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Probeware and Handhelds in Elementary and Middle School Science

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This paper reports a test on the feasibility and educational value of probeware and associated instructional materials in middle school science education. We addressed feasibility through consideration of costs, teacher professional development, and instructional design. In order to test our approach, we developed 2 middle school science curriculum units, 6 low-cost probes that interface between handheld Palm computers, and CCLabBook software for the Palms that presents the curriculum, interfaces with the probes for data collection and visualization, and supports guided exploration. The materials were tested by 30 teachers in the first year, and in a follow-up study by 8 of those teachers the second year. We found that teachers were able to conduct the investigations successfully in their classrooms, and that student learning was enhanced through the use of the probes and handhelds. Specifically, students experienced the physical correlation between phenomenon and modeling, which helped them to develop understanding and to confront misconceptions.

KEY WORDS: probeware; handheld computers; middle school science learning; professional development.

INTRODUCTION

The studies reported here were part of the Technology Enhanced Elementary Middle and Secondary Science (TEEMSS) project, which was designed to test the feasibility and educational value of introducing probeware and associated instructional materials into middle school (grades 5–8) science, mathematics, engineering, and technology (SMET) teaching. The project took a systemic approach to the question of feasibility—addressing costs, teacher professional development, and instructional design. The project focused on two topic areas and corresponding educational standards that are typically treated in the middle school physical science, but we intend to use data gathered from that experience to answer questions about the eventual feasibility of similar implementations that span all SMET content.

Our goal was to develop two instructional units that use probeware that could be economically implemented. We would then evaluate student learning of these units when they were implemented by typical teachers who had received a modest amount of in-service training. The content addressed was based on two middle school science standards: forces and motions, and transfer of energy. Teaching these is difficult and known to be facilitated by probeware. By demonstrating student learning of these difficult concepts with economical technologies and practical teacher professional development, we would have a powerful argument for a broad curriculum development effort using this approach.

The successful completion of this project would have an important impact on science education throughout the country. Developing and supporting alternative low-cost hardware will make improved, technology-rich science learning accessible to all. Providing high quality, flexible materials will make it easy to integrate these materials into any curriculum so that any school could use them. By providing extensive dissemination and professional support,

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we ensure that the materials will actually be used. Widespread use of appropriate technologies could result in a substantial improvement in science learning in grades 4–8.

Technology is needed in elementary and middle school science not just to give students exposure to the technology or to satisfy parents; technology greatly improves learning and supports science education standards that are difficult to teach without using technology. A substantial body of research (Adams and Shrum; 1990; Krajcik and Layman, 1992; Laws, 1997; Linn *et al.*, 1987) shows that using probeware can facilitate student learning of complex relationships. Similarly, models and simulations allow students to learn dynamic relationships and explore behavior that is difficult or impossible to understand by traditional means (Beichner, 1990; Brassell, 1987; Mokros and Tinker, 1987; Thorton, 1987). Online resources provide unique access to resources and collaborations (Berenfeld, 1994; Songer, 1996; Tinker, 1996).

While technology has implications throughout science education, it is particularly important in the following areas that are called for in the standards but not well-addressed in most elementary and middle school science curricula: data collection and analysis, integration with mathematics, understanding changes, modeling, and student-led investigations. But while the standards are clear about the supporting role of technologies, most elementary and middle school curricula make little or no use of technology. There are many reasons for this disconnect, but concerns for equity, teacher support, and obsolescence are the most important. For these reasons, the project has focused on handheld computers, low-cost probes supported by a new interface, software to support guidance and reflection, and online teacher professional development.

MATERIALS

Content

The content covers two areas of physical science—Force and Motion and Energy Transformations—selected because they are part of most standards for middle school science learning, they are difficult to teach well, and they can profit from the use of probeware. The primary learning strategy used was inquiry-based learning through guided explorations, followed by reflection, practice, applications of the basic concepts in new contexts, and relevant assessment.

Handhelds

One obvious barrier to the kind of implementation envisioned by our project is the cost of computers and probes. Our response to these costs was to develop for handheld computers. Handheld computers have yet to reach the low cost of graphing calculators, but will in a few years. When they do, they will offer the same cost and form factor as a calculator, while being far easier to use, more flexible, and easier to link into networks.

