AC 2012-3421: STUDENT-CREATED WATER QUALITY SENSORS

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Student-created water quality sensors

***Abstract-* This paper describes efforts to enrich STEM education through the implementation of a classroom project in which students design, construct, program and test water quality sensors. This paper provides an overview of the educational modules and sensors, which are suitably simple for design and construction from first principles by high school students while being accurate enough for students to make meaningful environmental measurements. The sensor building activities can be tied to core curricula, enabling the modules to be utilized in standard classes by mathematics, science and pre-engineering teachers without disrupting the semester teaching goals. Furthermore, the paper presents the project evaluation results of the three year NSF SENSE IT project, during which 36 teachers have been equipped, trained on these materials, and have implemented the modules with over 1,700 middle and high school students.**

I. Introduction

This paper describes the development and implementation of curriculum modules, tied to the state and national standards in science, math, and technology, that integrate fundamental STEM principles while at the same time introducing students to the field of sensors and sensor networks—technologies that are increasingly important in all fields, but particularly in the world of environmental research.

SENSE IT modules give students an opportunity to acquire and then use STEM skills while at the same time providing a real-world application of science (particularly environmental science), technology (pre-engineering and computing) and mathematics, all tied in a holistic way within the overarching theme of water quality. The specific project goals were to:

- To develop a sensor technologies curriculum for the high school classroom.
- To use environmental sensors to teach technology, engineering, mathematics, science, and critical workforce skills.
- To encourage learners to look at a local problem and local data with a global perspective.
- To promote awareness of sensor network-related careers and opportunities among high school teachers, students and guidance counselors.

The following sections will first address the question of why sensors are an excellent vehicle for such a curriculum, describe the curriculum and its participants in some detail, and then examine its impact on the students in terms of some of the specific skills and concepts that were embedded in the curriculum modules.

II. Why Sensors?

Sensors now play an important role in environmental research. The education of the 21st century environmental technology workforce therefore demands an understanding of sensor technology, as well as the ability to resolve complex environmental issues and to communicate findings to a broad audience. Developing and maintaining such a workforce calls for innovative educational programs that prepare future sensor technology professionals at a variety of levels and in a variety of environmental fields[1]. This type of multidisciplinary, technology-based approach is not sufficiently reflected in our current educational programs.

The classroom integration of sensor development is therefore not only topical but offers highly interdisciplinary subject matter, providing motivating scenarios for teaching science, technology, engineering and mathematics (STEM) topics and skill sets. SENSE IT provides students with the opportunity to learn about sensor technology through a hands-on, collaborative process of designing, constructing, programming and testing water quality sensors. Design-based activities such as SENSE IT provide a rich context for learning and lend themselves to sustained inquiry and revision. Application of learning is a worthy learning objective and an effective route to greater retention of knowledge and depth of mastery. As Caine notes[2], "Children learn best if they are immersed in complex experiences and are given the opportunity to actively process what they have learned." This emphasis on application through design has been informed by research on the use of design for learning complex and interrelated ideas[3,4,5,6,7,8]. Design-based activities also bridge to many of the models of project-based learning[9,10,11,12,13]. In addition, SENSE IT reflects the best practices for developing technical talent outlined in the BEST (Building Engineering and Science Talent) report[14], "What It Takes: Pre-K-12 Design Principles to Broaden Participation in Science, Technology, Engineering and Mathematics": (1) Defined outcomes; (2) Sustained commitment; (3) Personalization; (4) Challenging content; and (5) Engaged adults.

III. SENSE IT

A. Overview of the SENSE IT project

Using SENSE IT materials, students build, calibrate and test a set of sensors and circuits in order to measure water quality parameters (temperature, conductivity, turbidity and depth). When deciding what kind of sensors the students would build, care was taken to create sensor designs that were accurate enough for students to make meaningful measurements, but also simple enough that high school students could understand what they were building and how it worked. To build and understand their sensors, students must use core knowledge of mathematics and physical science, as well as learn practical hands-on technology skills such as soldering and debugging circuits. Students then interface their sensors with computers, write programs to gather raw signals, implement calibration curves, and perform data manipulation and data logging. In later modules, students program their own communications protocols for wireless transmission of the sensor data and connect their computerized sensor stations together to form a distributed wireless sensor network[15]. Additional modules explore the use and implications of this technology for biosciences and environmental research.

B. The Curriculum

The SENSE IT curriculum is comprised of four educational modules. In Module 1, "Sensor development," students learn about the principles of transducers, design, analyze and calibrate electronic circuits around their transducers in order to make numerical measurements of environmental quantities in appropriate units. Initially students work with thermistors to build temperature sensors, but additional add-on lessons enable students to develop a suite of sensors including temperature, conductivity, turbidity and depth sensors.

In Module 2, “Sensor deployment and data gathering,” students learn how to interface their sensors with a microprocessor, in this case, the LEGO NXT microcontroller. They use mathematical skills to calibrate the sensors’ outputs and write programs to integrate these calibration curves and display sensed quantities on a screen in appropriate units. In additional add-on lessons, students learn how to write data-logging programs to log time-stamped data over a sustained period of deployment.

The balance of Module 2 leads students through the development of additional sensors, including conductivity, turbidity and depth sensors. The conductivity sensor involves students passing a current between two lengths of copper wire and measuring the voltage between the electrodes to calculate the resistance, and then converting that measurement to a conductivity value. Students finish by writing a NXT program to collect conductivity measurements and calibrate their sensors.

The turbidity sensor consists of two main components, a light source (light emitting diode or LED lamp) and a light sensitive device (photo-resistor). The LED and the photo-resistor are fixed a short distance apart in such a way that water can flow between them. The more turbid the water, the less light from the LED lamp will reach the photo-resistor. The photo-resistor is a device which changes its resistance depending how much light falls on it. By measuring the resistance of the photo-resistor, students can measure how much or how little light reached it from the LED lamp, and therefore determine turbidity. Students construct and calibrate their turbidity sensor and write a NXT program to collect and display turbidity measurements.

The final sensor is a pressure sensor, used to measure depth. Students figure out the mathematical relationship between pressure and depth, calibrate the sensor, and then write a NXT program which converts the pressure signals from the pressure sensor into a depth measurement. The program actually takes two measurements--it measures absolute ambient atmospheric pressure at the surface and simultaneously measures the absolute underwater pressure at depth. An electronic circuit then subtracts the atmospheric pressure from the underwater pressure reading to give a gauge pressure, with pressure at the surface being defined as zero. Because the sensor takes two measurements and calculates the difference, it is known as a differential pressure sensor. Students calibrate the depth sensor and write a program to record and display the depth measurements.

