RESEARCH BRIEF

Improving Mathematics Performance Using Laptop Technology:
The Importance of Professional Development for Success

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Executive Summary

Improving Mathematics Performance Using Laptop Technology: The Importance of Professional Development for Success

This randomized control trial (RCT) study was designed to determine the impacts of a professional development program focused on integrating one-to-one laptop technology into classroom instruction. Middle school teachers in 24 Maine schools participated in a two year professional development program of over 200 hours designed to improve their ability to effectively use laptop technology in teaching mathematics. Results of the experimental study revealed that this type of professional development was effective in changing teaching and technology practices, which in turn led to improved student performance on standardized mathematics tests. The research also highlights the importance of maintaining high levels of implementation fidelity for improved student performance.

Improving Mathematics Performance Using Laptop Technology

The Importance of Professional Development for Success

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Introduction

For over seven years the State of Maine has been a national leader in introducing one-to-one laptop technology into schools and classrooms. To date, Maine is the only state that has provided laptop computers to all students and teachers in multiple grades across the entire state. Since 2002 Maine has provided all middle school students and their teachers with laptop computers. In addition, all Maine's middle schools have become wireless, permitting teachers and students to use their laptops throughout the school day and in a variety of settings and contexts. Students may also take their laptops home for use in the evenings, weekends, and during school vacations.

The Maine laptop program, called the Maine Learning Technology Initiative (MLTI), also has provided extensive technical assistance and targeted professional development programs to support the integration of the laptop program into all of Maine's middle schools. School districts provide technical support for teachers and students, while a designated teacher leader at each middle school site assists teachers in integrating the laptops into their curriculum and instruction. Many other types of support and professional development opportunities are provided to teachers as well. These include initial laptop training, regional teacher leader meetings, content specialists meetings, interactive websites, and other statewide and local professional development activities relevant to technology. Further, the Maine Department of Education provides staff development personnel to assist schools and teachers in implementation of the laptop program.

The evaluation of the laptop program has provided evidence that, indeed, the introduction of the laptops in Maine's middle schools has impacted teaching and learning in many ways (Silvernail and Lane, 2004; Silvernail and Gritter, 2007). From the very beginning a core component of the MLTI program has been the provision of ongoing professional development opportunities, and it is these professional development opportunities that have played a key role in Maine's success. Evidence collected over the past several years indicates that teachers who participate in effective professional development programs use the laptops almost twice as often in designing and delivering instruction as their colleagues who do not participate in these professional development programs. And the importance of effective professional development in creating positive impacts on student learning is borne out in the study described in this report.

Research Problem and Approach

The study described in the subsequent pages was designed to address a specific need in Maine's middle school. Analysis of results from the 2002 statewide Maine Education Assessment (MEA), the statewide test designed to measure Maine's curriculum standards, indicated that Maine 8th grade students were failing to achieve high levels of proficiency in mathematics. Statewide, over three-fourths of all Maine 8th grade students failed to meet the Maine mathematics standard, and only a very small percentage achieved the highest proficiency level. Additionally, evaluation data from the early phases of the laptop program showed that only about one-half of the mathematics teachers reported using the laptops in their instruction, in contrast to 85% of teachers of other subject areas.

In light of the statewide MEA mathematics results and the evaluation findings on laptop use, the State of Maine initiated several strategies designed to improve middle school mathematics teaching and learning. One strategy, the study reported here, was to conduct systematic research on the impact of a sustained professional development program focused on mathematics. To that end, in 2003 the Maine Department of Education was awarded an Evaluating State Education Technology Program, (ESETP) grant from the United States Department of Education, a grant designed to conduct a randomized control trial (RCT) research study of the impact of a two-year mathematics professional development program on student achievement. Partners with the Maine Department of Education in conducting the study were the Education Development Center (EDC) and the Maine Education Policy Research Institute (MEPRI).

Research Design

The fundamental premise of this study was that students' mathematics performance was linked to teachers' mathematics content knowledge and instructional practices. Further, it was hypothesized that changes are needed both in teachers' content knowledge and pedagogical practices, and that combining these with effective use of the laptop technology would lead to improved student mathematics performance. Thus the logic underpinning this study was that a robust professional development intervention program would result in improvements in teachers' content and pedagogical knowledge, classroom practices, and their use of the laptops in instruction. These changes would in turn have a positive impact on students' mathematics achievement.

