# Supporting Teachers Using Palm Computers: Examining Classroom Practice over Time

Richard Vath [1]

[1] Center for Highly Interactive Classrooms, Curricula, and Computing in Education,
University of Michigan
610 E. University, Ann Arbor, MI 48109
Tel: 734-764-2839, Fax: 734-763-1504
Email: vathrich@umich.edu

William Bobrowsky [1], Elliot Soloway [1], Phyllis Blumenfeld [1], Joseph Krajcik [1]
Alycia Meriweather [2], Paula Sarratt [2], Sylvia Wise [2]

[2] Detroit Public Schools

***Keywords:*** *handhelds, science education, urban reform, professional development, ubiquitous computing*

## Abstract

To meet the recent demand for reform in science education (NRC, 1996; AAAS, 1993), the Center for Highly Interactive Classrooms, Curricula, Computing in Education (hi-ce) at the University of Michigan has created inquiry-based, technology-infused curriculum at the middle-school level designed to help teachers engage in best practices in science teaching (Singer et al., 2000). Hi-ce is presently engaged in research that is attempting to understand how solving the problem of student access (Becker, 2000; Norris & Soloway, 2003) to handheld computers affects teacher practice and student achievement in science in urban middle schools. The research question addressed in this paper is: In what ways does 1:1 student access to handheld technology affect teacher practice in inquiry-based science curricula? In general, we found that teacher practice was affected in three ways: (1) in how teachers introduced and supported the *technology*; (2) in how teachers *managed* student use of the technology within the classroom; and (3) in how teachers provided *instruction* for students as they used the technology as learning tools. Based on our findings, we provide two recommendations for professional developers and practitioners interested in using ubiquitous handheld technology in science classrooms.

## Introduction

Recent work suggests that the use of computing technologies can lead to learning gains in K-12 science classrooms (Honey, Culp, & Carrigg, 2000; Krajcik et al., 2000; Krajcik & Starr, 2001; Norris & Soloway, 2003; Roschelle & Pea, 2002). However, to realize those gains, certain conditions must be in place within schools and classrooms to foster optimal use of those technologies. Primary among these conditions are *access*, *usability*, and *alignment*:

- Access – Paramount to the rationale for how computing technologies can lead to student learning gains is the condition that students have convenient and sustained access to the technology (Soloway et al., 2001; Roschelle & Pea, 2002). However, a range of national and statewide studies is showing that students do not have adequate access to technology in terms of resources (Anderson & Becker, 2001;

- Anderson & Ronnkvist, 1999; National Center for Educational Statistics, 1999;) and time (Becker, 2000; Norris & Soloway, 2003).
- <u>Usability</u> – In addition to having access, students need to be able to use computing technologies easily and with little sustained teacher support in order to capitalize on learning benefits (Luchini, Oehler, Quintana, Soloway, 2001; Soloway et al., 2001).
- <u>Alignment</u> – Finally, student use of computing technologies is most successful in yielding learning benefits when such use supports skills and thinking that are aligned with curricular goals and learning standards (CEO Forum on Education and Technology, 1999; Ertmer, 1999; Luchini, Oehler, Quintana, Soloway, 2001). As such, the technology should be designed to support students as they engage in specific instructional tasks that are part of a standards-based curriculum. In addition, the curriculum should be designed to support teachers in how to effectively use the technology in conjunction with the instructional tasks. This is essential for successful technology adoption because, as Cuban (1993) has argued, teachers are generally more willing to use technology in their classrooms if they are provided support for understanding how and when it might be used.

Researchers in the Center for Highly Interactive Classrooms, Curricula, and Computing in Education (hi-ce) at the University of Michigan have been working to ensure that these conditions are met. We are exploring the use of ubiquitous handheld computing devices (Palm ® m130s) in classrooms engaged in project-based science. The effort is part of a district-wide science reform initiative. Specifically, we argue that palm-size computing devices can address the above conditions in the following ways:

- *Access* – By taking advantage of low-cost ($100 approximately), portable computing devices, such as Palm handhelds, we can provide a 1:1 ratio of students to computing device.
- *Usability* – Palm handhelds, when compared to desktop and laptop computing devices, require significantly less maintenance and are easier to use and operate by students and teachers in classrooms because of their simpler architecture and size. In addition, hi-ce has developed a suite of software applications designed for ease of use and flexible use across learning domains and activities.
- *Alignment* – The hi-ce suite of software applications was also designed to support specific learning tasks present in the standards-based, inquiry-focused science curricula that have been developed collaboratively by University of Michigan researchers and administrators and teachers in the Detroit Public School system. Additional collaborative efforts between University of Michigan researchers and the Detroit Public teachers participating in this current study have yielded modifications to those curriculum materials to further take advantage of ubiquitous handheld computer use in the science classrooms.