New Probes and Interface

Another systemic cost saving was to design a high quality lab interface that contains circuitry that reduces the costs of probes. The interface is designed to accept either do-it-yourself probes or low-cost probes that are assembled and tested. The project also developed some very exciting new probes, including a new motion detector called the SmartWheel, a force probe, a temperature probe, a light probe, and a voltage/current probe.

Software to Support Guided Exploration

The TEEMSS project developed a software tool for the handheld computers, called CCLabBook. The software serves not only as an interface to running and viewing data from the probes, but also structures student investigations, supports guided exploration, prompts for student reflection, and stores student work. This information is managed by the software and can be beamed to other students and to the teacher.

Teacher Professional Development

A final area of potential implementation cost savings explored by the project concerned online teacher professional development. The project developed both online and face-to-face versions of a teacher workshop for the two units. A key question was whether an online workshop could lead to an effective implementation by typical teachers.

Research Plan

We developed 10 weeklong modules for the units Motion and Forces and Transfer of Energy.

The content, treatment, student investigations, and probeware were all based on learning objectives that are derived from the NSES standards. In order to compare online and face-to-face workshops, the materials were tested with two groups of teachers. For Trial 1, a group of 19 teachers was introduced to the approach at a face-to-face workshop. These teachers were from the United States, Australia, and Israel. For Trial 2, a second group of 11 teachers in locations around the United States received teacher professional development online. The next year, a sampling of eight of these teachers participated in Trial 3, a brief follow-up study.

The research design for the TEEMSS project included both evaluation of student learning of the science concepts, and an analysis of the effectiveness of the components of the project: the units, materials, software, and teacher professional development. Research staff frequently visited the classrooms to observe the materials being used throughout the implementation of the units.

There were three main categories of data collected for the project: Pre/posttests, surveys and interviews, and classroom observations. Multiple-choice tests of science content for each unit were given to students before and after they had participated in the unit. Surveys and interviews asked teachers about their experiences with and opinions of the TEEMSS project and materials, and also their attitudes about inquiry, willingness to try new things, comfort, and experience with technology. Some students were also surveyed for their opinions of the materials. Classroom observation of local classrooms focused on evaluating the effectiveness of the units, both the technical and pedagogical aspects.

FINDINGS

Usage

The teachers were very enthusiastic about the probes and materials, and were able to conduct the investigations successfully in their classrooms. There were some delays in developing and manufacturing the materials, and some difficulties with fragility of the prototype probes, but on average, the Trial 1 teachers used the materials for an average of 20 days over 2 months at the end of the school year, and covered on average about half the Motions and Forces unit and about one quarter of the Transfer of Energy unit. Trial 2 teachers used the materials for 9 days over 2 weeks at the end of the school year, and Trial 3 teachers, used the materials for 2–3 weeks and covered about 20% of one unit.

Table I. Student Performance on Pre- and Posttests of Motions and Forces

Teacher	Trial	Grade	#Students	Pretest (%)	Posttest (%)	Diff (%)
A	1	8	17	65	63	−2
C	1	8	15	58	60	2
D	1	8	23	57	55	−2
H	1	6	23	41	43	2
Q*	1	8	22	43	55	12
E1	2	8	14	60	65	5
C	3	8	38	37	52	15
G	3	7	42	59	65	6

Pre/Posttests

Tables I and II show students' scores on pre/posttests for Motions and Forces and Transfer of Energy, for the teachers who provided test data. The tables also note the grade level of the students and the number of students whose posttests were analyzed. An asterisk (∗) notes the teachers from Australia.

For Trial 1, the data shows that both Australian classes showed significant improvement: 12% on the MF test with teacher Q, and 18% on the TE test with teacher O. The two other TE test scores showed significant improvement as well: 12% and 15%. The other teachers' classes showed little to no difference between the students' scores on the MF test. For Trial 2, there was only one MF data set available, and those students showed a small 5% improvement. For Trial 3, there were 6 data sets, and all showed improvement, 15% and 6% on the MF test, and 3% to 17% on the TE test.