Researchers have established a number of key principles for effective professional development programs for K-12 educators. In a summary of these principles, Sparks and Hirsh (1997) described a "paradigm shift" in staff development, away from one-day in-service presentations to professional development as an integral, ongoing part of teachers' work, focused on improving student learning outcomes, based on inquiry into teaching and learning, and built upon interactions within professional learning communities. Major research studies and syntheses by Darling-Hammond & McLaughlin (1995); Ball & Cohen (1999); *National Staff Development Council*, (2001); *National Foundation for the Improvement of Education*, (1996) and others consistently agree that professional development is most effective when it:

- focuses on the curriculum standards for students and the alignment of teaching, curriculum, and assessment with those standards;
- fosters a deepening of subject-matter knowledge, a greater understanding of learning, and a greater appreciation of students' needs;
- centers around the critical activities of teaching and learning – planning lessons, evaluating student work, developing curriculum, improving classroom practices, and increasing student learning – rather than in abstractions and generalities;
- builds on investigations of practice through cases that involve specific problems of practice, questions, analysis, reflection, and substantial professional discourse;
- values and cultivates a culture of collegiality, involving knowledge, and experience-sharing among educators;
- is sustained, intensive, and continuously woven into the everyday fabric of the teaching profession, through modeling, coaching, and collaborations; and,
- begins with the mathematics content goals and effective teaching methods, rather than with the technology (when technology is employed).

These tenets of effective professional development informed the design of the professional development intervention program that was implemented in this research study.

The potential of computers to enhance students' learning of mathematics has long been heralded, and a number of researchers have found positive effects of technology in teaching mathematics. For example, Heid & Blume (2003) found that technology may positively influence the development of algebraic concepts and lead to improved visual reasoning skills, and that technology enables the goals and content of algebra to shift from a procedural to a conceptual focus. These findings are consistent with a review of the research on graphing calculators in secondary mathematics by Burrill et al (2002). They reported positive results in that "students who use handheld graphing technology have a better understanding of functions, of variables, of solving algebra problems in applied contexts, and of interpreting graphs than those who did not use the technology" (p. v). Further, in an analysis of different uses of technology in mathematics education based upon the 1996 NAEP data, Wenglinsky (1998) reported that "in essence, the study found that technology could matter, but that this depended upon how it was used" (p. 3). Specifically, Wenglinsky found that teacher professional development, the use of computers to teach higher-order thinking skills, and the frequency of student home computer use were all positively related to achievement.

Thus, reviews of literature on professional development and using technology in instruction suggested that by combining effective, sustained professional development with strategies for using technologies as instructional tools could enhance mathematics learning. To empirically test these causal assumptions, a randomized control trial (RCT) research design was used in this study. RCTs are considered the "Gold Standard" for conducting evidence-based causal research. The U.S. Department of Education and others are on record for supporting more so-called "scientifically-based research," and in recent years has encouraged giving funding priority to programs based on research which uses "an experimental design under which participants – e.g., students, teachers, classrooms, or schools – are randomly assigned to participate in the project activities being evaluated or to a control group that does not participate in the project activities being evaluated" (U.S. Department of Education, 2003a, p. 62446). In light of these recommendations a specific RCT design, a randomized pretest – post-test control group design, was utilized in this study to determine the impact of a two-year professional development intervention program on middle school student mathematics performance. Figure 1 represents the research design. After schools were randomly assigned to experimental and control groups, all 7th and 8th grade teachers and students in these schools were pretested. The experimental group then received the two year professional development program, and both groups completed posttests at the end of the two year intervention.

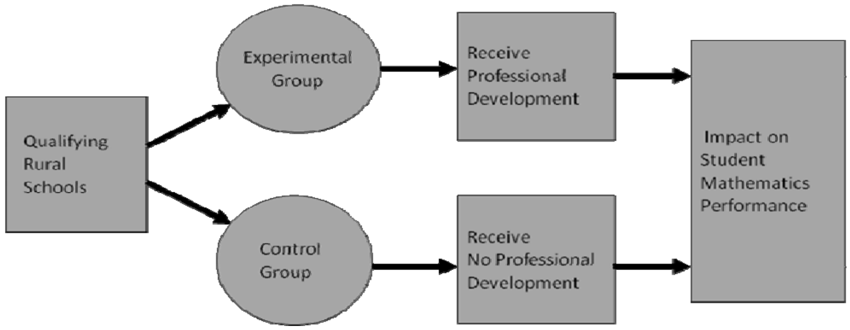

Figure 1: Overview of Randomized Pretest-Posttest Control Group Design

Sample

To be eligible to be included in the study middle schools had to meet two primary criteria:

1. The school MEA scores had to be below the state average in mathematics for the most recent two years; and
2. The school had to contain both 7th and 8th grade in the same building.

