provide information to be used as feedback to modify the teaching and learning activities in which they are engaged (p. 7)." While on the surface this may appear to be a trivial technique to master, Black and Wiliam (1998a) found that even when teachers, such as those in the US, use a series of assessments during the course of instruction, they tend to be short-term ways of obtaining summative information for the purposes of assigning grades rather than formative information for the improvement of teaching and learning. Two questions served to focus our study. The first is simply, "Were the physics teachers able to incorporate technology enhanced FA using PRS into their practice?" The second question, which follows from the first, is, "What did the physics teachers need to learn in order to do this?"

Review of Related Literature

This is a study of how teachers learn to incorporate technology into their practice for the purpose of FA. As such, we report on the literature on the use of instructional technology (IT), barriers to its use, and the role of professional development in helping teachers to incorporate it into their practice. We also look at the limited amount of research on CRSs.

Classroom Use of Instructional Technology

The good news is that teachers and students in the US make extensive use of computers and other electronic devices. Teachers use computers to prepare lessons, maintain grade books, communicate with colleagues and parents, and to do research on the Internet (Adelman et al. 2002; Cuban et al. 2001). They, of course, use computers extensively for their personal use (Cuban et al. 2001). Students also make frequent use of computers for word processing, communication, and Internet searches (Cuban et al. 2001). However, while teachers and students use them for *school work*, they are used infrequently for instructional purposes, and when they are, it is most often for "writing, improving computer skills, doing research on the Internet, as a free time activity or reward, and doing practice drills (Adelman et al. 2002, p. 4)." In essence, there is what Cuban and his colleagues call the "digital divide" between what teachers and students do at home and what they do in schools.

There is also good news about the amount of technical support available to teachers in school. Nearly 80% of teachers who responded to the Integrated Studies of Educational Technology (ISET) survey reported that there was a technology coordinator in the school. However, the expertise of many of these coordinators is in technology, and not the integration of technology into instruction (Adelman et al. 2002). In addition, while the vast majority of schools have computers available for instruction, most classrooms have at most one or two, which limits student use. As a result, even though schools have computers and technology coordinators, support and availability is still lacking and impedes teachers' everyday use of computers for instructional purposes (Adelman et al. 2002).

It is also reported in the literature that teachers are uncertain about how to use computers for instructional purposes and lack confidence in their own ability to develop ways to do so (Adelman et al. 2002; Jacobsen et al. 2002). One reason for this is that they do not feel prepared to integrate technology into their instruction (Zucker et al. 2000). This research is also compounded by teachers' lack of understanding and expertise associated with using technology. According to Becker (2001), teachers often grapple with ill-defined conceptions of expertise associated with using technology. Becker states, "Differences in computer use among subject-matter teachers are often dependent upon their own belief and confidence in using the technology themselves" (p. 21). In Becker's view, if teachers decide to use technology, they do so, not because of features inherent in the technology, but on the basis of their knowledge and expertise. Because of this lack of expertise, confidence, and knowledge, teachers need a significant amount of time to figure out how they can best incorporate IT into their practice. Unfortunately, time may be the commodity least available to teachers (Adelman et al. 2002; Cuban et al. 2001; Zucker et al. 2000). In addition, while there is widespread participation by teachers in professional development in educational technology (Adelman et al. 2002), it is largely inadequate for preparing them to integrate technology into their daily practice (Zucker et al. 2000).

Barriers to the Classroom Use of IT

We have already discussed two important barriers to teachers' use of IT. The first was teachers' lack of knowledge of how to use technology for instructional purposes. In a sense they are lacking instructional technology pedagogical content knowledge (Dun et al. 2000). The second was the lack of time for developing that knowledge. Cuban and his colleagues (2001) also suggested that the structure of schools, especially high schools, prevents the use of IT. In particular they point to the separate subject departments, which impedes the sharing of equipment, and what they call "cellular classroom arrangements", which impedes the sharing of ideas and expertise from teacher to teacher (Cuban et al. 2001). Two other barriers identified by Cuban and his colleagues are competing educational priorities and defects in technology. The former is evident in the current emphasis on testing, rather than on the use of creative pedagogy. Cuban and his colleagues also suggest that teachers may not be convinced that IT will help them raise students' scores on high stakes exams. The latter barrier is related to the reality that teaching is very much like theater or live television—there is little room for technical failure. If a teacher plans a lesson that relies on student use of computers and the system crashes, then they must resort to a backup plan. If the teacher feels that he or she cannot rely on the equipment, then rather than face the prospect of needing to have a plan B at the ready, he or she will stop using it (Cuban et al. 2001).

The barriers discussed so far are typical of what Ertmer (1999) refers to as first-order barriers, which are extrinsic to the teacher. Others are intrinsic to the teacher. These include beliefs about teaching, computers, and classroom practices, and beliefs about their students as learners. For example, a teacher who prefers frontal teaching methods may not see any use of IT other than to use presentation software like PowerPoint instead of transparencies and an overhead projector. A teacher may believe that his or her students cannot be trusted with expensive equipment or that they are incapable of learning in the types of collaborative settings often called for in IT use. Clearly these types of barriers are more difficult to mitigate than extrinsic ones.

Professional Development

In addition to surveying the use of computers and other technology by teachers, the ISET study looked at the role of professional development in preparing teachers to use IT. As with the first part of the study, there was good news: "Teachers reported that they needed more professional development in the use of educational technology and were willing to participate in more if they were provided with the time to do so" (Adelman et al. 2002, p. 5). In addition, participation in IT professional development activities was widespread, and it influences how teachers use IT (Adelman et al. 2002). However, the quality of the professional development is highly inconsistent, and while much of it focused on the technical use of the IT, teachers reported that what they need much more of is how to integrate it into their daily practice (Adelman et al. 2002).

While the ISET study found some good news about professional development for IT use, there are numerous studies, summarized in Chapter 8 of *How People Learn* (Bransford et al. 1999), that indicate that traditional teacher professional development activities, in which subject-matter knowledge or pedagogical content knowledge is delivered to teachers, has little effect on their practice. This is especially true when teachers need to learn how to use the new knowledge in the classroom. There is no reason to believe that this is not the case for learning how to use instructional technology in meaningful ways. Following on the recommendations in *How People Learn* and building upon our own research on action research (AR) (Capobianco 2007; Capobianco and Feldman 2006; Feldman 1994, 1996; Feldman and Minstrell 2000), we developed a plan in this study in which high school physics teachers joined together in a collaborative AR group that focused their inquiries on their use of FA with the CRS.

In our previous work we have used the following definition of AR:

> Action research happens when people research their own practice in order to improve it and to come to a better understanding of their practice situations. It is action because they act within the systems that they are trying to improve and understand. It is research because it is systematic, critical inquiry made public (Feldman 2002 p. 242).

In the context of this project we see AR as a process that can result in the improvement of teachers' practice, an increase in their understanding of their educational situations, and the generation of new knowledge that can be shared with other teachers, as well as science education researchers (Feldman 1996). By collaborative we mean teachers inquiring together rather than collaboration between teachers and university researchers (Feldman 1993). In addition to these cited works, we draw upon the large literature on AR; an overview of which is available in an ERIC Digest prepared by us (Feldman and Capobianco 2000). We return to our use of AR when we discuss the methods of the study.