Table II. Student Performance on Pre- and Posttests of Transfer of Energy

Teacher	Trial	Grade	#Students	Pretest (%)	Posttest (%)	Diff (%)
A	1	8	13	47	62	15
C	1	8	13	66	78	12
O*	1	6,7	29	47	66	19
B1	3	6	41	36	41	5
F1	3	6,7	6	56	73	17
M	3	7	47	35	40	5
Q	3	8,10	20	66	69	3

The following additional observations can be made from the data:

- The students had a substantial amount of preknowledge, with scores on the pretests averaging around 50%. Such high pretest scores lessen the usefulness of the tests as an assessment mechanism, and contribute to the low overall changes in scores between pretest and posttest.
- The Australian teachers (O and Q) showed the greatest improvement in Trial 1. The most obvious difference in the circumstances of the Australian teachers compared with American teachers is that Australian schools are still in session during our summer, so they were able to spend extra time with their students using the TEEMSS materials. The fact that the Australian students showed greater improvement on test scores is very encouraging, as it suggests that students can learn the content using the TEEMSS curriculum when they are given sufficient time to do so.
- Trial 1 test scores on Motions and Forces appeared to be adversely affected by the tests being administered at the end of the school year, when some Motions and Forces content had very likely been covered in class during the year. One indication of this is teacher C, whose Trial 1 class scored 58% on the pretest in April 2002, while next year's Trial 3 class scored 37% on the same pretest in October 2002.

Finally, we looked at student performance on specific test questions. For the Motions and Forces test, the most significant improvement was a 28% improvement on the following question: "A cart moves slowly forward for about 1 meter. It stops for a few seconds, then moves backward quickly for 2 meters. Which graph shows how the cart's position changes?" Four graphs were provided. This question is most clearly covered by the TEEMSS curriculum, suggesting that students learned position–time graphs through using the curriculum. Similar position–time graph questions also showed significant improvement.

For the Transfer of Energy test, the most significant changes were 11% improvements on two questions about heat flow, one on mixing water of different temperatures, and one on insulation, and one question about interpreting a temperature–time graph. The test score improvements suggest that the TEEMSS curriculum supported students developing a better understanding of heat flow, and again, improved graph-reading skills.

Surveys and Interviews

Postinterviews with the teachers found that student learning was enhanced through the use of the probes and handhelds for data gathering and visualization. As one teacher said, "It's wonderful to see the spontaneous position–time graphs and speed–time graphs. It's a very powerful tool for the kids. I see a huge difference in their understanding—in past years, their understanding of the shape of graphs correlated with motion was iffy at best, but this year it's much more on, there are many more students who are getting it." Teachers also observed that their students had developed a deeper understanding of the content areas, and more skill in reading graphs. Furthermore, some teachers reported that students also developed skills in patience and problem-solving, expressing their understanding in writing, working in groups, and asking questions and figuring out how to answer them.

Other findings from the surveys and interviews included the following:

- Teachers found that the probes worked well and were very useful.
- Teachers were very pleased and excited about learning the technology and using it in the classroom.
- Teachers agreed strongly that the TEEMSS technology was broadly applicable, useful, easy to learn, and easy to use once they and their students had learned it.
- All of the teachers interviewed said they intended to use the materials again and were eager to do so.

A quantitative survey was administered to the Trial 3 teachers, who were asked to rate the features of TEEMSS on a scale of 1–5. The teachers rated all features of TEEMSS above average, and rated the following features most highly (4.5 or higher):

- Using technology in general
- Seeing the graphs as you do the experiment
- Using the temperature probe
- Using Palms
- Doing the activities in general
- Students figuring things out for themselves
- Using the Smartwheel probe
- Beaming

On a similar survey given to students, their highest rated features (3.5 or higher) were:

- Beaming
- Using Palms
- Using technology in general
- Seeing the graphs as you do the experiment
- Using the temperature probe
- Doing the activities in general
- Figuring things out for yourself

Students were also asked to compare features of the TEEMSS activities to other typical activities they had done in science class, where 1 = less than average activities, and 5 = more than average activities. Students rated all of the features of the TEEMSS activities higher than in other science activities, except for difficulty level, which was rated just about average. The features with significantly above average ratings, in order, were:

- Interesting/fun
- Hands-on
- Technology use
- Learned the science content
- Discussing results with partner or teammate
- Figuring things out for yourself

Classroom Observation

Eight local Boston-area Trial 1 teachers were observed at least weekly, sometimes more often, as they were using the materials. Assistant researchers in New York and Australia also observed the teachers in those locations at least once during the project.