Further, to be eligible for selection, all 7th and 8th grade teachers who taught mathematics at the school had to agree to complete the two-year professional development program if they were selected for the experimental treatment. This was an important stipulation in the study because it was hypothesized that students who were taught for two consecutive years by teachers participating in a sustained two-year professional development intervention program would significantly improve their mathematics performance.

One hundred ninety-one (191) Maine middle schools were eligible for participation in the study, and a total of 56 schools volunteered to participate. After the principals, and all 7th and 8th grade teachers in a middle school, signed and returned a written agreement to the study conditions, the schools were randomly assigned to either the experimental or control groups. Random assignment was done at the school level to decrease the likelihood of sharing of resources, instructional strategies, etc., between the experimental group teachers and the control group teachers.

Twenty-eight (28) schools were randomly assigned to each study group (experimental and control). However, once the schools were assigned to the two groups, nine schools (7 experimental schools and 2 control schools) notified the researchers of their decision *not* to continue in the study. An analysis of school, teacher, and student characteristics of the schools that opted out from the original sample indicated that these schools were not significantly different from the schools remaining in the study.

Treatment

The experimental intervention consisted of four interrelated professional development components which were designed to model the effective professional development characteristics described earlier:

1. *Face-to-Face Workshops*: The face-to-face workshops focused on (1) building teachers' knowledge of the key Maine learning standards for mathematics; (2) deepening teachers' own knowledge and understandings of central mathematical ideas; (3) introducing the technology tools that were designed to help teach these ideas; (4) integrating work on formative assessments of students' learning with the use of the technology tools to support the identified learning needs; (5) working with the teachers on plans to integrate the tools into the curriculum to help students meet the identified mathematics standards; and (6) building a shared vision with school administrators regarding technology integrated mathematics instruction.
2. *Online Workshops*: Following the face-to-face workshops, an online workshop comprised of ten weeks of activities was provided. Teachers were expected to spend five hours per week on workshop activities, both online and offline. Teachers participated in the online and face-to-face workshops as members of the same group and with the same workshop leaders. The online workshops continued work begun in the first face-to-face workshops, extending it to additional content standards, mathematical concepts and skills, and software tools.
3. *Peer Coaching and Mentoring:* The third component of the professional development approach was the establishment of a system of peer coaching among the participating teachers and regional mathematics content leaders. Building upon the approach recommended by Loucks-Horsley, Hewson, Love & Stiles (1998), the coaching model provided opportunities for the participating educators to build upon their own strengths. The model was a collegial peer-coaching model where teachers were paired up with a peer who was assigned to teach the same grade level at a nearby school. They supported one another, problem-solved, shared strategies, observed and gave feedback to one another.

4. *Site Visits:* The fourth component consisted of site visits. The visits were designed to support the training and mentoring with on-going observation and feedback as teachers implemented new learning, resources and strategies into the classroom. This component was designed to provide continuous improvement and capacity building over the course of the two year intervention.

The goals of the experimental intervention in this study were fourfold:

- Content – deepen teachers' mathematical content knowledge in the areas of *Numbers and Operations and Patterns* in Maine's statewide learning standards.
- Pedagogy – improve teachers' pedagogical practice in technology enhanced mathematics classrooms.
- Technology Integration – develop and apply strategies that support the integration of technology for the teaching, learning, and assessment of mathematics.
- Professional Learning Community – engage teachers in meaningful interaction and dialogue about mathematics through face-to-face and online environments.

Overall, teachers received 30 hours of face-to-face and 50 hours of online professional development during each year of the two year intervention. Additionally, participating teachers received at least 24 additional hours each year of ongoing support via peer coaching, site visits, and the online forum and resources. In total, the professional development program consisted of approximately 210 hours for each teacher over the length of two years.

Instrumentation

A series of data collection tools were used to document and analyze the impacts of the professional development intervention. These included a series of student and teacher surveys, teacher logs, and online postings. In addition, student learning was measured using standardized achievement tests, and teacher knowledge was assessed using student work samples.

