How Notebook Computers, Digital Media, and Probeware Can Transform Science Learning in the Classroom

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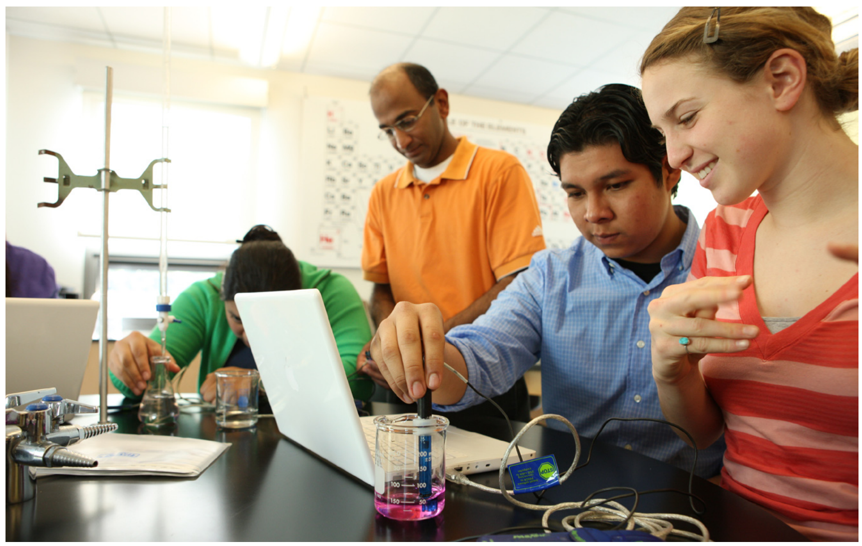
Technology and Educational Reform



Much attention is given to technology in discussions of current educational reform. Many have promoted technology as an appropriate tool and even a bridge between underachieving students and their schools. Proponents of technology for educational reform argue that it helps K–12 students in various ways, including its ability to provide familiarity with tools students use outside of school,[1] better training opportunities for future jobs,[2] and venues for better inquiry teaching.[3] Staunch advocates in support of technology in education even point to the lack of American students' science achievement on standardized testing[4] and other international demographics, comparing America to other industrialized nations (particularly China) as cause to invest heavily in technology for schools.

Technology is driving change both in and out of the classroom. Several authors suggest fundamental differences exist in our American culture that change who kids are and how they learn best.[5] For example, according to the Pew Internet & American Life Project,[6] 87 percent of children ages 12 to 17 use the Internet regularly. This number has increased over 25 percent since 2000. Seventy-five percent of today's teens use at least two digital devices daily and spend an average of nearly 6.5 hours a day with media.

Such observed changes in student behavior may be a seductive quick fix for adults who see incorporating technology familiar to students as a way to stay consistent with Dewey's challenge that we use the same psychology of learning at school that we apply to learning away from school.[7]

These arguments may be compelling, but as science educators, we need to consider carefully which tools assist in promoting scientific inquiry and how to thoughtfully incorporate them into instruction in ways that add value to science teaching.

Skills, Attributes, and Needs

Since the popularization of Howard Gardner's[8] work with multiple intelligences, much attention has been given to different kinds of student intelligences mediating the engagement with different academic subjects. His theory of multiple intelligence has been applied to a variety of learning environments and can be defined as the manner in which students of all ages are affected by sociological needs, immediate environment, physical characteristics, and emotional and psychological inclinations.[9] Differences exist among and between student groups, and not all curricula or technological innovations developed by teachers or science experts should be expected to achieve similar ends for all students. For all students to succeed at learning science, teacher practices and curricula must be designed to meet students' various interests, abilities, experiences, understanding, and knowledge. Technological implementations for students should consider ways that tools can expand opportunities to all students by offering different kinds of access to knowledge. Incorporating science lessons, for example, that allow students to demonstrate science competency through musical, dramatic, artistic, or other representations is one way to honor diverse student skill sets. Orchestrating the collaboration of diverse student knowledge and skill sets around a central problem or concept can also offer a greater opportunity for various students to be successful in classrooms.

Simply inserting technology into classrooms is unlikely to result in any positive change toward inquiry. Teachers need support, incentive, and practice in applying new pedagogical and technological innovations. Science teachers generally agree that technology should be incorporated into science instruction, but most are passive about seeking professional development in technology or finding time to learn new strategies and tools.[10] A major gap exists between science teachers' desired use versus actual use of technology in most science classrooms.[11] Researchers argue that the vast majority of teachers have had little or no training in how to apply computers specifically to the content they are teaching.[12]

Teachers may have a variety of purposes and goals when implementing technology, including improving test scores, incorporating tools that are familiar to students, developing problem-solving skills and critical thinking, promoting inquiry, and helping students co-construct meaning in science. The question is, which tools should be considered?

Researchers maintain that when considering implementation, investigation should be based on a critical perspective for use that relates specifically to the context in which it is applied—not based on dissimilar educational contexts.[13] Few empirical studies focus on the process of using technologies in elementary and middle school science classrooms and how these technologies function within the expectations, norms, and practices in current classrooms.

To better understand the role and influence of technology in science learning, researchers studied the effects of introducing new technology into science classrooms in a suburban New York middle school. The research subject of this study was a year-long implementation of instructional technologies, including MacBook computers, iLife software, probeware, and other tools. This white paper details the parameters and subsequent findings of the study.

Parts of this white paper were extracted from an initial study originally published in *Contemporary Issues in Technology and Science Teacher Education*, Volume 9, Issue 3 (2009), ISSN 1528-5804.