Module 3, “Environmental science,” puts the engineering activities in context by exploring environmental science issues that provide a meaningful motivation for the development and deployment of sensors. In this module, students work through a series of lessons that reveal water as a precious resource and demonstrate the importance of everyone doing their part to protect and manage that resource. Students investigate careers in environmental engineering that focus on the management of water and explore the sensors and sensor networks engineers are developing and deploying to monitor, manage and protect our water resources.

In Module 4, “Wireless sensor networks,” students learn about wireless communications and work in teams to build and program their own wireless distributed sensor network. Each sensor network consists of several remote sensor nodes, each node comprising temperature, salinity, turbidity and depth sensors, all built by the students. The students then program their own wireless communications protocols, so that each remote node transmits its sensed data back to a central hub, where it can be time stamped, logged and uploaded to a PC for analysis.

C. Materials

Students construct their sensors from scratch using standard off-the-shelf electronics components. Students are led step by step through the physics principles, circuitry and mathematical analysis required to build each sensor, with the aim of demystifying the “black box” effect associated with using commercially available probes in classrooms. Our thesis is that by building their own sensors, students will gain a better understanding, not only of how sensors work, but also of the meaning of the quantities that the sensors are used to measure.

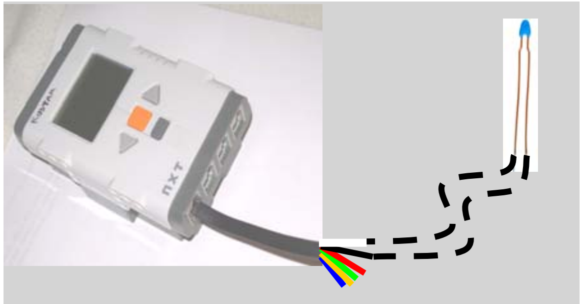


Fig. 1. Connecting a thermistor to an NXT computer to measure water temperature.

Once students have assembled a sensor, they connect it to a LEGO NXT microprocessor (see Figure 1). Students write programs on a PC and then download them to the NXT, where they are executed.

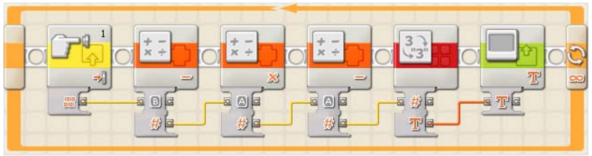


Fig. 2. A simple program in the NXT-G Mindstorms language. These programming blocks read a voltage from a thermistor circuit via a D-to-A converter, use math blocks to convert this into temperature °C by encoding the equation of a calibration curve, then convert this reading to a text string and then display it on the screen, before repeating this process within a continuous loop.

We used the NXT-G programming language, a very simple icon-based programming system that is easily assimilated by beginners with no previous programming experience. Despite its simplicity and speed of use in the classroom, this language is sophisticated enough for students to use it to take readings from D-to-A converters, encode the equations of calibration curves using math blocks, write wireless communications programs using Bluetooth, and write data-logging programs to store sequences of time-stamped sensor readings in files (see Figure 2).

D. Professional Development Experiences for Educators

SENSE IT included a professional development program to provide teachers with: thorough instruction on the curriculum; pedagogical strategies to successfully engage students in STEM-related activities; effective classroom management strategies and equipment necessary to implement the SENSE IT modules with students; support to strengthen teacher content knowledge of sensors and the relevant STEM concepts necessary to implement the SENSE IT activities; and technical assistance to effectively implement the SENSE IT program with students.

SENSE IT teachers completed 120 hours of professional development by participating in two summer institutes (two-week institutes during the summers of 2009 and 2010) and four professional development days (two during the 2009 – 2010 school year and two during the 2010 – 2011 school year).

The summer institutes were two-week experiences. During the first week, teachers learned the module content, in preparation for implementation during the upcoming school year. They were given time to work through all of the lessons themselves and began to devise implementation plans for their own classrooms. During the second week, they were invited to bring two students as part of a teaching laboratory. During this week, the teachers were responsible for teaching the modules to the students in a highly supported environment, surrounded by SENSE IT staff, who were available to assist with any questions or concerns. This gave the teachers the opportunity to review the materials, as well as to see how they work with students, thus enabling them to better prepare for full classroom teaching.

The SENSE IT teachers also participated in four full-day professional development workshops during the school year. The workshops gave the teachers an opportunity to share successes, challenges, and tips; introduced additional sensors; and provided STEM career information. Follow-up classroom site visits offered support to the teachers during module implementation and allowed SENSE IT staff to see first-hand any implementation barriers.

During the first series of summer workshops, the teachers were introduced to the project and worked exclusively with Modules 1 and 2, developing temperature sensors, understanding how to use the LEGO NXT and writing programs for the sensors. During the professional development workshops in the following school year, the teachers were introduced to the conductivity and turbidity sensors. During the second series of summer workshops, teachers were given the opportunity to build the temperature, conductivity and turbidity sensors and were introduced to the depth sensors. The teachers worked with Modules 3 and 4, pulling all the sensors and information learned together to develop their own local sensor networks. In response to discussions with teachers about their students' struggles with the math involved, a "fast-forward" version of the temperature sensor was created which eliminated much of the algebra required. The result is a sensor that is less accurate but still exposes students to the general concepts.

The staggered introduction of the information was purposeful, designed so that the teachers would not be overloaded with information all at one time. Even so, there some teachers struggled to master the information and feel confident with implementation in their classrooms. This is discussed further in the Project Evaluation section below.

In addition to the professional development offered to SENSE IT teachers, a webinar was offered to guidance counselors associated with the SENSE IT participating schools. The webinar focused on future employment opportunities, career preparation pathways, and advice on what teachers and students should look for in STEM programs when applying to schools.

Finally, all of the SENSE IT modules, developed support materials, and evaluation assessments were made available on the SENSE IT project web site (senseit.org).

IV. Project Evaluation

A. *The Participants*

SENSE IT was a three-year project, with the curriculum designed and teachers recruited during the first year and implemented in the second and third years. Teachers were expected to participate for two full years. The first series of summer workshops occurred at the end of project Year 1, with implementation in the following year. Although this was Year 2 of the project, it was the first of two years of implementation and is referred to as Year 1 in what follows.

In Year 1, the curriculum was implemented by 36 teachers in 41 courses, with over 900 students, mostly high school. In Year 2, it was implemented by 31 teachers in 32 courses, with about 800 students, about 75 percent high school and 25 percent middle school. The decrease in the number of teachers was due to the usual shifts in schools: some teachers left teaching while others were assigned to teach to non-STEM subjects. The shift toward middle school was the result of teachers moving levels and wanting to continue with the project. In addition, three teachers left the project because they felt the content was a mismatch with their school curricula and teaching goals.