Student Achievement

The mathematical focus of the research study was to develop students' readiness to succeed in algebra. The Maine learning standards, called the Maine Learning Results, are structured around four major mathematics clusters. Two clusters (1. Numbers and Operations & 2. Patterns) were the focus of this research study. An analysis of MEA mathematics performance over four years indicated that student performance in these two performance clusters was lowest on the statewide tests.

An analysis was undertaken of the existing statewide 8th grade MEA mathematics test to determine its viability for assessing student achievement in the two mathematics focus areas of this study. It was concluded that the state test alone would not be a sufficient assessment of student learning for two primary reasons. First, the content on the statewide tests covers a wide range of topics within each cluster, and for the purposes of this study, it was important to not only have a measure of broad mathematics learning within each cluster, but also to have a measure of the specific content which was the focus of the professional development program.

Second, even though random assignment was used in this study, it was done at the school level. That is to say, schools were randomly assigned to experimental and control groups, not the teachers or students. While random assignment is intended to create equivalency between groups, this assumption needs to be tested when randomization is done at the school level. At the time this study was undertaken, Maine did not have a statewide 7th grade MEA test that could be used as a pretest for determining group equivalency.

Given this analysis of the statewide MEA mathematics test, additional tests were designed and validated specifically for this study. Consideration was also given to how best to administer each of the assessments, using either paper-and-pencil or online formats. Because every middle school student and teacher in Maine has a laptop computer, and because the MEA was scheduled to be offered online in the future, the team decided that the Patterns portion of the student assessment and the entire teacher assessment would be delivered online.

Two separate instruments were developed for measuring student learning. One focused on the Numbers and Operations cluster and the other focused on the Patterns cluster. Each of the assessments was designed to take approximately 45 minutes, and the online assessment was designed to be accessible through an Internet browser. Figure 2 describes the student assessment

Cluster	Content	Type of Test Item
Cluster 1: *Numbers & Operations*	Use of numbers in a variety of equivalent and interchangeable forms in problem solving. (e.g., integer, fraction, decimal, percent, exponential, & scientific notation)	5 Multiple choice 7 Short answer 2 Constructed Response
Cluster 2: *Patterns*	Describe and represent relationships with tables, graphs, & equations. Use statistics, tables & graphs to communicate ideas & information in convincing presentations & analyze presentations of others for bias or deceptions.	5 Multiple choice 11 Short answer 3 Constructed Response

Figure 2: Student Assessments

instruments in more detail. The student assessments were designed by researchers at the Education Development Center with assistance from the Maine Department of Education. Over the course of the study, three different versions of each test were developed, field-tested, and analyzed for validity and reliability. Standard procedures for establishing the validity and reliability of the assessment instruments were used in examining test items, including principle component factor analysis, and reliability analyses, and procedures to examine item difficulty, item discrimination, and item biases. These analyses resulted in establishing that the student tests were valid and reliable for research purposes.

<u>Teacher Knowledge</u>

An important assumption underpinning this study was that improvements in teachers' own content knowledge and pedagogical knowledge were critically important to improving their use of technology in their instruction. Thus, the teacher assessments were designed to assess teachers' content and pedagogical knowledge in the mathematic areas which were the focus of this study. Pedagogical knowledge included understanding students' mathematical thinking, as well as understanding how to effectively build upon and develop mathematical thinking.

The teacher assessments were designed to assess teachers' knowledge in a new way. A review of available teacher tests revealed no existing tests which measured teachers' knowledge in the specific content areas which were the focus of this research, nor were existing tests in a format the research team felt acceptable to administer to experienced teachers. Accordingly, a new format was used for the teacher assessments. The teacher assessments consisted of a number of students' responses to mathematical problems, responses which included many student misconceptions. Teachers were asked to identify the student misconceptions, explain the students' thinking and suggest questions that would help the students to better understand the mathematics. Analysis of the new teacher assessments indicated they were also valid and reliable for use in research studies.

Results

Was the professional development program effective in changing teachers' content knowledge, classroom practices, and their use of the laptops? Did student achievement improve as a result of the professional development program? Gaining answers to these questions guided the analysis of the study results. But first, decisions needed to be made about the sample for the data analysis.

As described earlier, the original sample of 56 volunteer schools were randomly assigned to experimental and control groups, but nine schools (7 experimental schools and 2 control schools) chose not to participate in the study prior to implementation. Thus, the starting sample of schools was 21 experimental schools and 27 control schools with 57 experimental group teachers and 54 control group teachers. Analysis of teacher demographics revealed that the two groups of teachers were equivalent in characteristics such as education level, overall teaching experience, and years of experience teaching mathematics.