Classroom Response Systems

There has been little research reported on the use of CRSs. An extensive review by Fies and Marshall (2006) found 24 articles, which they divided into two categories: those that focused on pedagogical theory and those that focused on implementation. Those that focused on pedagogy looked at issues such as how to use the CRS to make the classroom more interactive and have students more actively participate in their own learning processes. For the most part the implementation studies identified the benefits of CRS use, such as improved attendance and participation, more student participation, and students finding the classes more enjoyable. Other studies compared whole class discussions to small group discussions, and individual responses to group responses. Fies and Marshall (2006) end their review with implications for future research. They suggest controlled comparisons of CRS use with traditional teaching; studies of the use of CRS with a variety of pedagogical approaches; studies of its use with diverse populations and content areas; and more studies on comparisons between its uses in individual mode versus group mode. We suggest at least two other areas of research, both of which we address in this study. Of the 24 studies reviewed by Fies and Marshall, all but one was at the post-secondary level. Only one looked at CRS use at the high school level and its focus was on networked graphing calculators. Second, none of the studies looked at how teachers or instructors learn how to use a CRS. Hence, we examine how CRS is implemented in the high school setting and what high school physics teachers need to learn in order to do so.

Methods

Modes of Professional Development

The project used two main modes of professional development. The first was a traditional workshop that was held during the summer. The PIs of the project designed and ran the workshop. During the week the teachers were taught how to use the hardware and software of PRS, participated as students in lessons that used assessment items developed by the PIs, and spent time examining their curricula to determine how the PIs' assessment items could be incorporated into their practice. The teachers also had the opportunity to practice using PRS and A2l items with their peers in the role of students and the PIs providing constructive feedback. The second model of professional development was the teachers' participation in collaborative AR. The method of AR used by the group of teachers, which came to be known as the Formative Assessment Action Research (FAAR) group, was enhanced normal practice (Feldman 1996), which consists of anecdote-telling, the trying out of ideas, and systematic classroom inquiry. The authors of this paper served as the facilitators of the AR group. FAAR had two main goals. The first was to improve the teachers' use of FA with PRS. The second was to use their experiences and the knowledge that they created through AR to develop a workshop for new users of A2L. The teachers used ethnographic methods, as well as surveys and questionnaires, in their research. The major products of their research were two presentations that they made at conferences (Kropf et al. 2001, 2003) and the development of a workshop that they gave on using PRS with A2L items in July 2001.

Research Methods

The teachers' AR also server our research purposes. This study continues our goal to come to a better understanding of how teachers learn new pedagogical methods and how they learn to incorporate them into their ongoing practice. In our studies we invite teachers who had already volunteered to learn the new methods to engage in AR on their practice. The purpose of the AR was for the teachers to inquire into their use of the new methods in order to improve their practice and to come to a better understanding of it. Our previous studies have involved teachers in a national education reform effort (Feldman 1995); a research project that examined the relationship between teachers' content knowledge and their pedagogical content knowledge (Feldman 1996); the development of a constructivist physics curriculum (Feldman 2000); and science teachers' use of gender inclusive pedagogy in their classrooms (Capobianco 2007). In all cases the teachers' engaged in AR on their practice, which we facilitated, and we studied the teachers' learning through the use of qualitative methods such as participant-observation, interviews, and focus groups (Marshall and Rossman 2006). We also surveyed the teachers and their students. In all but the last project described above we had as our goal to learn more about teacher learning and how it is mediated through AR rather than to promote the goals of the larger project. The same is true for the study that we report on here.

The participants of this study consisted of eight high school physics teachers located in the northeastern United States. Three of the teachers were women and five were men. Two were novice teachers in their first or second year of teaching. Four were highly experienced teachers, each having more than 20 years experience. One teacher taught at a private school and the other teachers taught in rural and suburban public school settings. The teachers' classes ranged from 9th grade "Physics First" curriculum to 12th grade advanced placement.

It is important to note that this study consisted of two sets of research. We already described the methods used by the teachers as they engaged in AR. The second was the research that we conducted to gain a better understanding of how the teachers learned to use PRS for FA. We used ethnographic methods (Fetterman 1989), as well as collaborative conversations (Hollingsworth 1994) to gather data about the teachers' practices and beliefs. The qualitative methods we employed included: 1) participation in collaborative action research; 2) interviewing; 3) direction observation, and 4) document review (Marshall and Rossman 2006). The main sources of data included audio taped group meetings, semi-structured interviews, field notes from classroom observations, supporting documents (e.g., lesson plans, curriculum materials, or assessments), and field notes from our research notebooks.

We interviewed each teacher individually on four separate occasions. The first interview focused on the following: 1) the teacher's academic background and professional experiences with teaching physics; 2) the teacher's interests in and experiences with the A2L project; and 3) the teacher's knowledge of and previous experience with FA. The second interview took place at the end of the first year of integration and focused on determining how the physics teachers began to incorporate formative assessment using PRS and what they learned from this experience. The third interview was conducted during the second year and emphasized the following: 1) the teacher's expectations for working on the A2L project; 2) the teacher's goals for incorporating FA using PRS; and 3) the teacher's knowledge of FA based on using PRS. The final interview was conducted in the last year of the project and focused on what the teachers learned as a result of using PRS, incorporating FA within their existing practice, and developing future plans for continued implementation.

We conducted a series of three to five classroom observations for each teacher per year. The purpose of observations was to collect data that depicted how each teacher attempted to incorporate elements of FA while using PRS. Each observation included a two-part process: describing what we observed and interpreting what it meant (Glickman et al. 2002). Additional data collection methods entailed the review of supporting documents, including curricular units, assessment instruments, and specific A2L prompts or tasks, developed by the teachers.

Data Analysis

Our primary purpose in doing this study was to understand if and how FA becomes an integral part of a teacher's practice. To meet this goal, we employed the use of grounded theory (Strauss and Corbin 1990), the organization of qualitative data (Miles and Huberman 1994), and case study methods (Yin 1989). Our first series of analytic steps were to examine data derived from interview and group meeting transcripts. We read and re-read each transcript, recording our initial thoughts and ideas relative to our research questions. We identified key statements where the teachers noted various ways they incorporated FA using PRS; problems they were experiencing using the software and/or hardware; and what they learned from their practical experiences. Using open coding, we labeled key events or incidents where the teachers indicated discrete ways they were learning how to use PRS, how to incorporate FA, and/or how to facilitate student learning. We then organized and re-organized our segments of coded data into categories. To determine the plausibility of our categories, we employed the process of peer debriefing whereby we consulted with one another. These consulting sessions allowed us to uncover patterns and emerging themes within each respective data set. This resulted in the conceptualization of how four technologies facilitated and/or impeded growth in the teachers' knowledge.

To gain an in depth understanding of how the teachers were enhancing their own practice and furthermore, build on our working theory for teacher change, we purposefully selected an individual teacher, Ken (a pseudonym is used to protect the anonymity of the participant), whose integration of FA using PRS grew from novice to expert. Before presenting Ken's case, we look at how teachers' conceptions of FA and how they described its use changed during the project.