In addition to addressing the above conditions, we also recognize the importance of providing professional development support for teachers as they use handheld computers for the first time. The research literature suggests that teachers tend to experience many of the same kinds of issues and challenges over time across a variety of technology adoption programs (CEO Forum on Education and Technology, 1999; Dwyer, Ringstaff, & Sandholtz, 1991; Yamagata-Lynch, 2003). However, we suggest that the issues and challenges faced by teachers in their classroom practice may be *unique* in a classroom with 1:1 student access to handheld technology. As such, we believe that professional development designed to support pedagogical content knowledge (PCK) of technology on the part of teachers (Margerum-Leys & Marx, 2002) by centering on collaborative discourse around problems of practice (Loucks-Horsley & Matsumoto, 1999; Marx et al., 1998) will provide teachers with opportunities to better understand these issues and challenges and, in turn, help them transform their classroom practice. However, as of yet we know very little about how teacher practices change over time in classrooms that provide students access to ubiquitous computing. In our current research project, we are examining these changing classroom practices within the context of sustained professional development support. Our driving research question addressed in this paper is: In what ways does 1:1 student access to handheld technology affect teacher practice in inquiry-based science curricula? By framing our work around this question, we believe we will make contributions to the as-of-now limited body of literature on ubiquitous handheld technology in classrooms.

## Research Context

### Background

Our work on the Palm Project is situated within a larger partnership between the Detroit Public School District and hi-ce at the University of Michigan. The broad goal of this partnership has been to work collaboratively in developing technology-rich inquiry science curricula to be used by teachers and students in the urban schools. These curricula have been designed using the principles of project-based science (Krajcik, Blumenfeld, Marx, & Soloway, 2000; Singer, Marx, Krajcik & Clay-Chambers, 2000) to support national science education standards (AAAS, 1993; NRC, 1996) as well as to address the needs of diverse students with respect to culture, race, and gender (Atwater, 2000). This work has been supported by broad-based professional development activities (Fishman, Best, Foster, & Marx, 2000), including intensive summer institutes, monthly Saturday workshops, and interaction with on-line materials (Brunvand, Fishman, & Marx, 2003).

### Setting and Participants

The aim of our work with handhelds (a.k.a., the "Palm Project") is to investigate how student use of palm-sized computers, equipped with appropriate software applications for science inquiry in middle school, influences learning science content and science attitudes. The setting for this investigation is in three classrooms from three different middle schools that are part of a large, urban school district where the majority of students are African American or Hispanic and more than half are below the poverty level. The three participating teachers (all female, with middle-school science teaching experience ranging from 2 to 10 years) were chosen based on the recommendations of the district's Math & Science Coordinator. The criteria for recommendation were: (1) past success with hi-ce curriculum; (2) active participation in hi-ce /Detroit Public Schools collaboration (i.e., consistent attendance and involvement in professional development activities); and (3) interest in using technology in their classrooms.

Project-Based Curriculum

In this study, the three middle school teachers enacted four project-based units as part of the 7th grade sequence over the course of the 2003-2004 and 2004-2005 school years. The units were:

- **Air Chemistry**: This project engages students in an extended inquiry into the question "What affects the quality of air in my community?" Learners develop an integrated understanding of science concepts such as composition of air, states of matter, chemical change, acids and bases, and the particulate nature of matter. Students use a variety of technologies in all the units including modeling & simulation software, and digital library resources.
- **Stuff**: This project explores the driving question: "How can I make new stuff from old stuff?" Throughout the unit, students develop an understanding of such chemistry concepts as substances, properties of substances, how substances interact to form new substances (i.e. chemical reactions), and conservation of mass. Throughout the unit, students develop several evidence-based explanations based upon data they collect.
- **Communicable Diseases**: This project explores the driving question: "How can good friends make me sick?" Throughout this unit, students learn the biology behind communicable diseases, including body systems, cell biology disease transmission, and the social interactions that constitute risky behavior for a variety of diseases.
- **Water ecology**: This project engages students in an extended inquiry into the driving question: "What is the quality of water in our river?" Learners build their understanding of watersheds, rivers, biodiversity, macroinvertebrates, bio-indicators, topography, and conduct various water quality tests, such as fecal chloroform, pH, and dissolved oxygen.