These were all experienced and stable teachers, with 87 percent having taught for more than five years and 80 percent having done so in the same school. All had undergraduate majors, and all but one was certified, in a STEM subject. However, they had much less experience teaching the actual material covered in the SENSE IT modules: less than half had taught electricity or water quality (with different teachers having taught each), and less than half had used sensors (or probes) in the classroom. Only a few were familiar with LEGO programmable bricks and even fewer had taught simultaneous equations (necessary for calibrating the sensors); 20 percent had taught none of these. Even integrating a problem-based learning project into the classroom was not common practice, with most saying they only did group projects occasionally. Having students design open-ended investigations was even less common.

The subjects covered, and materials used, in the SENSE IT modules were also not familiar to most of the students. Although these were almost all college-bound students (almost 90 percent in both years expected to get at least a college degree), only half reported that they had studied electrical circuits (mostly middle school students), only about one-quarter had ever used probes or sensors, and about the same percentage reported past experience (in or out of school) with the LEGO programmable bricks. Eighty percent of the teachers in Year 1 and 66 percent in Year 2 believed that most or all of their students were not prepared for the math involved (in this case, concepts presented in Algebra I). This lack of experience was confirmed by the students' pre-test scores, which were poor for both electricity and algebra, particularly at the middle school level.

In addition, only about one-third of the students in both years reported that they had designed an investigation that collected and analyzed data (mostly science fair projects), while less than half reported that they had studied water quality in school--although more had studied environmental issues, primarily global warming and pollution. Only a few of the high school students were able to describe what a sensor does. When asked on the background survey to list the two main environmental problems they saw in their own communities, they listed pollution and littering.

On the other hand, both middle and high school students were reasonably disposed toward science, with about three-quarters in both years reporting that they enjoyed science, although only about two-thirds said the same for math. However, when asked to specify a future career or job, only one-third in Year 1 and half in Year 2 listed a STEM-related career, with females twice as likely as males to list a science career and males five times as likely as females to list an engineering career.

One goal of the SENSE IT project was to test the modules for flexibility--flexibility to fit into multiple subject matter classes and flexibility to meet a range of student ability levels. During the first year, teachers were required to implement Modules 1 and 2, using the temperature sensor. Many found that they needed to augment or simplify some of the lessons to meet their students' needs (for instance, by adding more detail, deconstructing the lessons for note-taking purposes, assigning certain lessons as homework, restructuring worksheets make them easier to use, etc.). Others reported having to repeatedly reinforce the students' math skills. In the second year, when the teachers had four sensors to choose from--temperature, conductivity, turbidity and depth— they were asked to build at least two sensors but could design their SENSE IT units using any of the lessons contained within all four modules. As a result, 100 percent reported that their students built the temperature sensor, 63 percent reported that they built the conductivity sensor, 47 percent reported that they built the turbidity sensor, and 31 percent reported that they built the depth sensor. The differences were related to time constraints, the course that SENSE IT was integrated into, and the teachers' judgments about their students' ability levels. In addition, the "fast-forward" version of Modules 1 and 2—with no algebra--were used by about 25 percent of the teachers.

One of the greatest challenges reported by the teachers was finding the time to integrate such an extended project into their curriculum. As a result, the timing and structure of classroom implementation varied greatly from teacher to teacher and course to course. The courses in which the curriculum was taught covered a wide range in terms of broad academic area (mostly science but some math), in terms of specific subject (from regular curriculum subjects to special SENSE IT courses), and by level (from general science to AP and Honors). In both years, about one-quarter of the classes were Regents (the New York State requirement for graduation).

The way teachers integrated SENSE IT into their existing courses varied as well, as did the time they spent on the project. Teachers used SENSE IT to introduce a key topic, generally electricity; fit it in as a unit on its own; or used it as an add-on, extension, or reinforcement in their subject area. Thus teachers met with their students anywhere from two to ten times a week over anything from two to 40 weeks. In Year 1, the total number of minutes spent on SENSE IT ranged from 270 to 1680, with an average of 700; in Year 2, the total number ranged from 240 to 4200, with an average of 1138. In addition, the amount of time spent on water quality issues also varied, with about half of the teachers—mostly those teaching environmental science--reporting that they spent a considerable amount of time on it, while the other half reported spending much less time.

In summary, the SENSE IT curriculum did indeed appear to be flexible as it was integrated into a wide variety of courses and subjects with a wide range of students. On the other hand, the content was new to both teachers and students, while the pedagogy (group work, open-ended investigations) was not a common practice among most of the teachers or common to the experience of most of the students. Implementing a complex set of problem-based learning modules was therefore likely to be a challenge for the teachers and learning the concepts and skills embedded in the curriculum was likely to be a challenge for the students.

B. Teacher Ratings

The teachers were asked to rate how SENSE IT had helped their students in various academic areas, using a scale of 1 to 5, with 5 being the highest. The overall ratings for both student learning and student enjoyment were high, with the few teachers (2-3 each year) who gave lower ratings explaining them as being the result of their own failure to teach well. In terms of specific ratings, in both years most teachers felt that the curriculum had helped their students learn about sensors, but this was even more the case in Year 2 than in Year 1—possibly because they themselves knew more and also because their students built more sensors. They also rated it even more highly in Year 2 than in Year 1 for engaging students, for helping students learn about the environment, and for helping them learn the principles of electricity, and about the same for all other items—the higher ratings probably due to the fact that the teachers felt better prepared for all of these. (The items with the greatest change are highlighted in gray in Table 1 below.) Fewer teachers in both years felt that SENSE IT had helped their students with math—but this varied depending on the emphasis in the class:

Table 1
Percent of teachers who gave ratings of 4-5 by course in each year

	Year 2 (n=32)	Year 1 (n=41)
Helped your students learn the role of sensors	91%	85%
Engaged your students	84%	76%
Helped your students understand how sensors work	78%	76%
Helped your students learn about the environment	72%	56%
Helped your students learn to work well in groups	69%	71%
Helped your students learn the principles of electricity	66%	54%
Reinforced your students' existing math skills	56%	61%
Gave your students new math skills	34%	32%

In addition to the above, the teachers saw many additional benefits in using the SENSE IT curriculum with their students, ranging from the very specific to the more general. In part, their view of the benefits depended on the course that SENSE IT was integrated into, but most wrote about the general benefit that came from giving their students an opportunity to engage in a hands-on project that was tied to real-world problems. In fact, it was notable how many of their comments about the benefits included the phrase “hands on.”