Findings

Conceptions of Formative Assessment

In this section we look at how the teachers' conceptions of FA changed during that time. We interviewed the teachers at the beginning of the project in fall 1999. We then interviewed them again at the end of the 2000–2001 academic year. In each interview they were asked these same two questions: 1) Are you familiar with the term, formative assessment or formative evaluation? What does it mean to you? 2) Can you give an example of how you use formative assessment in the classroom? As one might expect, the teachers' had much more to say about formative assessment in the second interview. Their ideas about formative assessment and what it means to use it in the classroom changed significantly during that time. For the purposes of this paper we will look closely at two of the teachers' responses to illustrate those changes.

In fall 1999 Ken defined formative assessment in this way:

> Ken: Yes; to me assessing as in posing a question and getting a response for the purpose of learning…for the purpose of the student learning and the teacher learning. For the purpose of clarifying where the students' understanding is (Interview #1, Fall 1999).

A year and a half later he responded in this way:

> Ken: Yes…my understanding of what it means…is assessment for the purpose of teacher and student, knowledge of the students' knowledge state…and to find out what a student doesn't know as opposed to what a student does know…it's not necessarily for the purposes for assigning the grade but for the purpose of student and teacher information about a student's knowledge of content, problem solving knowledge, different areas where a student may or may not have understanding and that it would be used to guide instruction and can also be used as a tool for instruction as well. Those are the features of formative assessment and I have tried to contrast that with summative assessment, which would be assessment to determine the overall picture of what a student has learned and assigning a grade (Interview #2, Spring 2001).

While at some level there is little difference between these two responses, Ken has more information to share with the interviewer in the latter interview, including contrasting formative with summative assessment. In addition, he explicitly states that the formative information would be used to modify instruction.

In the first interview, Erik defined formative assessment in this way:

> Erik: Yes; ongoing measurement of student understanding with opportunities to revise teaching and learning strategies (Interview #1, Fall 1999).

In the second interview he gave this response:

> Erik: Yes; finding out on a regular basis where the students are in terms of their understanding and then modifying what I do with them and what I have them do for me in order to correct in midstream learning what is happening or redirect what is happening (Interview #2, Spring 2001).

Erik's first definition is terse and clear. This is not surprising because he has been working with the PIs for a number of years and is a leader in physics education in the region. It is also important to note that he is a man of few words. In the second interview he added that FA is something that is done midstream, as one is interacting with students. That is, to engage in FA means to make significant changes in how one is as a teacher.

The second question asked the teachers to tell us what we would see in their classrooms that would indicate that FA is happening. In the first interview, Ken described it as a form of Socratic dialog:

> Ken: A2L questions that I've developed always allow for different responses and when posed I would typically tabulate their answers and discuss the merits of each answer. That discussion is the formative part because sometimes I will, after the discussion had died down, give specific directions or corrections or ask questions. For example, "all things fall at the same rate…really…yeah…okay…if I drop off this table is that ok? If I drop off this building is that ok…no…why not? You fall at the same rate…" it's almost like a Socratic dialogue back and forth (Interview #1, Fall 1999).

In the second interview, he gave this description:

> Ken: One thing they might observe is that I might start off the introduction of a topic with a question. So in that case, I am interested in the students' responses to find out what they already know. The answer to the question, the scientific community's answer to the question, is not my intent. I am not intending to have them come to that answer, as much as to give an honest response based on what they currently believe and find out their current understanding is. I often include if we do a hands on activity, lots of other questions, not just ask them to collect data, but to answer thought question or the meaning of the data, or what ifs…and then what I then do is circulate among different groups. And I will come up to them and at whatever stage they are in their hands on investigation and I say, "so what if you did this what do you think would happen?" And I use the question as a way to focus on what they are investigating. It's not so much about getting it right but about causing that, "Well, I geez, I don't know? What if…" that kind of conversation to come up in their mind. Those are some of the ways I use questioning and that would be a small group conference so it's not like asking them in front of the class to come to an answer about something (Interview #2, Spring 2001).

We see a similar difference in Erik's responses. In the first interview he told us that he did FA by having students do "quick writes" to check for their understanding. At the time of the second interview, he described his use of FA in this way:

> Erik: Well, without the technology of A2L, the way that I would implement formative assessment is to question them and dialog either in a whole group setting, small group setting, or individually through the use of

> discussion and dialogue get a sense of what students are feeling. The advantage of this in a whole group is that you don't always key into subsets of individuals in a class or a class of 28. I have a class of 28 although I get a general idea of how the group as a whole is doing. I am missing many pieces and again A2L doesn't allow me, at this point, to zero in on individuals, but it gives me a much better sense in numbers how students are falling into which bins for the ideas (Interview #2, Spring 2001).

Erik had gone from a process of reflection-on-practice (Schön 1983) to one in which he attempted to use the formative information while teaching the class in real-time. For both Ken and Erik, we see in their descriptions the attempt to explain how the way that they are teachers changed when they engaged in FA.

A Case of Teacher Change

We now look more closely at changes in Ken's use of classroom communication systems to do FA. During the 1999–2000 academic Ken was an early adopter of A2L. The PIs traveled to his classroom to install the hard-wired version CRS, *ClassTalk*, which they had been using in their university teaching. While this system has more capabilities than PRS (e.g., text entry and analysis of classroom data sets), the need to install wires to students' desks and the use of Texas Instrument graphing calculators as input devices make it difficult to use in most classroom settings. In this first lesson (October 26, 1999), Ken used questions that he had modified from *Minds-On Physics* (Leonard et al. 1999), a curriculum also developed by the PIs. Ken presented the students with two graphs of motion, position vs. time and velocity vs. time. Each set of axes had five graphs on it, differing in shape and slope. Ken posed this question to the class:

> Question 3: Which of these objects (A through E) is accelerating at time t_2? Enter letter or letters (Field notes, October, 1999).

After displaying the histogram of responses, Ken began this exchange with his students (S):

> Ken: What is common among B–E? What feature of the graph?
> S18: The slope.
> Ken: Is acceleration the same as velocity?
> Several students: No
> Ken: What does acceleration mean, then?
> S11: The rate of change of velocity.
> Ken: B, D, E, what is common? Don't they have something… they all have constant velocity. What is the definition of acceleration?
> S0: Oh, sorry, I'm wrong.
> Ken: That's okay, you're learning. What is it about C that you liked?
> S12: It's not a straight line, so velocity is changing.
> Ken: Very good, you guys are picking it up (Field notes, October, 1999).

Later on in the same academic year (March 23, 2000), Ken had this exchange with students after their responses to an item regarding conservation of momentum:

> Ken: So what are some of the things we determined about the explosion in the last problem where something up in the air breaks apart and falls to the ground? Is there a net impulse?
> S13: While it falls to the ground?
> Ken: Okay, is there any net side-to-side impulse to the system?
> S18: No.
> Ken: Why not?
> S13: I don't know.
> Ken: Can you help him out?
> S14: No.
> Ken: Okay, what about the cart problem when they came together and stopped, we said they had the same momentum…
> S14: [shrug]
> Ken: How many people drew a picture? You have a test coming up. What do I have to do to get you to draw a picture?
> S5: Crayons.
> Ken: If I bring in crayons, you'll draw a picture? Some people can do this in their head. But if you're confused, draw a picture! I feel as though I'm failing you guys. Are you embarrassed about your art skills? I have drawn some really bad pictures on the board, but it is a skill that has helped me out a lot in my math and science classes. I am trying to share a bit of wisdom with you. When you have a picture, you can look at the side to side and up and down components. How much side-to-side momentum was there before?
> [Inaudible student response]
> Ken: So it started with zero. What did it have for side to side when it landed?
> S13: Zero.
> Ken: What about up and down?
> S13: Different.
> Ken: Right. The side-to-side momentum is the same but the up and down momentum is different. That's the point of this question.
> S5: But they have different speeds?
> Ken: There is a lot going on in this question. Side to side there are different velocities but equal momentum, for a

net of zero. And up and down, there is difference in momentum.