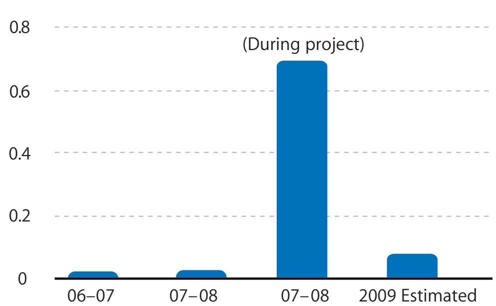
Defining the Study

This study analyzed the effects of integrating MacBook computers, iLife software, and science technology tools into middle school science classrooms. During the 2007–2008 academic year, science teachers at a suburban New York middle school were trained to incorporate technological tools into their classrooms and apply associated pedagogical strategies and curricula as a way to increase student engagement and help them learn science in ways consistent with current science education reform visions. Throughout the year, student engagement, achievement, and perceptions were studied in collaboration with researchers from the State University of New York at Buffalo (UB).

The Research Environment

The host middle school for this study was selected because of its involvement with ongoing teacher education, the strength and experience of its teachers, and the fact that there was little planning for technology integration. In fact, the school had postponed plans for technology purchases pending budget approval during the 2006–2007 school year, leaving less than 4 percent of its students with access to computers at any one time. Teachers at the middle school had similarly limited access to technology for their classrooms; there was one PC on each teacher's desk and an outdated PC laboratory with fewer than 24 computers for more than 400 students. This absence of technology at the school gave researchers an excellent opportunity to study and monitor how the introduction of technology into science classrooms would affect science instruction. The chart below shows the computer-to-student ratio during the year of the study. It's clear from the large differences in access that in the years prior to the project, students' access to computers was minimal during instruction. Teachers who self-selected out of the project allowed the computer-to-student ratio to be much higher, as indicated by the spike during the 2007–2008 school year.

Computer-to-student ratio



During the project, access to computers increased from less than one computer for every 20 students to 7 computers per 10 students.

Working with faculty at the University at Buffalo, science teachers from the middle school began learning to use equipment such as MacBook computers and digital science learning tools. They also collaborated with UB faculty to design curricula, explore science education literature, test lesson plans, and prepare evaluation measures for the 2007–2008 implementation of notebook computers, probeware, and other scientific hardware and software.

Parameters of the Study

In this study, two science teachers from the host middle school attempted to address the needs of their students through participation in a new technology integration project. Fifteen MacBook computers were provided to the two participating teachers along with a complete station of probeware and software for each teacher. The teachers supplemented the technology implementation with inquiry-based teaching strategies in their earth science and physical science classes. Two main purposes were emphasized for the implementation of technology in their science classrooms: a) the insertion of actual data to complement instruction and laboratory investigations and b) the use of media creation tools to give the students opportunities to co-construct knowledge of abstract concepts.

Throughout the 2007–2008 school year, researchers received full access to classrooms, achievement scores, and artifacts, as well as to the students for interviews. Because all teachers at the school were aiming for the same goal—New York State Regents Examination competency—teachers who self-selected out of the study provided a quasi-control group of students who did not have access to technology. This context also provided an excellent opportunity to gather data regarding the technology implementation from the students' perspective, contrasting with their past experiences learning science without technology in the classroom.

Given the opportunity to study different teachers in the same middle school environment covering the same curriculum but using different tools and teaching strategies, researchers thought it important to consider the following research questions:

1. What is the impact on students' learning and science knowledge when teachers employ inquiry teaching strategies with technological tools?
2. Which educational technologies do students perceive as helpful in learning science?
3. How do students perceive themselves as learners and their teachers' efforts with technology to improve science teaching?

Using technology for problem solving

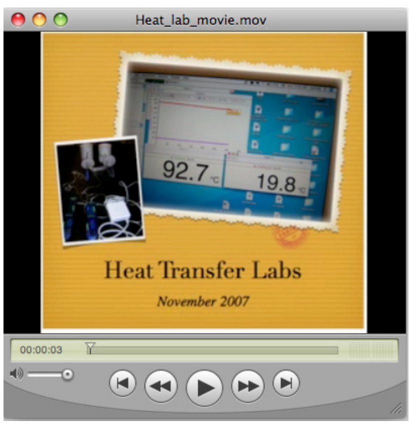
The middle school science teachers devoted weeks of their 2007 summer break to exploring inquiry methods for teaching that incorporated technological tools for scientific data collection and analysis. Using scores from past New York State Regents Examinations to direct their efforts, teachers developed lessons, labs, and projects that promoted problem solving and critical thinking about real-world data. Lessons included the use of global databases maintained by the U.S. Geological Survey (USGS), force and motion detectors, temperature probes, weather sensors, and scientific models and simulations of concepts students learned in physical and earth sciences. Teachers also developed assessments and rubrics to assess students' knowledge for each of their planned innovations.

Using technology to drive literacy

Research has demonstrated that students are continuously co-constructing knowledge in classrooms. To best capture what they were learning, students were given several opportunities to express their unique knowledge through multiple venues. Using MacBook computers and the built-in iLife software, they created podcasts, iPhoto photo books, slideshow presentations, and other digital media.

Using technology for critical thinking

In a typical week when science projects were assigned, logs confirmed that every one of the computers the university loaned to the middle school were signed out and used every hour of every day, including during lunch and before school. Why the student investment and interest? Science teachers employed problem-based learning strategies requiring students to collaborate, gather data, and propose solutions using scientific and communication tools. Solving a murder mystery by analyzing sand samples from around the world using the digital microscope, predicting weather patterns using their own probe and weather blog, and creating their own *Jeopardy!* game using digital images and mineral tests were a few of the innovations teachers used to promote inquiry in their classrooms.