Curriculum Modification

The participating teachers and University of Michigan researchers worked in collaboration to modify these existing curriculum units to take advantage of the ubiquitous palm handhelds. Researchers and teachers developed a preliminary plan for modifying the curricula for palm use, and this plan was revised and expanded based on classroom experiences over the course of the project during professional development meetings.

Hi-ce Software

In order to capitalize on the 1:1 access that students had to the handhelds, teachers and researchers worked to create opportunities for the students to use the handhelds for *every* lesson in every unit (i.e., students would be using the handhelds daily in the way that students use pencil and paper). A suite of software applications for Palm handhelds has been developed to support the learning goals set forth in the curricula (http://hi-ce.org/palms). They include:

- **FreeWrite**: A text processor that includes a spellchecker, the ability to easily format documents, and the capability to exchange text documents with other palm handhelds (via beaming).
- **PicoMap**: A tool to support (via built-in scaffolds) students in creating and sharing organized flow-charts and concept maps.
- **Sketchy**: A drawing tool that enables children to easily create animations.
- **Chemation**: A tool to support students in representing and creating chemical bonding and chemical reactions (includes animation feature).
- **Cooties**: An interactive simulation that allows students to better understand how viruses and germs are spread. Using the infrared beaming on a Palm computer, children "meet" each other and transmit either a germ-laden or a germ-free message from one Palm to the other. Once challenge, then, is to identify who was the initial carrier.
- **Palm Archive and Application Manager** (PAAM): A desktop and server synchronization application that allows teachers and researchers to manage the various artifacts created by students using the previously listed handheld applications.

Professional Development

In our project, we have provided continual professional development support for our participating teachers in the form of summer workshops and biweekly meetings throughout both years of enactment. Though we anticipated that the professional development needs of the teachers would be unique given the context (i.e., 1:1 student access within a standards-based science program), we designed our professional development support to be congruent with the recommendations extant in the literature on PD and technology use. Throughout our project, we documented the ways in which the teachers experienced these adoption challenges as well as the kinds of strategies that were introduced and negotiated to address these challenges within the context of professional development.

## Methods

Data Sources

We observed each classroom at least four times per unit during each year of enactment, for a total of 16 observations per year (about 9% of the year's 180 teaching days). Our observations were distributed across the units so as to capture a range of different activities and corresponding uses of the handheld tools. During each observation, researchers took annotated notes to document issues related to classroom practice. The notes included information about lesson content, task setup and support, tool use and support, and management and/or technology issues or challenges. In addition, annotated records from our biweekly professional development meetings were also used as primary data. These records included information about the successes and challenges that teachers experienced over the course of enactment as well as the strategies that were developed to address the challenges.

## Data Analysis

The annotated notes were examined for patterns both between and among teachers relating to their classroom practice experiences. In particular, we analyzed the notes according to a set of broad categories and subcategories (see Table 1) that we developed in light of the technology adoption literature (e.g., CEO Forum on Education and Technology, 1999; Dwyer et al., 1991; Yamagata-Lynch, 2003) as well as our previous work with handhelds in classrooms (Bobrowsky, Curtis, Luchini, Quintana, Soloway, 2002; Curtis, Luchini, Bobrowsky, Quintana, Soloway, 2003).

***Table 1: Analysis Categories***

| CATEGORIES | SUBCATEGORIES | DEFINITIONS |
|---|---|---|
| **(1) Technology** | (1a) Introduction | Experiences related to introducing Palm devices to students in terms of basic operation, program function, and general device care.<br><br>*Example: How to use stylus, how to charge and sync, how to use Graffiti, or how to beam documents in FreeWrite* |
| | (1b) Infrastructure | Experiences related to setting up classroom/classroom computers for syncing, keyboard use, etc.<br><br>*Example: Deciding which computers will be used for student syncing and making sure that they have appropriate software and internet access* |
| | (1c) Troubleshooting | Experiences related to dealing with technology problems as they come up during classroom enactment over the course of the year.<br><br>*Example: If student has trouble writing in Graffiti, (1) recalibrate digitizer, (2) hard-reset Palm, (3) exchange Palms with student for remainder of lesson, be sure to have them beam documents to Artifact Palm at end of class* |