S5: Okay (Field notes, March 23, 2000).

Ken then went on to the next item.

At that time Ken was a novice teacher. In addition, he was having difficulty with the hardware, which diverted his attention from the content and his students. Therefore, it is not surprising to see an I-R-E type of classroom discourse (teacher Initiates, student Responds, teacher Evaluates) even though he was trying to use A2L-type items to elicit formative discussions. By March of that year he had mastered the hardware and software, and was using actual A2L items. He was also trying to engender more discussion among the students by, for example, asking one student to help another with an explanation. However, he did not have the expertise needed to generate the type of classroom discourse that would produce student comments that could be formative information.

A third observation of Ken's teaching was done in January 2001. For this class Ken was using A2L items that focused on graphs of motion. They were similar to the ones that he used the year before that he modified from *Minds-On Physics*. This excerpt begins with a student's explanation why she chose a particular answer.

S9: I think it is 2, 3, 4, 5, and 6 because of increasing acceleration or constant acceleration.

Ken: Molly, do you feel the same way? Do you feel that 2, 3, 4, 5, and 6 are all possible?

S12: Acceleration would be constant. I guess I agree.

Ken: What about the sign?

S12: Positive.

Ken: Why?

S12: The position is increasing at an increasing rate.

Ken: Good. Can you tell which would be the acceleration?

S12: If the velocity is increasing constantly the acceleration is constant.

S8: [blurting out] I revoke that! It would just be 2 or 3.

S13: It would be number 2 only. So far we have only dealt with parabolas so I think we can assume that it is a parabola.

S8: I still have my question of earlier.

Ken: You're right, this is the same issue. I'll have to talk with someone in the math department but I think that upward curve indicates a 2nd order.

S5: You would have to see values or an expanded graph to determine which order it was (Field notes, January, 2001).

Ken then went on to the next item.

Lastly, we have an example of Ken working with a small group of students at the very end of the next school year (June 21, 2001). Classes had ended for seniors, and the PIs had asked Ken whether he would teach some sample lessons to be videotaped for training purposes. In this excerpt we observe him using an item in which a ball is rolling along a smooth table and then comes to an area covered with felt. The excerpt begins just after the histogram is displayed:

Ken: What we see, this is on a percentage scale, what it is indicating now is that over 60% of people indicated number 3, that the felt should be placed on the second half of the table. We did have people responding that it should be on the first half of the table and also that it doesn't matter where the felt is placed. I'm just curious; most people think that it does matter where the felt is placed. Only a few people said it really doesn't matter. So I'm curious if somebody could explain why they really think that it matters where the felt is placed. We still have the same felt, the same cart, the same table. What is it about the placement of the felt that makes it matter?…

S1: Well I sort of… how fast the cart… I imagined that it was going really, really fast so that it crossed the uncovered part of the table essentially in no time. When it hit the felt it started slowing down… that would be the only time it encountered, if the felt was on the first part it would slow down then. When it reached the other part of the table it wouldn't slow down as much…

Ken: Okay, really interesting. It sounds like he was thinking about how fast it was going and how long it would take to go a certain distance. The other interesting thing was that you had to deal with the question how fast the cart was going but the question didn't specify that. Who else? Were you raising your hand?

S2: I thought about how if the felt were the first thing it hit it would have stopped there and it wouldn't have made it all across the table.

Ken: Okay, great. So it sounds like people are thinking about it as ideas. As a bunch of ideas. Did you have anything different to say?

S3: No.

Ken: So the only question is whether it should be on the first half of the table or the second half of the table. Most of the people seem to be thinking on the second half of the table, and most of the reasoning has to do with thinking about how long it takes to go a certain distance (Field notes, June 2001).

At this point we can see that Ken is comfortable with himself as a teacher. He is an expert with the use of the equipment and has developed a way of being a teacher that evokes rather long responses from students. Ken is a different teacher than he was when we first observed his use of PRS and A2L. There are multiple reasons for this, including two more years of teaching experience, more familiarity with the school subject of physics, and the fact that he had changed schools and was now teaching at the regional high school in the same town as the University. However, it is the type of changes that we have seen in Ken's practice that the PIs would like be the result of using A2L in the classroom.

A Model for Teacher Learning of Technology Enhanced Formative Assessment

How do teachers learn to incorporate FA into their practice using a CRS like PRS? As we noted above and demonstrated with Ken and Erik, the teachers' conception of what FA is and their descriptions of how they used it in their teaching changed dramatically over the course of the study. As a result of our data analysis, and in consultation with the teachers, we developed a heuristic model of the knowledge and skills needed for the incorporation of technology enhanced FA into teachers' practice. We describe the knowledge and skills as a set of four technologies. We use technology to mean "the body of knowledge available to a civilization that is of use in fashioning implements, practicing manual arts and skills, and extracting or collecting materials" (AHD 1992). The first technology consists of the hardware and software that make up PRS. The second consists of the methods needed to construct FA items. It includes knowledge of research on science learning and assessment. The third technology consists of the pedagogical methods that a teacher uses to transform an information eliciting system into FA. Finally, teachers need to be able to incorporate the use of PRS and A2L into their existing curriculum.

We now turn to our data to illustrate the teachers' learning of these technologies. Figure 1 represents the interactive relationship among the first three technologies. That is, growth in teacher' expertise in any one of them relies upon and strengthens their expertise in the others. We use a conception of curriculum that comes from the work of Clandinin and Connelly (1992), in which curriculum is a socio-cultural construction of what happens in schools between teachers and students in classrooms. As the teachers use the hardware and software and assessment items in their classrooms, it affects the curriculum. But there are aspects of the curriculum that are resilient and impede change. Therefore, if the teachers are going to incorporate PRS/A2L into their ordinary teaching, they must have the knowledge and skills to actively shape both the curriculum and how they use PRS/A2L.

Hardware and Software

PRS consists of student transmitters, a receiver, a computer, and a monitor large enough for students to see from all points in the classroom. The software enables the system, constructs the histogram, and keeps a record of student responses. In addition, teachers need to have a way to present the assessment items to the class. They usually did this using an overhead projector.