C. Student Ratings

In their post-implementation surveys, the students were also asked to rate SENSE IT in terms of how much they felt they had learned and how much they felt they had enjoyed it, in their case using a rating scale from A to F, including + and -. The high school students’ ratings were high for both (85 percent gave an A or B for enjoyment and about 75 percent gave it an A or B for learning), but the middle school students’ ratings were higher (over 98 percent gave it an A or B or learning and 80 percent for enjoyment). Males at both levels were slightly more enthusiastic than females.

When asked what they liked most about the project, the items mentioned most frequently by the high school students in both years referred to the hands-on aspects of the project—for example, in Year 2 the building was mentioned by 60 percent of the students, the soldering by 59 percent, and the fact that it was “hands on” by 50 percent. The middle school students also liked the building (mentioned by 63 percent) but their second highest choice was working in groups (mentioned by 57 percent) and their third was the fact that the project was hands on (54 percent).

Their dislikes tell a great deal about why they like hands-on projects rather than more traditional forms of learning. In Year 1, the high schools students’ complaints focused on the instructions, which they thought were too difficult to read, involved too much reading, or were unclear. In Year 2, after the curriculum modules had been revised on the basis of the Year 1 experience, the most-mentioned complaints were not related to the reading but to the math, which was mentioned by 45 percent of the students, followed by the closely related tasks of analyzing data and using Excel (40 percent and 39 percent respectively). The Year 2 middle school students also had the math, analyzing data, and using Excel at the top of their lists (50 percent, 44 percent, and 38 percent respectively), but for them, reading the instructions came in second (mentioned by 46 percent).

D. Student Learning

Assessing the impact of a complex and multi-part curriculum that is used in so many different situations poses challenges of its own. However, since a key goal of ITEST, and of STEM education projects in general, is to reach all students, whether middle or high school, in wealthy or poorer schools, academically higher or lower achieving, and male or female, the data reported here will focus on these groups in terms of changes in the key content knowledge and skills embedded in the curriculum related to algebra, electricity, water quality, and understanding of sensors. The algebra assessment was pre-test only in Year 1 (because it was designed as a readiness assessment) but a post-test was added in Year 2, while the water quality assessment was post-test only in both years. The electricity and sensor assessments were both pre- and post-test. In what follows, we look at Year 2 data only, since it can be assumed that the teaching was better in the second year. In all instances, high school and middle school are compared, since middle school students’ scores on the pre-tests were always considerably lower than the high school students’ scores. However, analysis showed that there were few differences by gender, so gender differences are not considered.

1) SES

To determine SES, we used the percent of students at a school receiving free and reduced lunch, a common measure of the socioeconomic status of students in New York State. Since schools that have over 39.15 percent of their students receiving free or reduced lunch are considered low SES schools, all students in those schools were therefore considered to be lower SES—approximately 11 percent of the high school students and 50 percent of the middle school students.

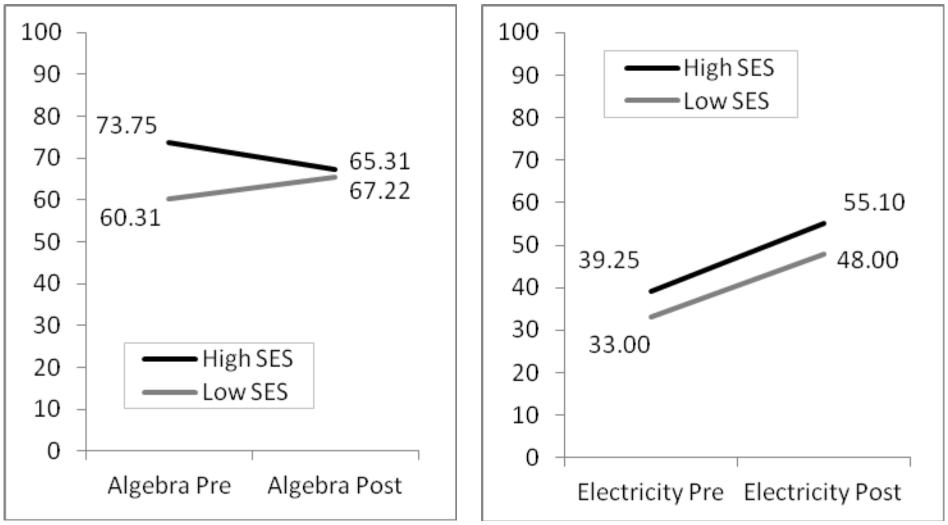
There were 828 matched pairs of electricity tests in Year 1 and 721 in Year 2 (542 high school students and 179 middle school students). In Year 1, there was no algebra post-test, but there was in Year 2, when there were 727 matched pairs of algebra assessments (557 high school students and 170 middle school students). Although there was a significant correlation between the students' post-test scores for algebra and electricity, they are analyzed separately because they call on very different skills and background knowledge, raising the possibility that a student could do well in one but not in the other.

As noted above, the teachers felt that the students struggled with the math needed for SENSE IT. In both years, students in higher SES schools had better pre-test scores for algebra than students in lower SES schools. However, in Year 2 (when there was a post-test), the results of an analysis of covariance at the high school level indicated that there was a significant interaction between SES and the covariate (pre-test scores), $F(1, 553) = 5.78$, $p = .02$ ($p < .05$). Therefore, an analysis of covariance was not the appropriate test here. Instead, a one-way analysis of variance was performed. The results show that students in higher SES schools did significantly better on the algebra pre-test, $F(1, 590) = 13.03$, $p = .000$ ($p < .001$), but not on the algebra post-test ($p > .05$). As Figure 3 shows, the scores of students in higher SES schools declined while those in lower SES schools increased, thus narrowing the gap.

This was not the case, however, for electricity, where the gap at the start, although narrower than that for algebra, remained ($p > .05$). Note that all scores have been converted to a scale of 100 so can be read as percents.