| | | |
|---|---|---|
| **(2) Management** | (2a) Distribution | Experiences related to distributing & retrieving Palms, charging/syncing cradles, and keyboards to and from students. Also refers to the distribution of software, whether that's new programs or specific files (i.e., FreeWrite documents with journal topics/agendas)<br><br>*Example: Use Palms in class only until students pass a Graffiti benchmark* |
| | (2b) Maintenance | Experiences related to Palm upkeep – syncing schedules, recalibrating schedules.<br><br>*Example: Students will be assigned syncing days based on seating/alphabetically* |
| | (2c) Discipline | Experiences related to student misuse of Palms, both inappropriate use outside of class and in class.<br><br>*Example: Students beam notes to each other, or students use Sketchy to draw inappropriate images and share* |
| | (2d) Policy | Experiences related to the replacement of damaged or lost palms, including potential disciplinary consequences.<br><br>*Example: Students will only get 1 replacement Palm after loss or accidental damage, or students will be required to attend a Palm Care Class after forgetting Palms at home or in other classrooms or for playing games at inappropriate times* |
| **(3) Instruction** | (3a) Task Design | Experiences related to the design of a Palm-related classroom task.<br><br>*Example: Talk about having the students use Sketchy to draw some observations during a candle experiment during the AIR unit* |
| | (3b) Task Enactment | Experiences related to the specific enactment steps of a Palm-related classroom task.<br><br>*Examples: (1) Talk about how to introduce what an observation is during an experiment; (2) talk about how to demonstrate an example Sketchy drawing using the FlexCam while modeling what it means to observe. Modeling involves identifying for students what kinds of things are important for them to take note of, and what are not, given a particular investigation.* |

## Findings

We developed a series of descriptive summaries using the previously described categories that highlight the major changes in classroom practice experienced by our participating teachers over the course of our 2-year project. We also developed three composite case examples to portray the teachers' classroom experiences in more detail. These examples are presented as individual teachers stories (using the aliases of *Mary, Tania,* and *Jasmine*), however they indicate experiences that were common across the three participating teachers. The descriptive summaries and case examples are presented below.

## Overview of Changes in Classroom Practice

### *Technology Experiences*

During year one of our project (Fall 2003 – Spring 2004), the teachers experienced several technology-related challenges in the course of their practice that persisted throughout the year. Among these were struggles to maintain a sufficient "infrastructure" of support for classroom use (e.g., successful use of PAAM archiving system, or maintaining keyboard software on all devices) and the challenge of providing sufficient and timely troubleshooting support for students as they used the palms in class (e.g., digitizing problems with multiple palms). We compiled strategies to address these challenges in our professional development meetings, and these strategies proved helpful during our second year of enactment (Fall 2004 – Spring 2005). Though some technology challenges persisted during year two (e.g., hardware problems with digitizers and batteries), the teachers were generally much more savvy and adaptive which created space for a greater focus on management and instruction.

### *Management Experiences*

The teachers also experienced a number of management-related challenges during the first part of year one (Fall 2003). Among these were problems of discipline (e.g., managing appropriate use of games) and policy (e.g., negotiating a plan for dealing with lost, stolen, or damaged palms). Generating strategies to address these challenges proved more difficult than addressing the technology challenges, though by the start of year two we had negotiated successful strategies that allowed the teachers to provide a greater focus on instruction and less of a focus on management (see Story Two below).

### *Instruction Experiences*

The demands of addressing the technology- and management-related challenges that arose during the first part of year one made it difficult for teachers to focus energy on instructional issues during that time. However, during the spring of year one and throughout year two, teacher focus moved away from managing the devices towards providing greater support for students (see Story Three below). In doing so, the teachers provided the students with more time and better feedback as they used the handhelds to engage in learning tasks.