For the most part we have observed little difficulty in teachers learning to use this technology. Their learning curve is accelerated by previous experience using computers with other external devices such as probe ware. Although the PIs visited each site on several occasions to help teachers set up the hardware and load the software, we found that some teachers, especially novices, were stymied by the logistics of using PRS. In order to use the system the classroom must have a computer, large monitor or data projector, and a way to present the items. This was not always easy to make this happen:

> Robyn: I got my system in today…we have it set up in the classroom I don't use but is the one on board that has the TV connected to the computer. I asked the teacher to switch classes during 6th period. Then there is more logistics of figuring out, because we don't have white boards and screens…so I've been working on how to display questions. I've been working on putting them on PowerPoint that uses a screen that uses the board space. I have to go back and forth from slide presentation to getting the PRS system back up … (Transcripts, March 15, 2001 AR meeting)

As it turned out Robyn referred to these logistical problems as impediments to her use of PRS throughout the semester:

> Robyn: The way my classroom is set up right now, I can't do it…the overhead is dead in front, there is no where else for it to go, because it is too far from outlets. It's incredible how much the flexibility of the classroom is involved here. … I've used it once since my last time. That has to do with two things. My PRS set up is not in my classroom. I don't have TV computer connection in my classroom. In order to use it, I have to go into his classroom. I have to get his approval really (Transcripts, April 25, 2001 AR meeting).

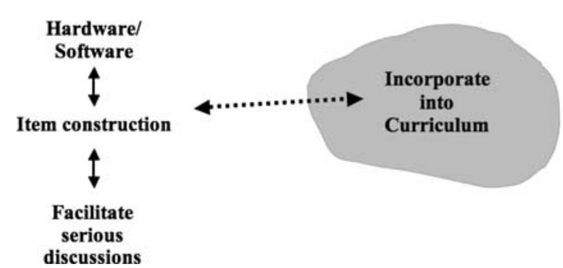


Fig. 1 Technologies of formative assessment and PRS

Robyn: I got the system in February this year, so I've been using it a couple of times because my room is limited in the technology that we have available to us and the space…My classroom is situated with teacher up front and lab tables in the back and it is very difficult to get students to move tables around and talk with each other… (Field notes, July 14, 2001 workshop).

Robyn used the system only a few times between February and July, and left the project after that academic year.

Robyn's story is reminiscent of the barriers to IT implementation suggested by Cuban et al. (2001). The cellular nature of high schools made it necessary for her to make arrangements to change classrooms with other teachers so that she would have access to the necessary hardware. But the difficulties of these logistics caused her to react in the same was as if she defective equipment—it just did not seem worth the effort required to use PRS and A2L in her situation.

Hardware and software issues also came up for the experienced PRS users. These issues can be thought of as the practical problems that one encounters trying to use a new technology in schools. However, they also had pedagogical outcomes. It had been mentioned at an AR meeting that it was difficult to know which students had entered their responses and which ones had not. At the March 28 AR meeting Peter, a new user, told the group that he had discovered that he could enter students' names into the computer and have them displayed on the monitor. While this would solve the problem of keeping track of students, it caused a logistical problem–how to make sure that students received the same transmitter each time they used PRS.

Ken: I just wanted to put this out there that the logistical hassle with; I tried assigning each student a number. I did it once and it was nightmare. They would spend time digging around for their remotes (Transcripts, March 28, 2001 AR meeting).

This is necessary because the system recognizes transmitters, not the students who hold them. The solution worked out by the teachers was to store the transmitters in a rack that was labeled so that students would be able to quickly find their transmitter and easily replace it after use.

Other practical problems concerned the presentation of the items to the students and how much time to give students to respond to the questions. As we already mentioned, most teachers presented the items to the students on an overhead projector. Ken had a different solution. Instead of relying on a projector to present the items to the students, Ken put together Xeroxed packets of items.

Ken: This allowed me to have a whole group of questions ready to go. I numbered them so I had an order I could follow. It was convenient to group questions together and having them on paper helped students focus and become engaged. It was my practice to have one packet for two or three students. This helped them to work with others…this gave me a back up…I found it did get me out of few jam… (Field notes, July 14, 2001 workshop).

Another problem centered on how to make sure that the students had enough time to respond to the items but not too much so that they would become distracted. Ken reminded the other teachers that the software could control the response time interval:

Ken: Part of it is also is just the skill of using the technology and one of things…sending the question out with a bunch of time. … If there is no response, I just stop the time. It's just one way to control the problem and that seemed effective (Transcripts, April 25, 2001 AR meeting).

Item Construction

The A2L project has as its main goal the creation of FA items that can be used with an electronic response system to embed FA in high school physics instruction. What this suggests is that once teachers are familiar with the use of the hardware and software, they should be able to access a bank of items provided by the PIs and use them in their classrooms. An example of one of the assessment items created by the PIs can be seen in Fig. 2.

As it turns out, the teachers rarely used the prepared assessment items. The teachers gave two main reasons for this. The first was that the vast majority of the items were within the domain of mechanics, which was only a subset of the topics in the teachers' curricula. But even when they were teaching mechanics, the teachers used the A2L items infrequently. That brings us to the second reason. In our analysis of our data, we found that the teachers desired what they called "better" assessment items. When we asked them what would constitute better items, we were first reminded that the prepared A2L items were very well written for eliciting students' conceptions of physics. However, what the teachers found lacking in the items was that they did not fit the teachers' contexts. They believed that the A2L items needed to be "better matched to our clients" (Erik, Transcripts, February 28, 2002 AR meeting) and "better tailored to an individual teacher's curriculum" (Vivian, Transcripts February 28, 2002 AR meeting).

Fig. 2 Assessment item 0020

A2L Item 0020: A bowling ball rolls down an alley and hits a bowling pin. Which statement below is true about the forces exerted during the impact?

1) The bowling pin exerts a larger force on the ball than the ball does on the pin.
2) The bowling ball exerts a larger force on the pin than the pin does on the ball.
3) The force that they exert on each other is the same size.
4) One of the two forces is larger, but which is larger can't be determined unless more information is provided.
5) None of the above.
6) Cannot be determined.

The teachers' need to learn a second technology arises from their reluctance to use the prepared A2L items, and the paucity of those items for topics other than mechanics. As it turns out, the technology of item construction is highly complex. That is because an item must satisfy a complex set of criteria. First, they must relate to the topic being taught. Second, they must use language with which the students are familiar. Third, they must reside in the "zone of proximal development" (Vygotsky 1978) so that students are challenged enough to engage in serious discussions about the concepts but yet are not frustrated by them. Fourth, the set of answers for an item should serve to *bin* the students' conceptions if the histogram is to be used as a diagnostic as well as a pedagogical tool.

The teachers found the first two criteria were relatively easy to meet. They were able to use their physics content knowledge and pedagogical content knowledge to construct items useful for their curricula. This knowledge also served them in meeting the second criterion. They did this by either writing items themselves, or by modifying questions from other curricular materials. For example, Ken has relied on the *Minds-On Physics* curriculum, Vivian on *Preconceptions in Mechanics* (Camp and Clement 1994), and Peter has found *CASTLE* (Steinberg and Wainwright 2002) to be a useful source of material for new items.

The third and fourth criteria are closely related. One of the ways that we explored the importance of item structure was to compare A2L with the "Ask the Audience" (ATA) option from the television show, *Who Wants to be a Millionaire?* Anyone familiar with the show will see the similarity between ATA and A2L. In both a question is posed with multiple-choice answers, a group of people responds anonymously, and their responses are displayed in a histogram. When we raised this semblance to the teachers at the March 28, 2001 AR meeting, the following discussion ensued:

> Peter: I have a hard time (pause) distinguishing between the two.
> Vivian: It seems to me, initially, they're exactly the same…we're asking them to voice an opinion and the difference is that's where it ends on the Millionaire program, and we want to do more with it. We want to generate discussion so then we can lead the kids …
> Peter: Another thing is the type of questions. They have factoids vs. construction bricks of learning that we are trying to put together in logical sequence or build on, one after another.
> Robyn: I definitely think the A2L questions are formulated to (pause) try to get at what the thought process is vs. what the knowledge is (Transcripts, March 28, 2001 AR meeting).