Figure 3

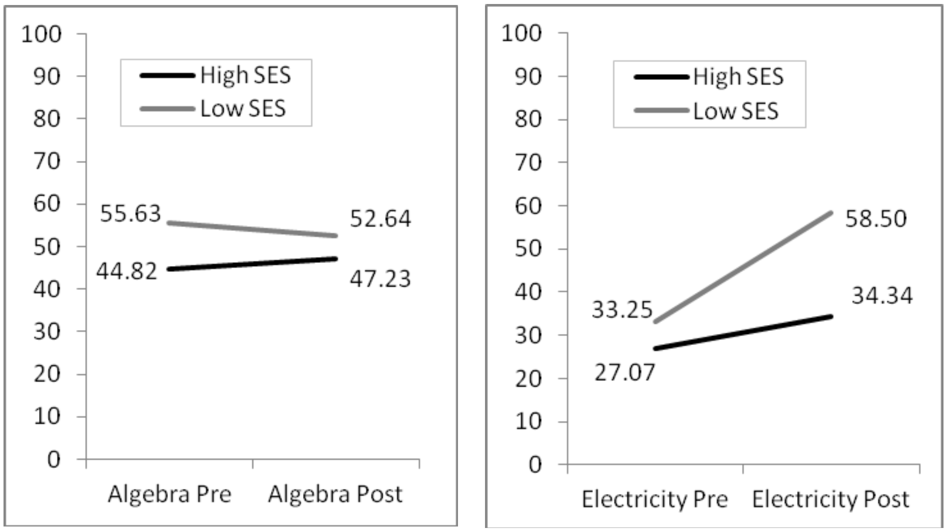
Year 2: (HS) Algebra results by SES **Year 2: (HS) Electricity results by SES**



It is not clear why the algebra scores for the high school students in higher SES schools declined, but it may have had something to do with the fact that many were nearing the end of their senior year.

At the middle school level, in contrast, students in lower SES schools did *better* than students in higher SES schools on the pre-tests for both assessments. However, while the results of two separate analyses of covariance show that the two groups were not significantly different on algebra post-test, students in lower SES schools performed significantly better than those in higher SES schools on the electricity post-test (see Figure 4).

Figure 4



Year 2: (MS) Algebra results by SES **(MS) Electricity results by SES**

2) Weaker compared to stronger students

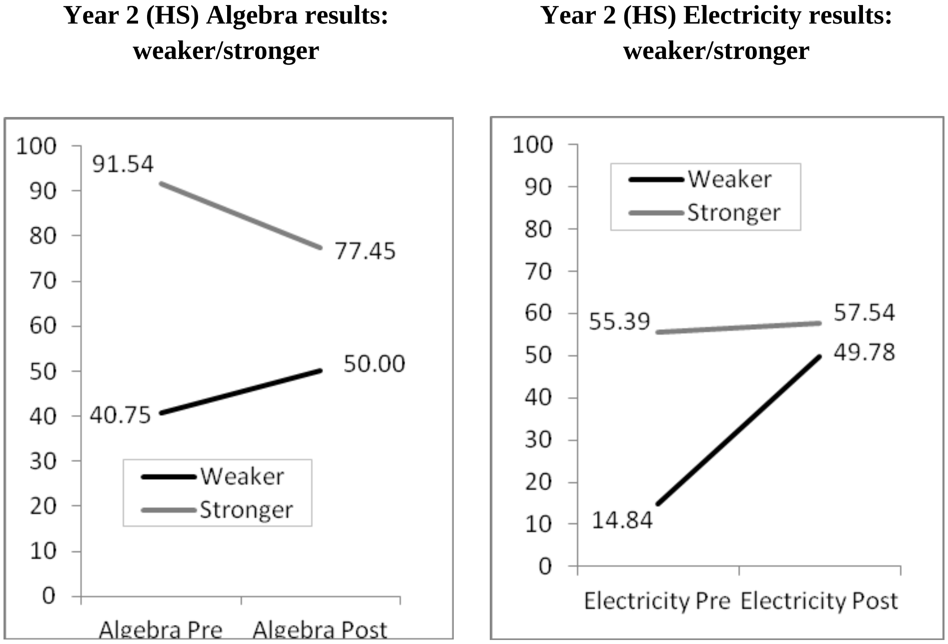
There was a similar pattern when weaker and stronger students are compared. Weaker and stronger students were defined according to whether they scored above or below the mean scores for each test: high school algebra (71.82), high school electricity (38.43), middle school algebra

(47.84), and middle school electricity (29.37). Approximately 40 percent of high school students and 55 percent of middle school students fell below the mean.

For algebra at the high school level, the results of an analysis of covariance show a significant interaction between the factor (weaker vs. stronger students) and the covariate (pre-algebra scores), $F(1, 553) = 4.61$, $p = .02$ ($p < .05$). Since an analysis of covariance was therefore not the appropriate test, a one-way analysis of variance was performed. The results show that the stronger students did significantly better on both the pre- and post-algebra tests, $F(1, 590) = 1715.48$, $p = .000$ ($p < .001$) and $F(1, 555) = 127.65$, $p = .000$ ($p < .001$), respectively. However, as Figure 5 shows, the gap narrowed--with the weaker students improving on the post-test while the stronger students performed less well.

For electricity at the high school level, there was also a significant interaction between the factor (weaker vs. stronger students) and the covariate (pre-electricity scores), $F(1, 538) = 4.85$, $p = .03$ ($p < .05$). Therefore, a one-way analysis of variance was performed. The results show that in this case as well, the stronger students did significantly better on both the pre- and post-tests, $F(1, 570) = 993.67$, $p = .000$ ($p < .001$) and $F(1, 540) = 9.22$, $p = .003$ ($p < .01$), respectively. Again, however, the weaker students improved far more than the stronger students and the gap narrowed.

Figure 5



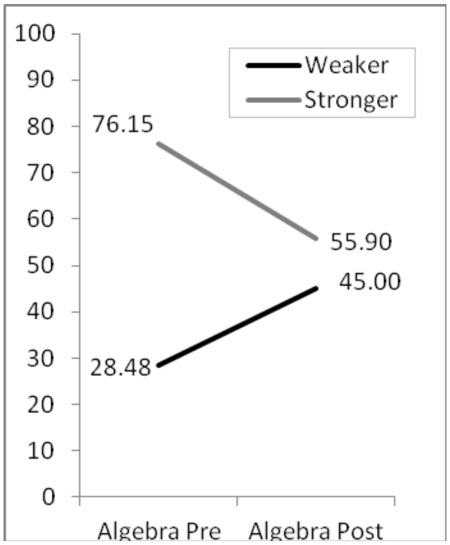
Year 2 (HS) Algebra results: weaker/stronger

Year 2 (HS) Electricity results: weaker/stronger

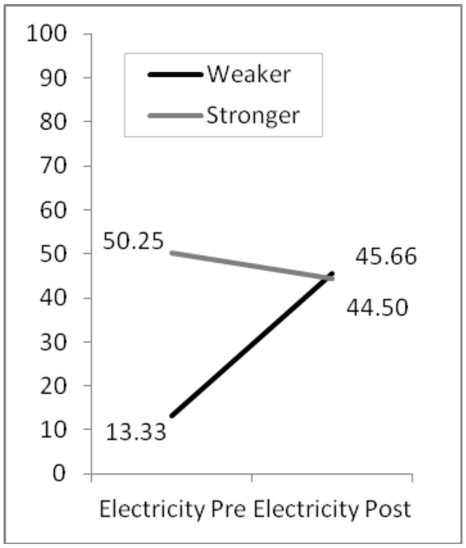
At the middle school level, the results of separate analysis of covariance indicated that although the two groups did not differ on the post-tests for either algebra or electricity, they did differ significantly on both pre-tests, $F(1, 192) = 508.10$, $p = .000$ ($p < .001$) and $F(1, 188) = 433.59$, $p = .000$ ($p < .001$), respectively. In other words, as Figure 6 shows, once again the gap narrowed for the weaker students.