## Individual Teacher Experiences

### *Story One: Introducing students to the Palm handheld*

Mary introduced the palms in her classroom in October, more than a month into the school year. Palms were engraved with numbers and included the software students would use. Mary's students quickly learned to use graffiti, but would often resort to using the internal keyboard against her wishes. Mary's students also began to have trouble tapping certain places on the screen and would proceed to tap harder and harder with their styli, eventually damaging the screen. Mary, having little experience, often did not know how to troubleshoot these problems when they arose. In such cases, she would have her students do their work on pencil and paper until a researcher was available. By the end of year one, about half the palms returned to hi-ce had some kind of digitizing problem. Also during this year, Mary was still familiarizing herself with the various applications and their features even as she was asking the students to use them in their work. Being new to this technology, Mary struggled during her first year of enactment with understanding the nuances of using these devices and software.

There were a number of changes in Mary's practice as she began year two, coming both from her greater knowledge of the palm and the group's combined experiences over the last year. The most important early change for Mary was her new emphasis on students treating the palm "right" - by taking care not to drop it and being gentle with the stylus on the screen, by keeping it charged up, and by digitizing regularly. Student ability to use graffiti for all writing throughout the year was made a priority in Mary's class. After using the software daily over the course of year one, Mary understood the software and was able to make better decisions in teaching students how to use it. Mary became proficient at using the software herself, and was now skillful at showing her students how to use it. All of the above changes proved to bear fruit in terms of palm longevity as well as student efficiency in using software and data input. By the end of year two, we expect only about 20% of palms to have some kind of problem upon return.

*Story Two: Use of "Palm Sytations" for infractions*

Over the course of the first year, Tania experienced various issues regarding student palm use. Early in the year, before students had become proficient with graffiti writing, some would use the internal keyboard to do their writing. As a result, when the writing workload became heavier, the students struggled to keep up because their graffiti skills were not what they needed to be. Some students were forgetful with their palms and would leave them at home, or remember to bring them, but almost out of battery power. Every once in awhile, a student would leave his palm in another classroom, or would accidentally drop it. All of these examples were counterproductive to what Tania was hoping to achieve in her classroom. During the first year, she would talk with students who committed one of the above infractions, trying to get them to do the right thing. Often this was successful. Sometimes, stronger incentives were needed. For a couple of students, their palm privileges were revoked, forcing them to use paper. This tiered consequence system worked for some students, but not as well as Tania had hoped. She wanted a better system to deal with these types of situations. Our palm teacher group thought about this issue, which was one they were all experiencing, and came up with an ingenious solution.

Tania started year two with a system of "Palm Sytations" (a play on words regarding "syncing" or synchronizing palm handhelds) that were like traffic tickets presented to you when you did something that was "against the spirit of using the palms in class." The sytation was a 4-part carbonless form where the student themselves would fill out what infraction they had committed, keep the top copy, and return the remaining three to the teacher. If that student was a recidivist and committed another infraction, he would repeat the process with the same set of forms, returning the remaining two to the teacher. Students took this very seriously, seeing it as an organized attempt to help them be better students. Past infractions were there to see as a student was filling out the second layer of the form. In class, it became a big deal to be issued a sytation, and students did their best to avoid being "called out" in front of their classmates. In fact, only one student received all four sytations. As a result, there were substantially fewer problems with forgetfulness, poor palm treatment, and graffiti use. Most importantly, student privileges were revoked much less often, giving students more opportunity to use the technology.

*Story Three: Use of concept mapping over the course of year one*

In the beginning of year one, Jasmine included opportunities for students to show what they knew about air quality in the form of concept maps using PicoMap done three times during the 8 week unit. Concepts maps are considered to be an important assessment opportunity for students within the units. At that time, our professional development working group of teachers and researchers did not discuss an instructional strategy or discuss how to score the maps for assessment purposes. Jasmine, not having much experience using concept maps or the PicoMap software, enacted the mapping lessons as best as she knew how. After looking over the first two sets of maps, it became obvious to all of us in our group that more attention was needed to provide students with appropriate scaffolding to create better, more representative, maps. For example, students in Jasmine's class were unsure how to show proper relationships among similar concepts, didn't understand the idea of hierarchy, and struggled with using appropriate linking words. The working group then decided to create guidelines for constructing concept maps (using Novak & Gowin's (1984) and Ruiz-Primo & Shavelson's (1996) work on concept mapping) as well as a feedback sheet to provide students when revising their maps. The information provided by Jasmine in the feedback sheets allowed her students to take advantage of the ability to easily revise concepts, links, and relationships in PicoMap. Following the new guidelines, Jasmine's enactment of concept mapping lessons greatly improved and, as a result, the quality of students' concept maps improved.