Heat lab movie
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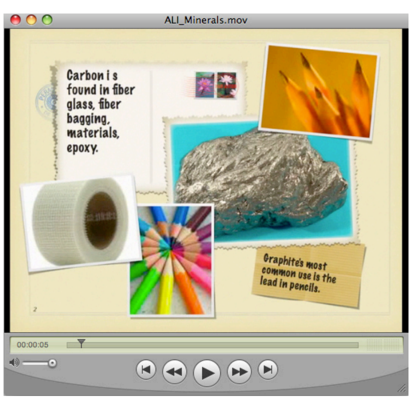

Minerals movie
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Using technology tools to promote inquiry

Throughout the year, notebook computers, probeware, software, digital microscopes, and cameras were inserted into classroom lessons through a variety of instructional strategies. One example that students mentioned often in the debriefing focus groups was the use of digital microscopes, Google images, and Apple Keynote and GarageBand software. Students were required to create mineral reports and present their findings in a "jigsaw" strategy. Class time was spent reporting on the research that students gleaned from their books, their library, and the Internet as well as the found images or created representations that best expressed their learning. Following the completion of their podcasts, students used one full class period to share and discuss their projects. Though lectures and labs supplemented these projects, students most noted their ability to present information in ways that made the most sense to them. As an assessment strategy devised by the teacher, students then used digital microscopes to gather images of rocks and minerals in various magnifications to display concepts such as grain size and composition. These images were then used to create a *Jeopardy!* game in which students competed against one another to prepare for their exams.

This strategic use of the tools to demonstrate content, promote exploration, and encourage students to restate content in ways that best suited their learning styles was typical in the year's activities. Teachers continued to learn new ways to engage children in science through exemplary strategies and tools. Probeware was also a central tool to the science classroom. Concepts such as phase change in states of matter, heat of fusion, heat of vaporization, and the conservation of energy are all challenging and abstract concepts. Labs associated with phase changes and heat transfer often resulted in errors and led to many misconceptions among students. Probeware allowed students to gather live data quickly with minimal time for lab setup and then analyze findings in the same class period. Using stainless steel temperature probes allowed students to heat ice in beakers with consistent temperature readings without stirring vigorously—a task impossible with standard glass alcohol thermometers. Students used these probes in other labs as well to monitor live data, scale their graphs, and share their work electronically. The heat lab video to the left demonstrates the kinds of applications probeware served in teaching specific concepts about heat and heat transfer.

The tools used to promote inquiry included MacBook computers, PASCO probeware, Bodelin ProScopes, Explore Learning Gizmos, Inspiration, Froguts, iLife, iWork, Starry Night, Microsoft Office, and the Earthbrowser.

Data Analysis

Following the yearlong implementation of instructional technologies, including probeware, ProscopeHR, iPhoto, MacBook computers, Datastudio software, GarageBand, and other tools, teachers and university faculty involved in the study reviewed a variety of measurements to determine how successful they had been in addressing student needs.

Test scores and surveys of learning styles and attitudes were administered anonymously so as not to taint the selection of students sampled or influence their reports of teachers' pedagogical practices. More than 400 students were surveyed for their use of technology at home and in class, for their self-assessed learning styles, and for their observation of teaching styles. To supplement field notes and interviews with teachers, students were interviewed in individual debriefing sessions lasting from 45 minutes to one hour; they were asked about specific observed lessons and general perceptions. Focus groups were also conducted to filter out the individual versus collective consciousness of the classroom interpretation. More than 30 hours of interviews were transcribed, and themes were initially identified prior to specific applied coding. Teachers were consulted in interviews regarding these potential themes, and follow-up interviews were conducted when discrepancies occurred.

Taking into consideration the age of the students being interviewed, one possible threat to credibility and verifiability was student hesitation to say "bad" things about their teachers. A conversational tone was maintained throughout the interviews, establishing rapport but trying not to cross over into the "we" mentality described by Seidman.[14] Furthermore, the protocol included built-in redundancy and repetition in the questioning, giving students chances to support or refute their previous statements. Excerpts and scores presented in this study were a part of a large data set drawn from teacher interviews, survey data, classroom artifacts, notes gathered from participant observations, and New York State test scores.

Interviews were recorded digitally. After review, selected sections were transcribed for analysis. Using the NVivo program, transcriptions were analyzed for recurring themes pertinent to the research questions. Themes were identified and specific quotes were drawn from the transcripts. These themes led to the creation of the assertions presented later in this paper.

The following sections examine the student survey results, academic results, and analyses of student interviews that support these conclusions.

Achievement Results

No educational innovation in the state of New York would be recognized as valid without reference to its impact on New York State Regents Exam scores. Though the students at this middle school already achieved at high levels relative to the rest of the state, students showed increased achievement across the board where curriculum areas were targeted. More important, students reported specific ways technology assisted them in learning science concepts. Supplementing the analysis of Regents Exam scores, dozens of hours of interviews and student focus groups were conducted to study the fidelity of the implementation as well as the student and teacher interpretation of the strategies and tools employed. The following sections review some of our analysis of the state achievement test scores.

Earth Science Achievement

Earth science enrollment had historically been based on recommendations from previous science teachers. If students were struggling, they were quickly advised to enroll in an alternate course with a less rigorous schedule. The year of this study marked a shift in policy. Students were allowed to enroll in the New York State Regents earth science course and choose the challenge levels they wanted to set for themselves. Earth science teachers no longer enrolled students only on the basis of teacher recommendations. Students could nominate themselves for the higher challenge in the more difficult course, which they did.

Earth science enrollment increased over 42 percent for this school year, increasing from 110 students in fall 2006 to 157 students in fall 2007. With this policy change and the associated increase in enrollment, the science department chair anticipated more than a few calls from concerned parents about the difficulty level in the classroom. What she found surprised her. With the introduction of MacBook computers, probeware, iLife applications, and new teaching strategies, students spent even more time in her class, and substantially more students achieved the highest level of success in this rigorous course. Furthermore, students maintained 100 percent of test takers scoring in the top two testing brackets (scoring 65 to 100 percent). Though the number of students dropping the class was expected to increase, no students resigned the class during the school year.