The result was that the group made it explicit that what they were after with their use of PRS was to go beyond whether an answer is right or wrong to get students to engage in serious conversations about their ideas.

> Ken: …how is A2L different [from ATA]…okay, we understand this, but what does the person in the hot seat get out of this experience? If they were to face a similar question with a slight difference, they are not better prepared…these are some of things we attempt to do when using A2L is to, not only learn what the answer is to this question, but how one gets to that answer …
> Vivian: When we were talking about this last time, I had the same feeling that; first of all, [in ATA they're] focusing the question on the right answer, correct response which is often different than the A2L component where we have a lot of fuzziness that we want to generate discussion with the students (Transcripts, April 25, 2001 AR meeting).

A skillful teacher can get students to engage in serious conversations even when the items do not meet the third and fourth criteria. However, a comparison with ATA helped the teachers to see that if they were going to be able to change their students' expectation that every question has a "right answer," then items need to be constructed so that multiple conceptions get onto the floor. This concern can be seen in Peter's reasons for not using PRS towards the end of the academic year:

> Peter: I guess (pause) because I don't feel that I have really good questions this month. When someone

> mentioned…getting the right answer and that I got me to thinking, I said, well, I better just hold off to have some time to formulate good questions which is what I want to do this summer. That's going to be one of my major tasks—a whole bank of questions.

He continued,

> Peter: I just don't want to over do it…just for the sake of using the technology like a toy. I want it to have some meaning for them. I need help formulating meaningful items (Transcripts, May 16, 2001 AR meeting).

In addition to making sure that the items reside in the students' ZPD, it is necessary for the choices to *bin* the students' conceptions. The idea of binning was described to the teachers by the PI of the project. The A2L PIs have researched students' conceptions of physics and has used their knowledge of how students think about physics to construct answers that correspond to those conceptions. This can be seen in Item 0020 from A2L in Fig. 2. In the A2L *Teachers' Aids*, the correct answer is identified as #3 "as required by Newton's Third Law." But the other answers are examples of what the PI refers to as "right answer to the wrong question" (Transcripts, May 31, 2001 AR meeting). Students might choose #1 because the bowling pin is affected more than the ball, or vice versa for #2. Numbers 4 and 5 are options that the PIs provide to elicit student ideas that they had not foreseen.

The complexities of item construction can be seen in Item 0068 (Fig. 3) that seeks more than the numerical solution to a problem. In this case what students are being asked is not the answer to the problem, but rather the most efficient way to solve it. The *Teachers' Aids* state that it is most efficiently solved by noting that the radially thrown ball gains no angular momentum, so therefore it cannot affect the angular speed of the disk and child. Therefore no calculations need to be done, and hence this is the most efficient way to solve the problem.

Facilitation of Serious Discussions

As we have seen, to use A2L items and PRS successfully in the classroom, teachers must know how to use the hardware and software and must have items that they are willing and able to use. In addition, they need to know how to create the educational situations that lead to serious discussions among the students about physics concepts. When we initially developed our model, we thought of this as a technology to produce serious discussions. From additional analysis of our data, it appears that there are at least three factors that interact dialectically in order for these discussions to occur (Fig. 4). They are

1. Knowledge of a variety of ways to use PRS in the classroom;
2. Knowledge of students roles; and
3. Knowledge of pedagogy.

We look at each in turn.

Ways of Using PRS

The PIs had a clear-cut vision of how PRS would be used by teachers and for what purposes. It was to be tied to the use of the A2L items that they prepared to encourage student discussions. Teachers would then use the information supplied by the histogram and how the students talked about physics concepts for formative purposes. That is, the teachers would gain information from the use of A2L and PRS to modify their practice to help students learn. There was also an expectation that students would metacognate about their own understandings as a result of the classroom interactions. Ken described how he used PRS in his teaching:

> Ken: I think I put the most attention to categorizing different ways in which I use A2L and PRS. I came up with these five categories: pre-test; introducing new ideas; midstream formative assessment; predict and show; and review … Sometimes I use it to introduce new subjects, sometimes to review something we've just learned … sometimes in the middle of everything … (Transcripts, April 25, 2001 AR meeting).

We have already indicated that the teachers rarely used the A2L items prepared by the PIs. While we had some reason to expect this, we were surprised to learn of the multiple uses that the teachers devised for PRS in addition to what the PIs envisioned. Some of the teachers used PRS to review material before tests and exams. This included the use of assessment materials from Advanced Placement Physics exams, traditional multiple-choice questions, and the use of PRS in a quiz game format. One of the teachers used PRS for the students to prioritize those concepts they wanted to review for a test.

The teachers also discovered that the system could be used as a way to survey students about a variety of topics including their attitudes toward science, their feelings about the use of PRS, and gender issues in science.

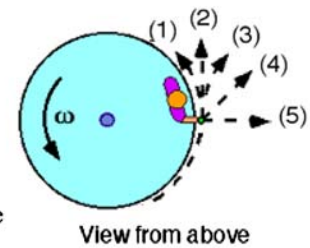
> Vivian: I got several ideas, some ways to use PRS that we hadn't tried before. One of them that stuck out in my mind…was a gender, brain gender presentation. They were talking about male–female differences in the brain and he actually had a variety of tests that put up on the overhead for different … And I thought it would lend

Fig. 3 Assessment item 0068

A2L Item 0068: A child is standing at the rim of a rotating disk holding a rock. The disk rotates without friction. The rock is thrown in the RADIAL direction [path (5)] at the instant shown. You are given:

Mass of the child
Radius of the disk
Mass of the thrown rock
Velocity of the rock
Initial angular speed of the system

You want to find the final angular speed of the disk and child.



What principle would you use to solve the problem MOST EFFICIENTLY?

1) Kinematics only
2) F= ma or Newton's laws
3) Work-Kinetic Energy theorem
4) Impulse-Momentum theorem
5) Angular Impulse-Angular Momentum theorem
6) More than one of the above
7) None of the above
8) Cannot be determined

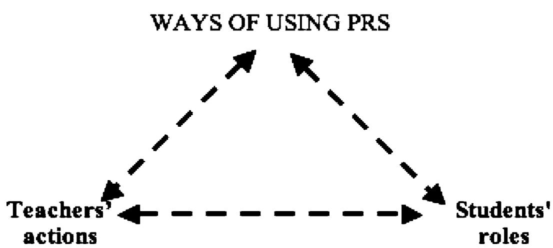


Fig. 4 Facilitation of serious discussions

> itself if you get a hold of some of those tests to kind of survey the class to see if you getting differences because you could use the "H" and the "L" button[i] for the sender to indicate whether they were male or female (Transcripts, March 28, 2001 AR meeting).
> Peter: I did [PRS] today. I wanted to find, I had two questions for my ninth graders, not much to do with physics per se…but more how they are learning…how they felt about their learning. One was learning about electricity and how they felt about it compared to other stuff we've done. … The other was how they felt about learning after they left the class…when you leave, do you always feel like you've learned something…sometimes, most of the times, few times, or never…I got pretty good feedback from that (Transcripts, May 31, 2001 AR meeting).