Figure 6

Year 2 (MS) Algebra results: weaker/stronger



Year 2 (MS) Electricity results: weaker/stronger



We can summarize these findings as follows:

For SES

- For high school algebra, the gap between high SES and low SES students *narrowed.*
- For high school electricity, the gap was not as great and *remained about the same.*
- For middle school algebra, low SES students scored higher than high SES students on the pre-test and the difference between them *did not change*.
- For middle school electricity, low SES students scored higher than high SES students on the pre-test but they also *increased more.*

For weaker compared to stronger students

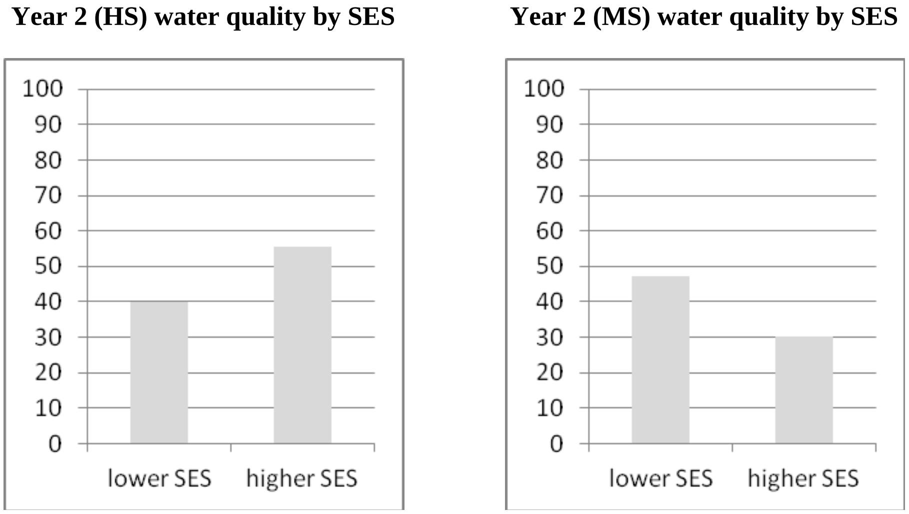
- For high school algebra, the gap between the weaker and stronger students *narrowed.*
- For high school electricity, the gap between the weaker and stronger students *narrowed*, and to a greater extent than for algebra.
- For middle school algebra, the gap between the weaker and stronger students *narrowed*.
- For middle school electricity, the gap between the weaker and stronger students *closed completely*.

Taken together, these results suggest that participating in SENSE IT led to higher scores for all but higher SES and academically stronger high school students, and that this participation particularly benefited students in low SES schools and weaker students in all schools.

3) Water quality

The students were given a post-only assessment in the use of sensor data in determining water quality. There was a bank of ten questions, two of which were required, with five being the minimum number of questions each teacher was asked to use. The results of two separate analyses of variance, for middle school and high school, showed that, at the high school level, students in higher SES schools did significantly better on the water quality assessments, but at the middle school level, students in lower SES schools scored significantly higher (see Figure 7).

Figure 7

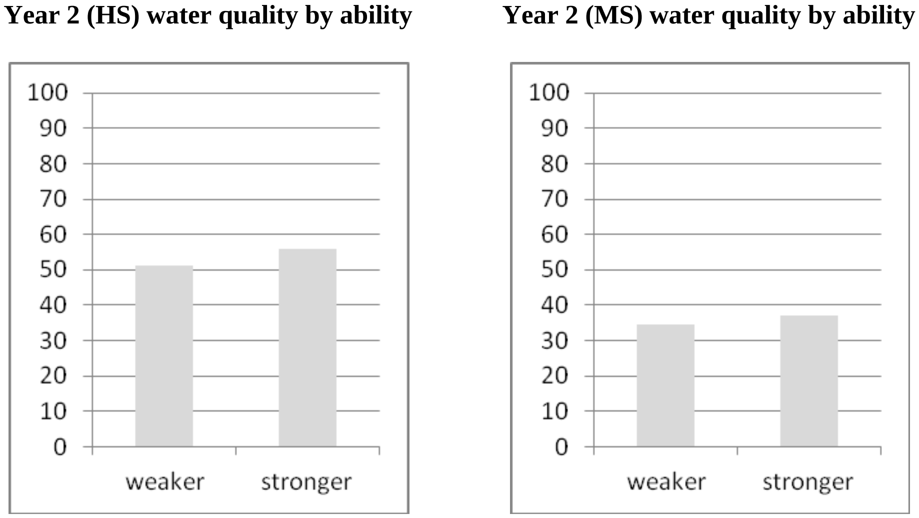


Year 2 (HS) water quality by SES

Year 2 (MS) water quality by SES

The same was not the case for the weaker compared to the stronger students at either the high school or middle school level. In this case, the stronger students did significantly better than the weaker students, whether the two groups were defined by their algebra pre-test scores, $F(1, 490) = 85.43$, $p = .000$ ($p <.001$) or by their electricity pre-test scores, $F(1, 477) = 4.48$, $p = .04$ ($p <.05$). The differences using the electricity pre-test scores are shown in Figure 8.