When making claims about educational innovation, isolating variables in a complex learning environment is a high priority. To monitor the knowledge and experiences of incoming students and examine the effect of teachers' planned integration of technology, pre- and post-test assessments were given for each unit taught. Student performance on these assessments revealed large increases in knowledge across the content area as well as increased growth from previous years.

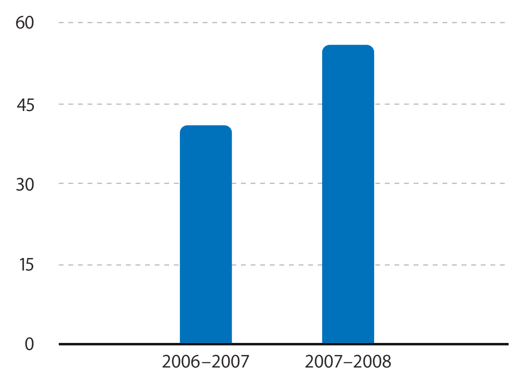
Physical Science Achievement

The state scores for physical science improved as well. The data showed that 91 percent of the students scored a 3 or 4 on the New York State Grade 8 Science assessment with no infusion of technology. Excluding the mainstreamed special education students (commonly referred to as 12:1 students because of school educational policy), this score increased to 96 percent. For the year of this study, with the infusion of technology, 94 percent of eighth grade students in the study school achieved a score of 3 or 4. Excluding the 12:1 student scores, this score increased to 99 percent. The number of students achieving the highest possible score of 4 (mastery level) went from 41 percent in 2007 to 54 percent in 2008, a 13 percent increase. This statistic is even more impressive when viewed in light of the fact that substantially more students elected to enroll in earth science, changing the demographic of students in the physical science course. Yet, the high levels of achievement were not only maintained but actually increased with the infusion of technology into the course.

"I just want to thank you [for] a very inspirational evening on how your team is furthering our children's science knowledge! You've captured their natural [inquisitiveness] and allowed them to investigate and experience this wonderful world of science around us! I believe you are fully equipping our children with tools of the future to become future scientists and intellects!"

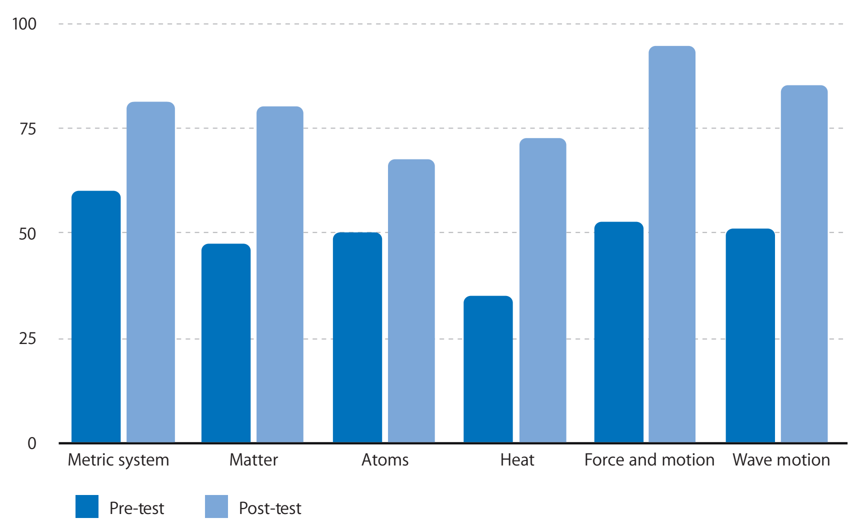
—Parent of student in project

Student mastery of science



Student mastery of physical science content at the highest level increased from 41 percent in 2007 to 54 percent during the project.

Pre- and post-test science achievement



Scores and growth per topic in physical science.

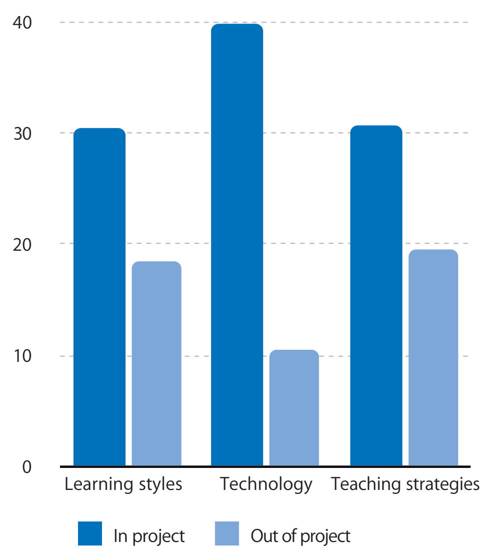
Technology Use

Students were asked to report on the technology they used at home, in the study science class, and in other science classes they attended. As expected, based on findings from other reports we have cited, we found that students used a variety of technology for a wide range of purposes, from doing homework to downloading music to conducting research for reports and making electronic presentations. Students reported that cell phones and gaming devices were part of their typical daily technology use.

The Right Strategies and Technologies

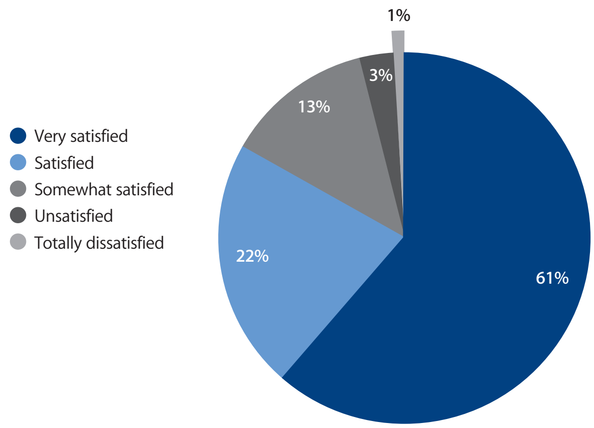
Students want their learning environments to match the strengths, knowledge, and experiences they bring with them to school. Yet, in this study, there was a great disparity between the kinds of tools and resources middle school science students used outside of school and those they used in the classroom. When teachers in this project changed their routines, students noticed. Students in the project science classrooms were twice as likely to report that their teachers incorporated enough technology into their teaching. In addition, a significantly greater number of students strongly agreed that their teachers "used methods that matched my learning style" and "used a good balance of teaching strategies" during science instruction. Clearly the shift to incorporate more technology into science teaching was properly aligned with the needs of today's teens.