Much of the classroom observation focused on the collection of formative data intended to inform future versions of the materials. For example, we observed issues about the curriculum, the investigations, the software, and the probes. Many of these observations were instrumental in causing us to make changes to the materials as the project continued; we delivered new versions of the software to the teachers as bugs were fixed, and we designed ways to improve the hardware and to strengthen the probes so that they wouldn't break.

The classroom observations were also useful in summarizing the range of ways that teachers implemented the TEEMSS materials in their classrooms. We observed that all of the teachers used the TEEMSS materials in conjunction with their own curriculum materials. Most teachers followed the investigations as written with minor alterations. Several teachers also designed their own inquiries, for example, finding hot and cold areas of the room, or modifying carts to make them go faster. One teacher also used the temperature probe in a weather unit.

In general, we observed that teachers and students were very motivated to use the materials and engaged during the activities. They were able to successfully complete the experiments of most of the investigations that they tried. We observed many "a-ha" moments as students made the connection between the activity and the graph. For example, a student might exclaim, "Oh look, I thought how fast you speeded up didn't change the position graph, look it makes a difference."

The following anecdotes illustrate typical classroom experiences:

Using the Smartwheel Probe (Teacher B, 9th Grade)

Students are doing Tracker, Trial 2. First students are asked to complete the prelab, and to draw on paper their predictions for the graphs that the four motions will make (i.e., pulling the cart forward at a constant velocity, pulling the cart at a slow constant velocity, then a faster constant velocity, then coasting, etc.). Then the students go out into the hall to roll their carts and try to generate the four motions that the activity calls for. After 20 min, at the end of the class period, most groups have completed the first two graphs. Students are excited when they get the graphs to come up on the Palms, they exclaim excitedly to their teammates, making comments like "look, here's where I started to go faster," and "you gotta start slow, so that it shows on the graph when you go fast."

Using the Temperature Probe (Teacher H, 6th Grade)

The class is doing Temperature Trial 1. They did the prelab already, and today are starting the investigation. The teacher tells the students to read the instructions on the Palm, she is not going to tell them what to do. Students easily find the right place in the LabBook to read the assignment, and collect their materials. They set up the probes with no trouble, and all students are working well, answering the questions (on a paper handout) and doing the activity. The teacher observes that "this is the first time they're using these [temperature] probes, and they're doing great."

Each pair of students gets a cup of hot water and a cup of cold water. They measure the temperatures of the water in the two cups, and predict what the temperature will be once they are mixed together. Then they try the experiment and see. One pair has hot water at 59°, cold water at 15°. They predict it will be 45° once mixed, but when they mix it the result is 27°. When asked why they think it turned out to be colder than they thought, the student says "maybe we used more cold water than hot water."

As the students are cleaning up, one student says to the teacher, "That was really great. I liked that." Teacher: "What did you like most?" Student: "Trying all the different experiments and seeing the graphs. It makes me think about the temperatures of different things, like I never thought about the air having a different temperature than the water."

Using the Force Probe (Teacher B, 9th Grade)

The students are doing Collisions 2: Trial 1. Two force probes are connected together with a rubber band. Students stand 8 or 9 ft away from each other, each holding one of the force probes and pulling. Students are asked to predict what the force graphs will look like for each probe, will they be the same or different for the two probes. Then they do the experiment. As students look at the graphs, there are comments like "It kind of looks like the same thing," and "it's basically the same!" The teacher asks one student what he thinks would happen if one person pulled harder than the other. The student says "one graph would go up a lot higher than the other." They try the experiment over and over, until they are all convinced that it is the same even if one pulls harder, or even if one does not pull at all.