**Discussion**

In an effort to represent the classroom practice and professional development experiences of both the teachers and ourselves during the first two years of our project, we offer two broad assertions and recommendations about what it takes to successfully support the use of ubiquitous technology in inquiry science classrooms. It is our hope that these recommendations can inform both providers of professional development support for teachers interested in adopting such technology as well as for the teachers themselves:

*(1) Teachers using ubiquitous handheld computers daily in the classroom for the first time face serious technology and management challenges and as such have substantial professional development needs.*

Even if teachers are oriented towards thinking about and using handhelds as learning tools, the technology and management concerns make serious focus on such things difficult during the early phases of adoption. Furthermore, these technology and management issues might eclipse in the teachers' minds other pedagogical issues around using the technology that arose during the course of classroom practice. Finally, even though we anticipated these needs in our efforts to plan out our professional development, we did not anticipate how much daily, sustained use would magnify the salience of these issues for the teachers.

- Recommendation: Professional development for using ubiquitous handheld computers should have a sustained focus on technology and management issues during the first year (and perhaps beyond). However, the providers of professional development must also recognize that these issues may overshadow issues of using the technology as learning tools.

*(2) Teachers using ubiquitous handheld computers need specific professional development support around pedagogical issues in addition to technology and management support in order to sustain frequent and daily use.*

In addition to being overwhelmed by technology and management concerns, teachers needed assurance that using the technology could provide a learning benefit for students. This is consistent with what Dwyer, Ringstaff, & Sandholtz (1991) found about teacher apprehension during the early stages of technology adoption. Teachers also are more likely to adopt the technology if they are given support in how such technology can be used in instruction (Cuban, 1993). In our PD efforts, we were more successful in addressing the above issues when we framed our discussion of palm use around pedagogically-sound practices for specific instructional tasks (e.g., concept mapping). In other words, we began with discussions of the principles of good concept mapping, and how to introduce students to this task. Afterwards we connected the details of how to use the tool to better support students in the task.

- Recommendation: Professional development for using ubiquitous handheld computers should frame support around specific pedagogical practices that are part of the curriculum. In addition, this support should happen in parallel (that is, concurrently in time through the PD sequence) to the support around technology and management so that teachers can confront their apprehension about ubiquitous technology as they are faced with the other classroom challenges.

Schools continue to invest in technology, but it is unlikely that they will soon provide 1:1 access for students using the desktop or laptop as the model purchase. Our work in the Palm Project illustrates some of the challenges, as well as some solutions, that arise for teachers in classrooms with 1:1 student access to handheld technology. We believe that there is great potential for meaningful use of handheld technologies in science classrooms, but that success depends on teachers' understanding of how to use the technology as learning tools in ways that are consistent with classroom learning goals and science standards, and of how to change their classroom practices accordingly. We also believe that the changes in classroom practices that our teachers experienced - such as moving away from a focus on how to use the handheld tools towards a focus on how to engage students in meaningful tasks – happened as a direct consequence of the handhelds being ubiquitous, and as a result of the reflection opportunities provided for the teachers through professional development.

**REFERENCES**

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy, Project 2061*. New York: Oxford University Press.

Anderson, R. E. & Becker, H. J. (2001). *Teaching, learning, and computing: 1998 national survey*. Report #8. Irvine, CA: Center for Research on Information Technology and Organizations; and Minneapolis, MN: University of Minnesota.

Anderson, R., & Ronnkvist, A. (1999). *The presence of computers in American schools*. Irvine, CA: Center for Research on Information Technology and Organizations.

Atwater, M. M. (2000). Multicultural science education. *Science Teacher, 67*(1), 48-49.

Becker, H. J. (2000) "Who's Wired and Who's Not," in *The Future of Children*: David and Lucile Packard Foundation, 2000.

Bobrowsky, W., Curtis, M., Luchini, K., Quintana, C., & Soloway, E. (2002, October). *Exploring the affordances of handheld computers: Helping teachers engage in best practice*. Presented poster at the meeting of the International Conference of the Learning Sciences, Seattle, WA.

Brunvand, S., Fishman, B., & Marx, R. (2003, April). Moving professional development online: Meeting the needs and expectations of all teachers. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL.