Figure 8

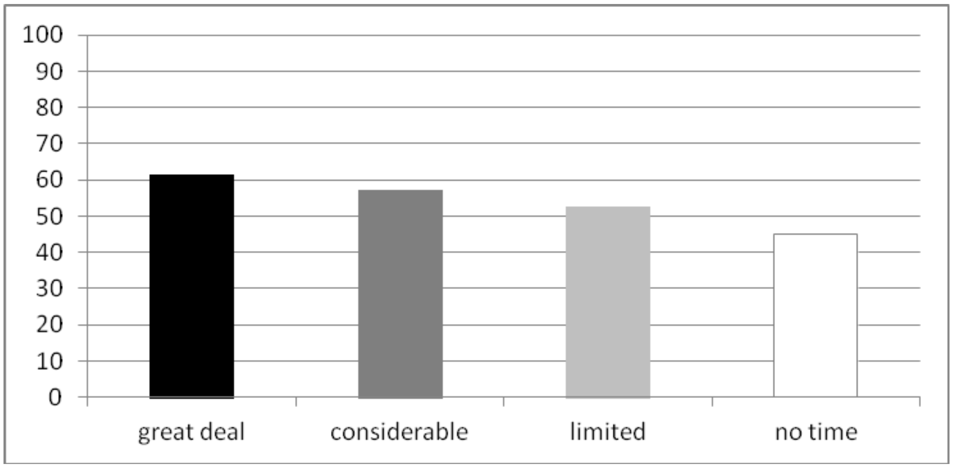


Year 2 (HS) water quality by ability

Year 2 (MS) water quality by ability

Not all teachers focused on relating sensor use to water quality—many of the Physics and Engineering teachers, for example, did not feel that water quality fit well with their content. For water quality, therefore, time spent--rather than SES or student ability-- seems to have made the difference between lower and higher scores on the water quality assessments. Teachers reported if they had spent "a great deal of time," "a considerable amount of time," "a limited amount of time," and "no time" on water quality issues. At the high school level, student performance on the water quality assessment differed significantly by time spent, $F(3, 499) = 5.53$, $p = .001$ ($p < 0.1$), with all those who spent at least a limited amount of time scoring significantly higher than those who spent no time. In addition, those who spent a great deal of time scored significantly higher than those that spent limited or no time, but did not differ significantly from those who spent a considerable amount of time (see Figure 9).

Figure 9
Water quality scores by time spent



There was also a more subtle impact in terms of student awareness of environmental issues, at least for some students. In Year 1, the teachers had been unsure if their students' awareness of environmental issues had changed as a result of the project, with 46 percent saying yes and 49 percent not sure. In Year 2, in contrast, 72 percent said yes and only 25 percent said they were not sure. The response depended in part on the course that SENSE IT was taught in, with the Environmental Science teachers being much more likely to make the connection than the Physics teachers.

This increased emphasis on the water quality aspect of the curriculum was also evident in the student responses to a question that asked what environmental issues they saw in their communities. As noted earlier, on the baseline survey the most common responses were pollution and littering. This was again the case on the post-implementation surveys, but by then students were more than twice as likely to list not only pollution, but water pollution in particular.

4) Understanding of sensors

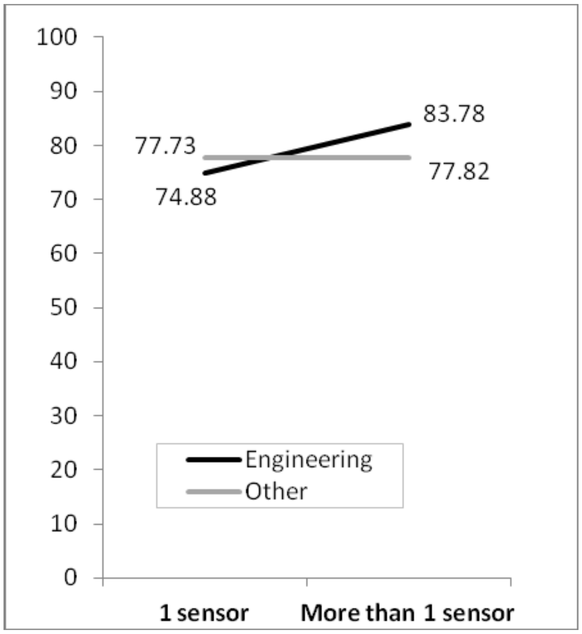
The teachers reported that SENSE IT helped students understand the role of sensors in monitoring the environment, but this appreciation did not translate immediately into the students' ability to define what a sensor does. After participating in SENSE IT, 50 percent of high school students and over 80 percent of middle school students were unable to answer a question on the post-implementation survey that asked them to describe what a sensor does--and most of those who could offer a description only included the sensor's ability to read or gather data, not to convert it.

This finding is confirmed by a second assessment of student understanding of sensors, introduced in Year 2. This was a pile sort, a Flash-based activity that asked the students to sort eighteen cards, twelve of which had pictures of items that have sensors and six of which had pictures of items that do not have sensors. Not all classes did the pile sort, primarily because of lack of access to computer labs, with the result that there were 562 matched sets of pile sorts from 22 schools.

Students had the most trouble with items that control for temperature but at first glance might not appear to, such as a pop-up toaster as opposed to an oven. In the non-sensor category, a majority of students believed that anything electronic or mechanical in appearance must have a sensor in it, for example, iPod ear buds. In addition, there was not as much change from pre to post as was expected. While 54 percent of the students' scores increased, 28 percent decreased and 18 percent did not change. As we have found in previous projects[16, 17], students who can succeed in building and deploying complex artifacts do not necessarily learn the underlying principles. The students' inability to define what a sensor does and the pile sort results suggest that the students needed more explicit instruction for them to understand the role that sensors play in everyday life.

It seemed possible that students in engineering-related courses (n=84) would have a better grasp of how sensors work than students in other science courses (earth science, biology, general science, etc., n=478) and also that students who build more than one sensor would improve more. A two-way analysis of covariance was performed to see if the two factors together affected student scores on the post pile-sort activity. The results showed that while there was a significant difference for those in engineering-related classes between those who built one sensor and those who built more than one, this was not the case for those in other types of classes, $F(1, 557) = 6.40$, ($p < .05$). In other words, as the Figure 10 shows, students in engineering-related classes better understood what a sensor was when they built more than one sensor, but this did not make a difference for students in the other classes.