Student Roles

Students must take on an active role when A2L/PRS is used in the ways envisioned by the PIs. When the teachers initially began to use PRS the students saw it as a game, albeit an educational one, similar to what they see on television or when teachers use game show formats for review of factual knowledge. Their participation in the classes has also been shaped by years of being asked to complete tasks for grades and to come up with the "right" answer to teachers' questions.

> Peter: I know in our school you can't talk about what students are doing without talking about grades … [The students] were okay with the first part of the A2L cycle, where they would express their ideas at the beginning. But then after the small group discussion or after an activity, and we got into the class wide discussion then they started to grumble… "Aren't you going to tell us the right answer?" (Transcripts, March 28, 2001 AR meeting).

The teachers needed to gain the knowledge and skills to transform the classroom into one in which activities are intellectual and questions have multiple "right" answers. When this happened, students found themselves in new roles.

One of the teachers, who had been a student in a college physics course that used PRS and items similar to A2L, described her role as a student in this way:

> Robyn: … that's my vision still…what it was like to sit there and answer questions and have the classroom dynamic of student to student, discussing conflicting ideas…(pause) and really thinking aloud about what was

> going on with a situation…trying to think logically … for me as a student it was a matter of learning to trust my own reasoning and develop my own concepts, my own trust in my own understanding (Transcripts, February 26, 2001 AR meeting).

The teachers found that they needed to get the students to “play the game:”

> Vivian: Another big issue is students who choose not to participate. That’s an issue that I think needs to be addressed if you are talking to a group of teachers who are planning on using the technology (Transcripts, April 25, 2001 AR meeting).

They also found it important for the students to feel comfortable with the hardware and software, and to gain some benefit from using it:

> Ken: Kids really have to experience success or some kind of satisfaction you know. You have to set it up so they experience satisfaction out of this process early on (Transcripts, March 28, 2001 AR meeting).

As this happens the teachers with the students “build a culture within a culture” (Peter, transcripts, May 16, 2001 AR meeting) that provides the possibility for all students to engage intellectually with physics.

> Ken: Well, also the classroom dynamic has evolved to the point where I think students are a lot less reluctant to share a view even if they turn out to be wrong.
> Andy: So they are more likely to answer?
> Ken: Correct. The whole issue of anonymity has become irrelevant…we all know each other quite well and so people are not going to say, or withhold an opinion simply because they are not confident…I think that is a good thing… (Transcripts, May 16, 2001 AR meeting).
> Peter: And with the A2L approach and using a lot more than I have ever done before with small group discussions, there was a very favorable comment on my evaluation that they really liked the opportunity to sit down and talk to one another and then come back as a class and talk about what they discuss (Transcripts, June 21, 2001 AR meeting).

And, as Ken found from a survey that he administered to his students

> Ken: Twenty percent used the word, ‘fun’, in their description of PRS and quite a few used the word, ‘anonymous’, in a positive way…” what I liked about it was that is was anonymous” … 20–30% of the students pointing that out to me…the question was how would you describe PRS…and they said, “it’s great because it’s anonymous” … it allowed the students who might not speak up “and it was a good way to make me think quickly and think about the answers instead of waiting for someone else to give it” … there wasn’t peer pressure; that you were less afraid of making a mistake…it helped them to understand…it was like 30% of my students said that… (Transcripts, June 21, 2001AR meeting).

This shift in student roles does not come about by itself. Teachers need to know how to use the hardware and software, to select or develop items, and use PRS in a variety of ways that lead the students to take on these roles. It also requires them to modify their pedagogy so that discussions in the form of democratic conversations become the norm.

Teachers’ Roles

The teachers, like the students, take on new roles when PRS is used in the ways envisioned by the PIs. Peter told his students “my job is not to tell you whether you are right or wrong, that it is your job! My job is to just clarify and to make sure that we all know what you are saying…” (Transcripts, Interview #2, February 26, 2001). Several teachers told how they incorporated the new role into their regular classroom practice:

> Ken: [The questions] were mixed in with some demos and chalking and talking. I liked it where it was not the entire 60-min class was question after, question…it was integrated into and stuck in the middle (Transcripts, April 25, 2001 AR meeting).
> Erik: I decided it was going to be less of me, and more of them…active learning. I think in terms of four modes…each period there will be time for me…maybe a teacher-centered thing at the beginning of the class. Then student hands-on activity or minds-on activity…and I like students find things on their own… (Transcripts, July 14, 2001 AR meeting).

The teachers saw a number of benefits to their change in role. One is that classroom management problems were reduced. This is because the teachers attended to the students in a new way as the students’ roles changed. Robyn, who was in her first year of teaching, noticed this one of the first times that she used PRS:

> Robyn: … student behavior becomes much more obvious … The kids who are trying to distract me or are sleeping or talking with others …their behavior is not very obvious in a teacher centered structure where other students are sitting quietly, listening intently…but when I use [PRS], the difference is that there’s even groups

> that are obviously discussing the question or there are groups doing nothing or distracting others. Their behavior was just so more obvious (Transcripts, April 25, 2001 AR meeting).

Hannah, who was also a new teacher, agreed with Robyn:

> Hannah: [The PRS] helps them pay attention to what is going on. I know they are on task at that time than other times. They got to see the other side of the class. I think it was interesting for them (Transcripts, April 25, 2001 AR meeting).

Even Peter, a highly experienced teacher, noted that his students were more on task:

> Peter: [The PRS] got them, engaged and they were listening to the questions and paying attention to the histogram and talking about it. That was a real thrill to see that, you don't get that often with the lower level kids in my school. And the class dynamic does change when we bring the remotes out, they do become more interested. If I look at their faces, when I'm just explaining something to them, I can see them tuning out and not listening and I'll ask questions to those not paying attention. But with the remotes, there's almost 100% participation…and they all know what the question was (Transcripts, May 16, 2001 AR meeting).

The teachers also found that by changing their roles in the classroom they made their classes more equitable and increased the accessibility of the physics concepts.

> Robyn: I have a lot of international students and it gives them an opportunity to speak more in a situation where they are not speaking to the whole class (Transcripts, April 25, 2001 AR meeting).
>
> Hannah: Another thing is looking at how communicative my students are in using A2L. I think it really improved relationships and drew them out and may actually be a good tool for a novice teacher in building a relationship with their kids. If they get trust with A2L, you get info from them…additional info from more students in a short time…I think it's just a good idea (Transcripts, April 25, 2001 AR meeting).

Ken saw the way that PRS allowed more students to participate in classes:

> Ken: Just getting back to the value added…the idea of accessibility and that it provides an opportunity for more different students to participate in a way that they in that kind of classroom environment, participate differently or might not participate (Transcripts, June 21, 2001 AR meeting).