CEO Forum on Education and Technology. (1999). *Professional development: A link to better learning (Year Two Report)*. Washington, DC: CEO Forum on Education and Technology. Madison, WI: National Center for Improving Science Education.

Cuban, L. (1993). Computers meet classroom: classroom wins. *Teachers College Record, 95*(2), 185-210.

Curtis, M., Luchini, K., Bobrowsky, W., Quintana, C., & Soloway, E. (2003). Handheld use in K-12: A descriptive account. *MSTA Journal, 48*(1) 21-29.

Dwyer, D. C., Ringstaff, C., & Sandholtz, J. H. (1991, May). Changes in teachers' beliefs and practices in technology-rich classrooms. Educational Leadership, 45–52.

Ertmer, P. A. (1999). Addressing first- and second- order barriers to change: strategies for technology integration. *Education Technology Research and Development, 47*(4), 47-61.

Fishman, B., Best, S., Foster, J., & Marx, R. (2000, April). Fostering teacher learning in systemic reform: A design proposal for developing professional development. New Orleans, LA: National Association of Research in Science Teaching.

Honey, M., Culp, K. M., & Carrigg, F. (2000). Perspectives on technology and education research: Lessons from the past and present. *Journal of Educational Computing Research, 23*(1), 5-14.

Krajcik, J., Blumenfeld, P., Marx, R., & Soloway, E. (2000). Instructional, curricular, and technological supports for inquiry in science classrooms. In J. Minstrell & E. H. v. Zee (Eds.), *Inquiring into inquiry learning and teaching in science* (pp. 283-315). Washington, D.C.: American Association for the Advancement of Science.

Krajcik, J. & Starr, M. (2001). Learning Science Content in a Project-based Environment In Tinker, R., & Krajcik, J.S. (Eds), *Portable Technologies: Science Learning in Context*, Netherlands: Kluwer Publishers.

Loucks-Horsley, S., & Matsumoto, C. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics, 99*(5), 258-271.
Luchini, K., Oehler, P., Quintana, C., & Soloway, E. (2001). An Engineering Process for Constructing Scaffolded Work Environments to Support Student Inquiry: A Case Study in History. In T. Okamoto, R. Hartley, Kinshuk & J. P. Klus (Eds.) Proceedings of IEEE International Conference on Advanced Learning Technologies (ICALT2001) (August 6-8,2001, Madison, WI, USA), Los Alamitos, CA: IEEE Computer Society, 55-56.
Margerum-Leys, J. & Marx, R. M. (2002). Teacher knowledge of educational technology: a case study of student/mentor teacher pairs. *Journal of Educational Computing Research, 26*(4), 427-462.
Marx, R. W., Blumenfeld, P., Krajcik, J. S., & Soloway, E. (1998). New technologies for teacher professional development. *Teaching and Teacher Education, 14*(1), 33-52.
National Center for Education Statistics. (1999). Internet access in public schools and classrooms. Washington, DC: U.S. Department of Education.
National Research Council. (1996). The national science education standards. Washington, DC: National Academy Press.
Norris, C., & Soloway, E. (2003). The viable alternative: Handhelds. *School Administrator, 60*(4), 26-28.
Novak, J. & Gowin, D. B. (1984). *Learning how to learn*. New York, Cambridge University Press.
Roschelle, J., & Pea, R. (2002). Awalk on the WILD side: How wireless handhelds may change CSCL. *Proceedings of the Annual conference of Computer Supported Collaborative Learning*, Boulder, CO January 7-11.
Ruiz-Primo, M. A. & Shavelson, R. J. (1996). Problems and issues in the use of concept maps in science assessment. *Journal of Research in Science Teaching 33*(6): 569-600.
Singer, J., Marx, R. W., Krajcik, J. S., & Clay-Chambers, J. (2000). Constructing extended inquiry projects: Curriculum materials for science education reform. *Educational Psychologist, 35*(3), 165-178.
Soloway, E., Norris, C., Blumenfeld, P., Fishman, B., Krajcik, J., and Marx, R. (2001). Handheld Devices are Ready-at-Hand, *Communications of the ACM, 44,* 15-20.
Yamagata-Lynch, L. C. (2003). How a technology professional development program fits into teachers' work life. *Teaching and Teacher Education, 19*(6), 591-607.