Learning styles, technology, and teaching strategies



Students reported on their teachers' abilities to match student learning styles, use of technology, and efforts to change their teaching strategies. Clearly the project's teachers outperformed nonproject teachers, according to their students.

Student satisfaction with technology choices



Over 80 percent of the students involved in this project were satisfied or very satisfied with the types of technology selected for use in their science classes.

Throughout the year, students were asked to report on how the tools used in their science classes helped them learn. The blue areas in the chart above show that over 80 percent of students were satisfied or very satisfied with the technology tools their teachers chose to integrate into their lessons. Given these results, it is probable that the teachers' new strategies are connecting better with students previously neglected by a heavy emphasis on lectures and text geared toward test success. Future studies will help make this connection more explicit.

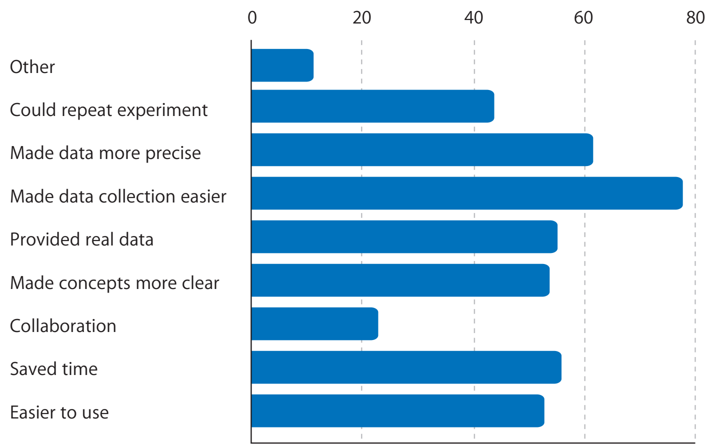
"You get to see what's going on in a real-world situation. Like, instead of just the teacher saying this is what the sand looks like, you can use the ProScope and you look at the sand, and see what's actually in it. You can see the way the ice melts."

—Eighth-grade science student

Improvements in Science Instruction

Without actual data to lay a foundation for scientific discussion, science teaching can fall short. Authentic data collection was a regular part of teaching in the project classrooms; students gathered live data to solve problems posed by the teacher or explored the results of other students' experiments during the same class period. Because of the ease of setup, probeware and other data-mining activities, as opposed to recipe labs, helped the students focus on data analysis and critical thinking. In the survey, students mentioned other strengths of computer use in the lab, including making concepts more clear, the ability to repeat experiments, and the ability to make more precise measurements. Each of these aspects of the classroom environment mentioned by students in focus groups is regarded as an important aspect of a 21st-century science classroom.

Specific improvements in science instruction using selected technology



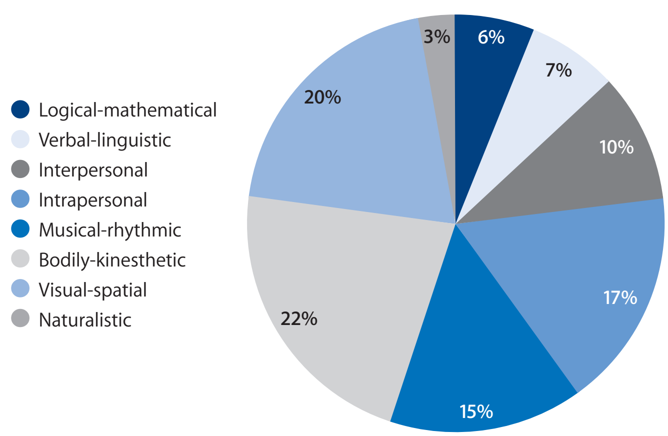
Students reported the various ways in which technology helped them learn science.

Student Survey Results

Learning Styles

For more than a decade, educational researchers have heralded Gardner's work on multiple intelligences and the subsequent work that led to learning style research. Promoting the notion that not all students learn in the same way, and standing on the premise that all children can succeed, several kinds of research-based teaching strategies have been developed. Instead of assuming which kinds of learners populated their classrooms, project teachers began to use formative assessments of their students to gauge how their methods were reaching children. Of the more than 500 science students surveyed, less than 15 percent identified themselves as logical-mathematical or verbal-linguistic kinds of learners. This is significant because traditional science instruction using lectures, notes, and text-books meets the needs of only a small percentage of students surveyed. Over 40 percent identified themselves as either visual or kinesthetic learners; these students would be left out with a monolithic teaching approach.

Students' self-reported characterizations as learners



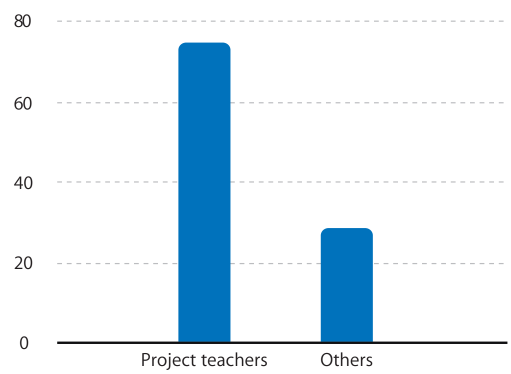
"In previous years we didn't use much technology. My science grade wasn't as great as it is in this class. Because you weren't as hands-on you weren't learning everything—you're just hearing them. When you do the labs and stuff—we didn't have the technology that we have to take pictures—and so you got to see it in a different eye."