The teachers had two main problems when shifting to their new roles. The first was that if they were not working within the students' zone of proximal development (ZPD) (Vygotsky 1978), For example, Hannah told us how three or four students in her class were saying that the work was too hard and were even yelling at her because of their frustration (Transcripts, February 26, 2001 AR meeting). Vivian responded to her "I think the confidence issue is big. I think you have to validate students thinking at the right time. Get them at a place where they feel comfortable in a discussion and voicing their own ideas" (Transcripts, February 26, 2001 AR meeting). She reiterated this at the next meeting:

> Vivian: Are the kids who you feel are not really participating—especially the kids who don't normally raise their hands? Is it an issue of shyness in the class? Then that's one of the things you really need to set the stage for when using this type of technique that their comfort level is such that they feel okay about expressing an idea. Because then you can either sort of ask them, maybe to explain, maybe not what they voted for but maybe say, could you tell us why someone might have chosen A. (Transcripts, March 28, 2001 AR meeting).

The second problem came up when the novelty of using the hardware and software wore off, as Peter noted toward the end of the school year:

> Peter: it's getting harder and harder to keep the kids on task in terms of discussions, small group work, focusing on the question and then coming back together and letting them lead the class-wide discussion. It's getting kind of difficult. But we're forging. (Transcripts, May 16, 2001 AR meeting).

This was even a problem for the most experienced PRS users, especially toward the end of the year when "senioritis" is in full bloom:

> Ken: I've actually found at this point in the year what I feel the students want and need has pulled me away from using the transmitters because I'm not doing whole classes that are built around A2L formative assessment, instead built more around either demos or short lectures and the questions are sort of interspersed and as a result I am doing it more informally where I'll just ask a question spontaneously or respond to a student question…take a poll just by a show of hands and write several answers on the board and then ask them to take a vote. I've reached the point that there is a sort of shift in the class. They weren't really highly engage as much as more. To keep them actively engaged right now, they

need something really directive and concrete. (Transcripts, May 16, 2001 AR meeting).

During the summer workshop for new teachers, Vivian reiterated her approach to solve these problems:

> Vivian: No matter what techniques you have, you sort of have to set the stage. Nothing works like when you put it together and come in and throw it up. You really have to prepare the environment (Field notes, July 14, 2001).

Learning to teach with PRS required the teachers to learn a complex technology consisting of a variety of ways to use the hardware and software, helping to create new roles for students, and to take on new roles as teachers. But there is one more technology that the teachers needed to master—how to fit their use of PRS and FA into their curricula.

Fitting into Curricula

At the end of the first year of the FAAR group activities it was how to fit the use of PRS and A2L into their own curricula that was most problematic for the teachers. This was true for all, novice or experienced. This is not surprising given that the use of PRS and of A2L items is not an integral part of any comprehensive set of curricula materials. In addition, its use is not the "default mode" for any of the teachers. For example, if the teacher was not as well prepared for the lesson as he or she would have preferred, it was unlikely that he or she would reach for PRS as a way to make use of the time. For that to happen all of the other technologies would need to be mastered. The hardware and software would need to be up and running for every class, the teachers would need to have appropriate materials for any if not every lesson, and they would need to know how to teach with PRS in a wide variety of instructional settings. Both of these reasons were evident when we asked the teachers to complete the sentence, "I would be more successful in using A2L/PRS if …" (see Table 1).

There was one other factor that we noted in how the teachers fit PRS and A2L into their curricula. Several of the teachers used materials from curriculum projects that they had been involved with in the past. Ken had worked with the PIs on a previous high school physics curriculum project (Leonard et al. 1999) and tended to use those materials with PRS. However, because most of those materials concentrated on mechanics he had little to work with in other domains of physics knowledge. Peter had been heavily involved in a project that made extensive use of hands-on activities to engender conceptual understanding of electricity (Steinberg and Wainwright 2002). He often spoke about those materials and struggled with how he could combine them with PRS and A2L. Vivian was part of a group that developed methods to help students change their conceptions of physics through analogies (Camp and Clement 1994). She often used the language of that project to describe her use of PRS and A2L, and she used the methods of that project to encourage classroom discussions.

Conclusion

In this study we sought to understand if and how FA becomes an integral part of a teacher's practice. Our data suggests several answers to these questions. First, it takes a considerable amount of time for teachers to change their ways of being so that FA becomes an integral part of their practice. While we are reluctant to propose a stage theory, it is clear that the teachers we worked with have had to progress from novice to expert in each of the technologies that we describe above. Second, it is possible to be expert in various combinations of the technologies without having expertise in FA. For example, although all of the teachers interviewed in 1999–2000 were at ease with the hardware and software, they had different levels of expertise in the

Table 1 Teachers' responses to "I would be more successful in using A2L/PRS if …"

Ken	The hardware and software was up and running and ready to go at all times; the clock (timer) was more prominently displayed on the screen; and students/parents were not so obsessed with grades!
Erik	New and more items—both developed by UMPERG and high school teachers and opportunity to test these. Time to do this—writing and developing items and to then process results; and time in class to do this—while not sacrificing something else. A possible solution to the time issue involves restructuring the way I integrate the techniques into classroom setting.
Vivian	…I had a adequate planning time to formulate items that are appropriate to my curriculum during the school year (during the teaching day) when the ideas are fresh; …also time built into the school day for colleague collaboration concerning curriculum enhancement.
Peter	I was more confident in the item construction and I was more certain that the PRS was contributing to the learning/thinking of my students and if I were more certain that the items were engaging my students and if I used the material more routinely and more frequently.

construction of assessment items and in the ability to use the formative information to modify their teaching. Third, the teachers' conceptual understanding of FA grew as they developed expertise in the four technologies to use PRS and assessment items in their teaching, and engaged in the process of enhanced normal practice with their colleagues through collaborative AR.

The latter finding suggests that a complex interaction among a host of different ways to learn, are needed for teachers to integrate FA into their practice. The teachers who have taken part in this study have engaged in "long and serious conversations" (Feldman, 1999) with their colleagues and us; they have read articles from research and practitioner journals about FA; they have engaged in the practice of FA; and they have had an opportunity to see themselves teach through our eyes in observation reports that we shared with them.

What we have learned is that for these teachers to make FA an integral part of their practice using PRS, they must engage in (or participate with) the four technologies that we outlined above. In addition, we found that it is necessary for teachers to come to a conceptual understanding of the nature of FA. While it may be possible that traditional training and teaching methods may enable teachers to gain these skills and knowledge, a large body of research has shown that there is little likelihood that their teaching will change in the desired manner (Bransford et al. 1999). This suggests that the teachers' participation in AR over a 2-year period provided them with the opportunity to talk with their colleagues about the decisions that they made about their practice and why, and to discuss with them the experiences that they had with the effects of the choices that they made. Action research also provided them with the opportunity to inquire collaboratively into shared problems, dilemmas, and dissonances of practice. We believe that this had aided the teachers in their efforts to construct educational situations that are similar to those espoused by the PIs of the project and are more able to construct their own understanding of what is meant by FA.

We end by returning to how we began this article—the review of the studies that identified barriers to teachers' implementation of instructional technology (IT) into their practice. Those barriers included limits to the number of computers in classrooms, teachers' lack of expertise in using IT, the "cellular" nature of schools, and teachers' beliefs about teaching and their students. While it should be clear from our analysis that these barriers played a part in how the teachers implemented PRS and A2L, we believe that our model, which identifies what teachers need to learn and master rather than identify what stands in their way, provides a framework for a richer understanding of teacher learning of new instructional technology.

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