The teacher walks around making sure the students answer the postlab analysis questions on their papers. He asks several students to make sure to explain why they think the graphs look the same. One student says "because there was an equal force." The teacher says "right, that's Newton's 3rd law. Every action has an equal and opposite reaction." The teacher is very pleased after this trial, commenting that "Everything has worked perfectly!"

The following are general observations about different classroom practices and their impact on the success of the materials:

- Students and teachers experienced a learning curve while using the technology. Later investigations went more smoothly with less frustration and higher engagement.
- Those teachers whose students practiced with the Palms ahead of time were able to use the LabBook software with fewer problems.
- The most important factor for success was the teacher. Teachers who took the time to review the curriculum and make it their own had significantly greater success than those teachers who tried simply to drop the curriculum as is into their classroom.
- Other factors for success included the teachers' openness to learning technologies, comfort level with trying new things, content ability and level of understanding, and classroom management skills.
- Students' engagement and learning increased when they were personally able to read the instructions, do the activity, and view the graph. In those classrooms where students worked in larger groups, the students who were not personally holding the Palm were less engaged in the activity. In particular, students who watched the Palm but did not manipulate the probe, or vice versa, learned less than students who were able to both watch the Palm and manipulate the probe at the same time.
- The teachers varied significantly in their decisions to use paper versus Palm for investigation activities such as reading instructions, answering questions, drawing graph predictions, and saving and viewing graphs. Some teachers had their students sketch their graphs, even making worksheets so that students could first draw their predicted graph, then draw next to it the graph that was generated when they did the experiment. This sometimes worked quite well, but other times student unfamiliarity with graphs caused their sketches to be incomplete or inaccurate. Also, teachers would have benefited from being able to project graphs for class discussion.

There were also several technical issues that we identified through classroom observation, primarily related to the circumstances of the Trial 1 and 2 pilot testing. These issues were: delays in manufacture and delivery of materials, software fixes and updates, probe breakage and repair, and difficulties in beaming, downloading, and viewing saved data. Most technical issues were resolved during the testing process, bug fixes and improvements were made and released during the classroom testing period, and the feedback from classroom observations was very useful in informing this process.

DISCUSSION

In considering the educational value of our probeware and instructional materials, the data from the student pre/posttests shows that students often showed significant improvement, up to 19% higher scores on posttests. The greatest improvements were seen when students were able to spend extended periods of time using the materials, as was the case in the Trial 1 Australian classrooms. Smaller improvements were seen when the materials' use was rushed, or when high scores on the pretest indicated that students had already learned much of the content on which they were being tested. Looking closely at specific test questions, we saw the most significant improvement on those questions that matched most closely with the portions of the curriculum covered by the students—these were Motions and Forces questions relating to position–time graphs, and Transfer of Energy questions relating to heat flow, insulation, and temperature–time graphs.

In post-interviews and surveys, the teachers reported that their students had learned significantly from their use of the TEEMSS materials. Teachers said especially that the direct experience of doing the activity, using the TEEMSS probeware, and seeing the graph on the Palms in real-time greatly helped their students learn the material, confront their misconceptions, improve their graph-reading skills, and learn science content. Trial 3 teachers felt that TEEMSS supported students learning the science content better than the average science class activity, and rated the TEEMSS materials above average in almost all aspects. Our classroom observation reinforces this conclusion, as we were witness to many enlightening moments of understanding as students made connections between the physical and the graph. And finally, the students themselves reported that they "learned the science" better from the TEEMSS activities than in other activities they've done in science class.

Our research was also concerned with the feasibility of using these materials in middle school science education. The data showed that, with minimal training either face-to-face or on-line, teachers were able to implement the units quite well. Classroom observations and post-interviews showed that teachers and students managed to succeed in almost every investigation they undertook. And when asked to rate their understanding and ability to use the technology, Trial 3 teachers agreed that it was easy for them to learn, easy for their students to learn, easy to use, and that they were able to solve technical problems as they occurred.

In summary, we conclude that the TEEMSS project successfully demonstrated that the TEEMSS materials and technology can be effective in teaching science concepts through hands-on, inquiry-based investigations, and in motivating teachers to pursue the use of inquiry and technology in science education. Further and more in-depth studies are needed, and we hope to continue our research in developing the curriculum, the training, and the technology.

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