—Eighth-grade science student

Preparation for the Future

Students commented on their teachers' enjoyment and commitment to science and how they passed on that enthusiasm. They described themselves as being engaged, like scientists, while gathering live data to solve problems. Other strengths students mentioned were the ability to repeat experiments and to make better measurements. Students also indicated that computers made concepts more clear through simulations and the capability to tell what they learned in their own voices using GarageBand and iPhoto photo books—all aspects of a 21st-century science classroom. Not surprisingly, over 70 percent of the science students reported that teachers using MacBook computers in the classroom were preparing them for the future; only 38 percent of students of other science teachers at the middle school thought they were being prepared.

Preparing students for the future



Nearly 75 percent of students in the project reported that their teachers were preparing them for the future. Only 38 percent of students in other classes felt this way.

Student Interviews: Analysis

Observations from eighth-grade science students

"You got to see what was actually going on instead of having a teacher explain what was actually happening. Well, in other labs, we sometimes don't use the laptops and the technology, and I really like the technology, so I think I learn better and I remember it better when I use it. So it was easier for me to understand the whole concept of specific heat." [In response to, "What about that lab stood out for you?"]

"Originally we would have drawn the graphs ourselves, and that helps too, but seeing it appear on the laptop screen is really cool for me because I never used this type of technology before, and also the [probes] and the screens on the machines for the [probes], I like looking at those and it helps me remember it better when I can see it."

Following the implementation of the project, interviews were conducted at the end of the students' eighth-grade school year. Students were chosen to reflect a variety of ability levels so as to provide information from several vantage points. Selections were based on recommendations from teachers involved in the technology integration project.

Throughout the analysis, several themes emerged across student responses. For example, during interviews, without prompting, each student mentioned lessons that featured educational technology as both their favorite lessons and the lessons they felt were most effective. Students identified the value of the technological tools by recognizing that they inherently allowed important repetition and activation of visual learning styles. While the students engaged in numerous nontechnologically enhanced labs throughout the school year, students identified the technology labs as their favorites—specifically and without prompting. While labs were completed without technology, the students recognized that technology improved their ability to learn.

Technology Helps Address Different Learning Styles

The students identified two distinct preferred learning styles: hands-on kinesthetic learning and visual learning. It is interesting that the "traditional" conception of teaching science (for example, memorization and repetition of scientific "facts") addresses neither of these styles. Students we interviewed recognized this difference and often addressed how the tools chosen in the project classroom directly addressed their needs as learners. The students mentioned how both the novelty

"With the technology it was easier to see the different phases of the stream table. If you were thinking about that specific lab, then it would be looking at it from interval to interval. You could compare it without having to remember what each looked like. So it really helped."

"Well, I am learning more quickly so it's kind of easier and for some reason it is easier to learn with technology than without. It is hard to explain but you do."

and the inherent properties of the tools helped them learn. Students recognized the need for this shift away from the traditional methods, which cater primarily to auditory learners. We noted increases in both students' motivation and academic achievement. Students felt that the activation of other learning styles is preferred to just hearing the information. Through this activation, students began actively constructing knowledge. They were able to connect what was being learned to a "real-world situation" in ways that would not have been possible by memorizing facts and theories.

No students reported technology to be a hindrance to their learning. None mentioned any difficulties in learning or implementing technology. Each student interviewed felt that the technology had helped him or her to learn, and none of them, after an entire academic year of implementation, could cite an instance where technology was not helpful. Instead, they tended to cite instances where the tools allowed for collaboration. If trouble arose with the technology, students came together to find a solution. Students collaborated to teach and learn the technology, with no interference in their learning. The collaboration, developed through the science class, allowed the students to act as experts. It provided the opportunity to learn through interactions with their classmates, and it directly addressed interpersonal, social learners.

Technology Meets Individual Learning Needs

Not only did the students strongly believe that the technology helped address their individual learning styles, but they also felt that it did so in a way that would have been impossible otherwise. The technology made it easier to both gather and understand the information because it was presented in a way the students preferred. Students felt that technology helped facilitate their learning in ways that they had not experienced in previous years. Students indicated that the specific tools helped meet their individual needs and that without them, their retention would have been limited. Once again, it is apparent that the students were not just more motivated, but also better able to assimilate what they learned because of the way in which the learning took place. The tools chosen for instruction addressed learning style needs. The teachers involved in this project were able to activate learning styles and address the needs of their students while maintaining student motivation and interest. Students not only liked the technological tools being used, but they also recognized that these tools helped them to learn and succeed.

Parents and Teachers Respond

Parents Respond to the Technology in Science Classrooms

Many parents have commented on the notebook computer project. Several are thankful for having their children enrolled in a strong academic program while at the same time wishing students had more of an opportunity to be creative and focus on something other than high test scores. One parent put it best.

> *"I have been a parent in this district for years. It is obvious that many teachers spend the school year just teaching the NYS assessment test. While I appreciate the importance of performing well on the test, I have often wondered what our students miss because of that strong emphasis. This year I may have found out. The eighth-grade science program my daughter participated in was outstanding. She wrote and published a book; she helped produce a podcast available to the world (and her out-of-state grandparents). She produced movies, and she learned to solve problems while working on a team. All of this while she was being taught the required aspects of the NY State science curriculum. The hard work of her science teachers and innovative use of Apple technology made this possible. Thank you for giving my daughter this great opportunity!"*
> —Parent of student in project

Integration and Richness Are Pathways to Greater Success

The collaborating district enjoys a long history of instructional excellence, and a part of the district's strategy for high literacy achievement has been to integrate content within their curriculum and incorporate new literacy and writing strategies into their teaching. Most recently the district has invested in projects that incorporate writing throughout the curriculum. In the same way, technology experience has led to greater engagement and learning. Students have written and edited books, lab reports, podcast scripts, presentations, and even fictional and creative writing samples with the expectation that their work will be shared with parents and others. Students are eager to share their work.The students have increased their abilities to use creative ways to communicate and express the content that they have learned, which is consistent with calls for reform like those of the Partnership for 21st Century Skills.