However, the final study sample used in the analysis was considerably smaller than the original sample, in large measure because of loss of data and attrition. To answer the research question in this study, it was important to examine the optimum set of experimental group teachers and students. That is to say, the best test of the causal assumptions underpinning this study was to examine the performance of those schools and classrooms where:

1. All the 7th and 8th grade teachers in the school had participated in the professional development intervention program for 20-24 months;
2. The teachers used the laptops to implement teaching strategies they learned through professional development activities; and
3. There were pretest and posttest data for the participating teachers and their students.

Put another way, the final study sample used in the data analysis included students who were in classrooms, both in the 7th and 8th grades, who were taught by teachers who had participated in the two-year professional development program. The resulting sample became 37 teachers (10 experimental teachers and 281 students, and 27 control teachers and 692 students).

Did teachers improve their content knowledge? Did they change their classroom practice? The answer to these questions is **Yes**. In terms of teacher content knowledge, analysis of the teacher pretests indicated no statistically significant differences in teacher knowledge between groups. Teachers in both the experimental and control groups had similar content knowledge at the beginning of the study. However, by the end of the two year professional development program, teachers in the experimental group scored significantly better on the posttest ($t = 7.13$; $df = 35$; $p < .01$). Teacher content knowledge had significantly increased for the experimental group of teachers.

Teacher practice also changed. Analysis of teachers' self-reported technology use levels before and after the two-year intervention revealed significant differences ($p < .001$) in favor of the experimental group of teachers at the end of the project. That is to say, teachers in the experimental group reported higher levels of use of technology in their teaching than teachers in the control group. These findings were also supported by analyses of teacher logs and online postings. Experimental group teachers changed their instructional strategies, and increasingly were integrating the use of laptops into their curriculum and instruction.

Did these teacher and teaching changes result in improved student learning? **Yes**, student achievement improved. Table 1 reports the student achievement scores at the beginning

Table 1: Student Total Test Score Results After Two Year Intervention (percentages)

Type of Test	Experimental (n=281)	Control (n=692)	T=	P=
Pretest	32.1	27.8	3.80	<.01
Posttest	54.6	47.9	3.62	<.01

and end of the two year intervention on the test specifically designed for this study. As the results indicate, experimental group classroom students and control group classroom students did differ at the beginning of the study. But when this initial difference was taken into account by using the statistical technique called analysis of covariance (ANCOVA) for group effects, test score results were significantly different at the end of the two year intervention, in favor of the experimental group students. Overall, the experimental group students who were taught by teachers who had participated in the sustained professional development program gained more knowledge over the two years. Both groups of students improved their mathematics knowledge over the course of the two years, but students in the experimental group improved more. The same may be said of student performances on subsections of the 8th grade MEA. Students in the experimental group significantly outperformed students in the control group on the two subsections of the MEA mathematics test dealing with Numbers and Operations and Patterns. And these results held up even when more sophisticated statistical techniques were used to analyze student performances. Analyzing the results using both causal modeling techniques and hierarchical linear modeling (HLM) techniques (Silvernail, 2007) yielded similar results. Thus, the evidence in this study supports the logic underpinning this study. Changing teachers' content and pedagogical knowledge and helping them learn how to integrate the laptop technology into their instruction resulted in improved student achievement.

Further analysis of the results also points to the importance for teachers to continue to practice what has been learned through participation in professional development programs. To further examine the achievements results, test scores were analyzed by the two clusters subtests (Numbers and Operations and Patterns) on the tests designed for this study. This analysis uncovered some additional differences in performance as shown in Table 2. For both clusters,

Table 2: Student Subtest Score Results After Two Year Intervention (Percentages)

Content		Experimental (n=281)	Control (n=692)	t=	p=
Numbers & Operations	Pretest	30.1	25.8	3.87	<.01
	Posttest	56.0	51.5	0.35	>.01
Patterns	Pretest	35.4	31.2	3.30	<.01
	Posttest	53.4	44.8	5.97	<.01

there were statistical differences in the pretest, and analysis of covariance (ANCOVA) revealed the Numbers and Operations cluster posttest scores for the experimental group students did not differ significantly from the scores of control group students. However, in the case of the Patterns cluster test scores, the differences between groups were statistically significant. Experimental group students scored significantly higher on the posttest. Thus, whereas the earlier analysis indicated students in the experimental classrooms had significantly higher total test scores, the secondary analysis revealed that the greatest difference in performance, in favor of the experimental classroom students, was in the Patterns mathematical content area.