> *"I believe the infusion of technology into my science class has been a positive, beneficial, and exciting experience. I see that there are real-world applications to the techniques and tools that I am teaching my students. They will continue to use and improve these skills as 21st-century learners."*
> *—Science teacher*

> *"The students apply learned concepts by analyzing data, reporting their findings, and making podcasts, movies, and slideshows about science. Using their 21st-century skills, students have created digital media artifacts that go beyond memorizing facts. The ability to share their thoughts, ideas, and knowledge has been widened by the ability to share their work with family and friends across the country by publishing it to the web. They are proud of their work and are eager to show friends, as well as family and their friends, what they have made."*
> *—Science teacher*

Implications for the Future

Future Research and Practice

This yearlong study offers a window into what may be possible in an already high-achieving district. From state to state across the country, educators are scrambling to raise test scores and use them as the major barometer for student success. But at what cost? Teacher and student creativity and other 21st-century skills are being sacrificed. Excuses for not changing classroom practices are made out of fear that taking time away from necessary instruction might lower scores. However, in this study, students performed better and reported their classrooms were meeting their needs better than before. This data shows that "teaching to the tests" is not only contrary to research-tested, evidence-based practice, but also it stands in the way of meeting students where they are.

Investing in Students and Teachers

The notebook computers and scientific tools used by the middle school for this study were not permanent—the equipment was on loan for this short-term study only. However, after the district saw the student outcomes, they decided to invest in the Apple MacBook Learning Lab and commensurate PASCO probeware utilized in the study. There is currently no equivalent technology for these graduating eighth graders at the local high school, where it is likely that their science experiences will be incongruent with these efforts. If students are going to continue on a course that prepares them to compete in a global society, this district must consider that other schools locally and nationally are taking recommendations seriously from the Partnership for 21st Century Skills and the National Education Technology Standards.

It should not go unnoticed that teachers involved in this project received dozens of hours of professional development during the summer and not less than 10 hours weekly of teaching and technology support throughout the year. It is no small feat to raise the bar for students, especially in an already high-expectation environment. However, science teachers did not grow tired from their enormous investment and remained dedicated to personal growth and helping other teachers. Districts serious about implementing similar notebook initiatives and professional development efforts need to support efforts for professional growth if the goal is to scale up projects of this kind.

The New York State scores have improved, despite taking the equivalent of nearly a full month of precious class time away from "covering" curriculum to help students make sense of science. But why would scores improve in an environment where the "ceiling effect" would predict minimal change? One answer may be found in the ability of teachers to reach a wider audience with their newly acquired teaching strategies and tools. Teachers indicated that the visualization of concepts experienced in labs and the new teaching strategies are helping the students recall information on the test more readily. Given these results, it's probable that the teachers' new strategies are connecting better with students previously neglected by a heavy emphasis on lectures and text geared toward test success. Future studies will help make this connection more explicit. One thing is clear: Students are learning more in classroom environments where technology access has been improved and teaching strategies have adapted to this new learning environment. Future studies should begin to isolate the differences achieved across all science content areas and help identify with which tools and for which reasons students choose to engage more authentically.

Summary

The effects of technology in the classroom were clearly evident in students' scores on the New York State Regents Exam. Although the students in this study were already high achievers compared to the rest of the state, their scores in the science assessment rose across the board. In earth science, even when students chose to take the more difficult course, all of them scored in the top two testing brackets. In physical science, the number of students reaching the top two brackets increased, and 13 percent more students achieved the mastery level (a score of 4).

Of course, an appreciation of science means more than just good test scores. Students in the study reported higher achievement in less tangible areas, such as greater engagement with the scientific process and the ability to pass on their knowledge to their classmates. They felt that technology in the classroom directly addressed their individual learning styles, making it easier to retain what they'd learned and apply it in a testing situation. And their confidence improved as they used technology in science, so they stayed in class and committed themselves to learning. Perhaps that's why nearly 75 percent of students in the study felt that their teachers were preparing them for the future, compared with only 38 percent of their fellow students.

Much remains to be learned about the most effective ways to incorporate technology into the classroom, but the results of this study suggest that science education is a fertile field for technological innovation. With the right combination of hardware, software, and teacher training, we can not only improve our children's scientific knowledge, but engender in them an enthusiasm for science that will continue to pay benefits throughout their lives.

Appendix 1

Student Interviews

The interview protocol was developed to gather qualitative data about student learning style preferences, opinions on the effectiveness of the use of technology in the classroom, and students' feelings regarding how their science classes were meeting their needs. Developed as questions that emerged from teacher interviews and classroom observations, the protocol included nine questions with suggested prompts and follow-up questions. An outline of the protocol is included in this appendix. Students were interviewed at the school, separate from other students.