Why these differences? Why did students in the experimental group outscore control group students in one area of the tests but not the other? One possible explanation is the testing format. The Patterns cluster section of the test was given online, so the testing procedure more closely mirrored the instructional practices of the experimental group of teachers (i.e., using the laptops and online interactive learning content in their classroom instruction). This may in fact be true, and it suggests that additional research needs to be done in this area. But an even more plausible explanation may be what is often referred to as “implementation fidelity.” Implementation fidelity is a concept for describing the degree to which an intervention (in this case, the professional development activities) was implemented as prescribed. That is to say, how faithfully did teachers incorporate what they learned in the professional development activities into their actual classroom practice? In this case, further analysis of teachers’ logs, online entries, and discussion board entries revealed that while teachers incorporated instructional strategies in both mathematics cluster areas into their classroom, they practiced strategies related to the Patterns cluster considerably more often. In fact, almost twice as often (81% vs 46%). Thus, it may be said that there was greater implementation fidelity in the area of the Patterns cluster than in the Numbers and Operations cluster, which in turn may explain the differences in student achievement in these two cluster areas.

Further, the results of this study point to the need to maintain a high degree of implementation fidelity in continuing to work with students like those in this study. Lower performing schools were the target of this study, with the goal of determining whether a robust professional development program could be effective in remediating poor student performance. The evidence supports the premise that this type of sustained professional development can indeed be effective. But even after two years of intervention in this study, average scores were still below desired proficiency levels. This might be anticipated, given the pre-treatment performance of the students, and it points to the fact that substantial amounts of remediation may be needed to overcome several years of sub-par performance. It also suggests that the introduction of a professional development program similar to the one examined in this study in earlier grades may be very effective in preventing the need for remediation in later grades.

Conclusions

The findings from this study support the importance of sustained professional development to the successful integration of laptop technology into classroom instruction. It suggests that providing teachers and students abundant access to laptop technology is only the first step toward using the technology as an effective instructional and learning tool. It is a necessary step, but not sufficient to lead to improved student learning. Professional development is also needed. In this case, for student learning to improve, sustained teacher involvement in professional development activities (20 + months) and higher levels of implementation fidelity were key to improved student learning.

Implementing randomized control trial (RCT) studies, what is referred to as the “Gold Standard” for conducting evidence-based research, faces significant challenges in establishing cause and effect relationships in education (as well as other social science discipline) settings. This study clearly exhibited many of these challenges, and highlighted the tensions between internal and external validity in conducting experimental research. To answer the core research question in this study, several modifications to conducting a RCT were necessary. Participation by schools was voluntary, and while schools were randomly assigned to treatment and control groups, the study experienced some key fidelity of treatment problems. Students experienced varying levels of intervention implementation across the two-year intervention (e.g., differences in implementation by their 7th and 8th grade teachers). Some data were not collected from various teachers and their students because of local conditions, digital problems, and simple non-compliance. In addition, all student assessments were locally administered (i.e., by classroom teachers) and not monitored externally. These are potentially significant threats to the internal validity of this study. The results from this study still provide evidence of the importance of professional development to the successful implementation of a laptop program, and suggest a clear link between this type of professional development, the integration of laptop technology into classroom practice, and student achievement.

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Authors' Biographic Sketches

Dr. David L. Silvernail

Dr. David L. Silvernail is director of the Center for Education Policy, Applied Research and Evaluation, and professor of research and evaluation in the College of Education and Human Development at the University of Southern Maine. Dr. Silvernail has over 25 years of research and education policy experience in the fields of school reform and school finance. Currently Dr. Silvernail is conducting several research studies including ones related to high performing schools, district efficiency, and technology in schools. Dr. Silvernail is also director of research for the newly established Maine International Center for Digital Learning.

Dr. Pamela J. Buffington

Dr. Pamela J. Buffington, Project director and Senior Technology Associate at the Education Development Center, Inc. (EDC), has extensive experience as a professional development leader, assessment developer, mathematics and science teacher, school and district technology coordinator, and has taught education and technology courses at the higher education level. She has directed multiple professional development and research projects in the areas of technology and mathematics. She is currently leading two Math Science Partnership grants utilizing technology and formative assessment, supporting the Maine Learning Technology initiative in mathematics content, and is acting as a liaison to state educational leaders through work with the Regional Educational Laboratory of the Northeast and the Islands.