Example student interviews
The MP4 file below includes a student's remarks on the use of the technology and the value it added to science instruction. More student interview excerpts are available in the Interview Clips media gallery. These are included so that readers can understand the context from which these quotes were taken and hear students commenting on teacher responsiveness and technology in their own words.

http://edcommunity.apple.com/ali/galleryfiles/19075/Interview_Clips_2.mp3

Interview Protocol Tier 1

First-tier questions: Teaching and learning (without mention of technology)

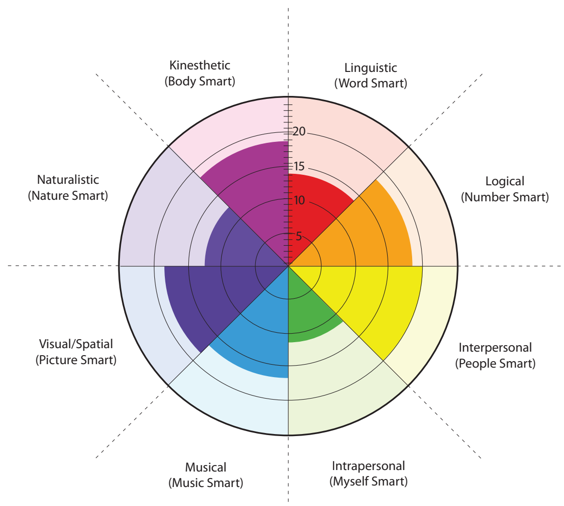
- Can you please tell me your name, your science teacher, and what period you have science?
- How do you like to be taught in your science classes? What type of learner are you? What are your strengths as a student?
- Can you tell me about a science lesson where you learned something really well? What made it such a good lesson?
- How would you describe a normal science lesson?
- What does your teacher do to help you learn in science class? Can you compare your current science teacher with science teachers you have had in the past? What is the most important attribute of a teacher that helps you learn?
- Can you think of a science lesson that did not go well? Can you describe it for me? Why do you think this lesson didn't go well?
- What would you have done differently to improve this lesson for students?
- If you were a science teacher, how would you go about teaching your class? What strategies would you use? What tools, if any, would you need to teach your class?
- How is your learning measured in school? Do you think this is the best way to measure your learning? Can you think of other ways that your learning can be measured?

Interview Protocol Tier 2

Second-tier questions: Referencing technology use in teaching science

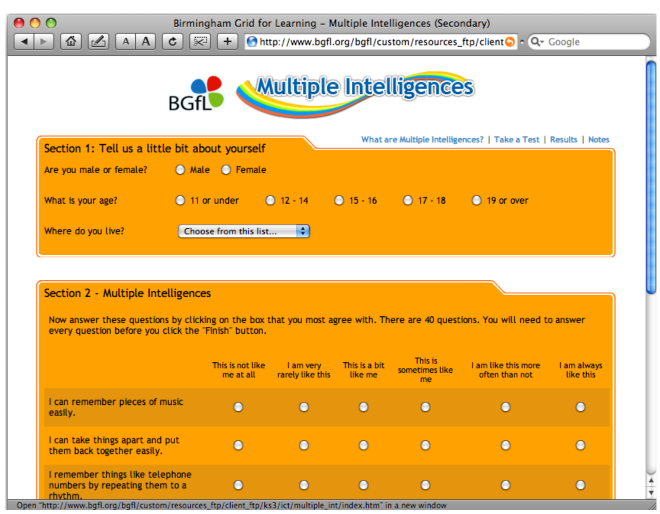
- How do you use technology at home, outside of school?
- How often would you say you use technology outside of the classroom?
- How do you use technology in your science class?
- How often do you use technology in science?
- Does technology help you to learn science?
- Can you think of a specific lesson in which your teacher used technology?
- How was it used? If it was helpful, how did it help you?
- What about it did you like or dislike?

Multiple intelligence inventory



To familiarize students with the notion of learning styles and discussion of their own strengths, students completed an online survey to help them determine their particular learning habits and attributes. After they completed their self-inventories, students were surveyed about whether they were being taught in ways that addressed their particular learning needs and styles.

An example of this survey can be found at www.bgfl.org/bgfl/custom/resources_ftp/client_ftp/ks3/ict/multiple_int/questions/choose_lang.cfm.



Appendix 2

Classroom Inventory

1. Members of the class do favors for one another.
2. The class has students with many different interests.
3. Students who break the rules are penalized.
4. The pace of the class is rushed.
5. The books and the equipment students need or want are easily available to them in the classroom.
6. There is constant bickering among class members.
7. The class knows exactly what it has to get done.
8. The better students' questions are more sympathetically answered than those of the average students.
9. The work of the class is difficult.
10. Failure of the class would mean little to individual members.
11. Class decisions tend to be made by all the students.
12. Certain students work only with their close friends.
13. The students enjoy their class work.
14. There are long periods during which the class does nothing.
15. Most students want their work to be better than their friends' work.
16. A student has the chance to get to know all other students in the class.
17. Interests vary greatly within the group.
18. The class has rules to guide activities.
19. The class has plenty of time to cover the prescribed amount of work.
20. A good collection of books and magazines is available in the classroom for students to use.
21. Certain students have no respect for other students.
22. The objectives of the class are not clearly recognized.
23. Every member of the class enjoys the same privileges.
24. Students are constantly challenged.
25. Students don't care about the future of the class as a group.

This is a set of sample questions taken from Fraser's "My Classroom Inventory" of 100 questions used to categorize the inquiry environment for students.[15] We supplemented 20 additional questions for the survey and analyzed the survey for statistical differences among students reporting how technology was used to further science inquiry in the classroom.

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Citations

[1] TBWA, 2000; Apple, 2003; Pew Research Center, 2005; Metiri, 2006.

[2] Tapscott, 1999; Partnership for 21st Century Skills; NETS, 2007.

[3] AAAS, 1989 and 1993; NRC, 1996.

[4] TIMSS, 2003.

[5] Pink, 2005; Friedman, 2005.

[6] Pew Internet & American Life Project, 2005.

[7] Dewey, 1956.

[8] Gardner, 1983.

[9] Carbo, Dunn & Dunn, 1986.

[10] Pedersen & Yerrick, 2000; Odom, Settlage, & Pedersen, 2002.

[11] Pedersen & Yerrick, 2000.

[12] Bradshaw, 1997; Berger, Lu, Belzer, & Voss, 1994.

[13] Czerniak, Lumpe, Haney, & Beck, 2001; Abd-El-Khalick & Waight, 2007.

[14] Seidman, 1991.

[15] Fraser, 1982.

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