Figure 10
Year 2: Difference in pile-sort scores for engineering student, by number of sensors built



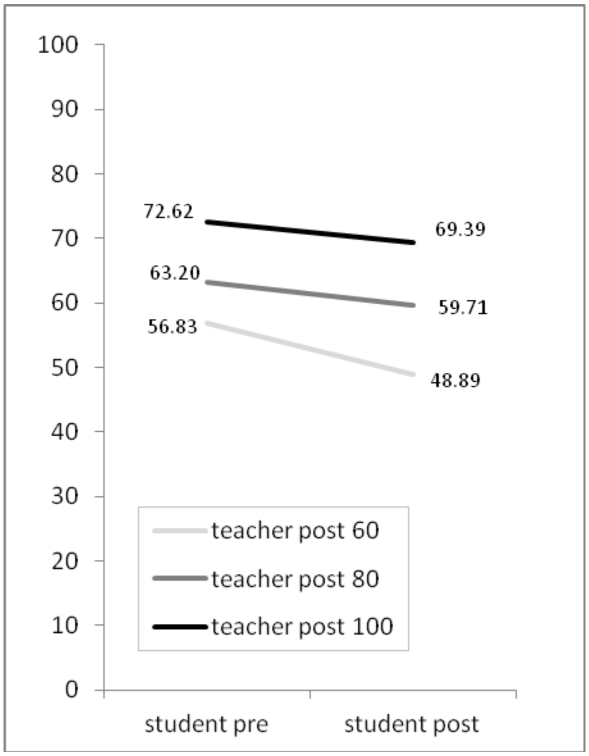
5) The link between teacher performance and student results

At the beginning of the Year 1 summer institute, the teachers took the algebra pre-tests and the electricity pre- and post-tests, partly to familiarize them with the process and partly so the SENSE IT staff could assess their background knowledge. In Year 2, when there were both algebra and electricity pre- and post-tests, the teachers did both. Since it seemed likely, based on findings from other projects[18, 19], that teachers who knew the material well would be better able to teach it, we used these results to explore the relationship between teacher and student performance.

In Year 1, when we only had electricity post-test scores for students, we categorized the teachers into two groups—those with high pre- and post-test scores and those with low pre- and post-test scores--and found that although the students' pre-test scores were not significantly different, their post-test scores were significantly higher if their teachers had high post-test scores, and that in addition, these students improved more than the students of low-scoring teachers.

In Year 2, we found that there was a similar relationship between student and teacher scores. For algebra, we broke the teachers into three groups based on their algebra post-test scores. As Figure 11 shows, although all the student scores declined, they declined most for the teachers with the lowest scores.

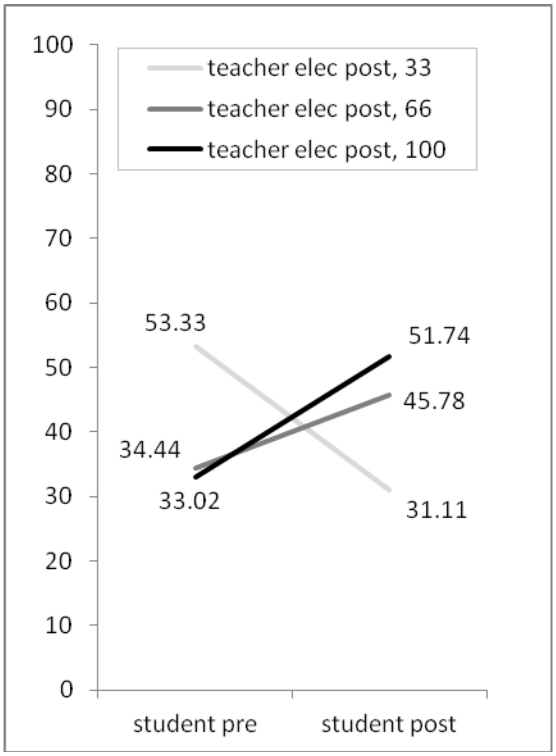
Figure 11
Year 2: Relationship between teacher and student algebra scores



To confirm this, a linear regression was performed. It showed that the Year 2 teachers' algebra post-test scores were indeed a significant predictor of their students' Year 2 algebra post-test scores, $F(2, 688) = 7.06$, $p = .001$ ($p < .01$).

For electricity, in Year 2, most of the teachers got all the answers correct on the pre- and post-test—probably the result of their work in Year 1—so these scores were not useful as covariates. However, the teachers' Year 1 electricity post-test scores remained significant predictors of their students' Year 2 post-test scores, with those having low scores in Year 1 being the only group whose Year 2 students' scores decreased (see Figure 12).

Figure 12
Year 2: Relationship between teacher and student electricity scores



Again, the results of a linear regression showed that the teachers' post-electricity scores in Year 1 were a significant predictor of the students' electricity post-test scores (in Year 2), *F*(2, 439) = 4.46, *p* = .01 (*p* < .05).

The relationship between teacher and student scores is also evident when we look at the weaker compared to stronger students. Thus for high school algebra, there was not only a significant difference between weaker and stronger students, *F*(1, 518) = 133.81, *p* = .000 (*p* < .001), but also a significant difference in the students' algebra post-test scores depending on the teachers' algebra post-test scores, *F*(2, 518) = 3.18, *p* = .042 (*p* < .05). While both weaker and stronger students had higher scores if their teachers' had higher scores, the weaker students in particular did poorly if their teachers' scores were low.

The same was true for electricity at the high school level, where there was again a significant difference in the students' electricity post-test scores depending on the teacher's (Year 1) electricity post-test score, *F*(2, 354) = 4.25, *p* = .015 (*p* < .05). As with algebra, both weaker and stronger students had higher scores if their teachers' had higher scores.

At the middle school level, the picture is slightly more complicated. For algebra, although there was a significant difference in the students' algebra post-test scores by pre-project ability level (weaker vs. stronger), *F*(1, 164) = 11.73, *p* = .001 (*p* < .01), and also a significant difference in the students' algebra post-test scores depending on the teachers' algebra post-test scores, there was a significant interaction between the two factors, *F*(2, 164) = 4.05, *p* = .019 (*p* < .05). In this case, again, the weaker students did particularly poorly if their teachers' scores were low.

For electricity, there was no significant difference in the student post-test scores by student ability level ($p > .05$), but all the teachers scored 100 on the Year 1 electricity post-test, so there were no comparisons.

In summary, in all cases, teachers' scores were significant predictors of student scores. In addition, weaker students were more likely to better if their teachers' scores were high and to do poorly if their teachers' scores were low.

6) The link teacher practices and student results

In both years, teachers were encouraged to discuss the pre-test results for algebra and electricity with the students. In Year 1, however, the teachers would have had to analyze the results themselves or enter them into an online system and few did this early enough to make it useful. In Year 2, the tests themselves were put online, with the entire class's results immediately available to be shared, in graphical format. As a result, about half the teachers reported that they discussed the results with their students.

For algebra at the high school level, although the stronger students did significantly better than the weaker students, $F(1, 553) = 34.18$, $p = .000$ ($p < .001$), and the students whose teachers discussed the pre-test results did significantly better than those whose teachers did not, $F(1, 553) = 1.30$, $p = .000$ ($p < .001$), there was a significant interaction between the two factors, $F(1, 553) = 4.41$, $p = .036$ ($p < .05$). The difference was smaller for stronger students than weaker students.

Similarly for electricity: The stronger students did significantly better than the weaker students, $F(1, 539) = 7.70$, $p = .006$ ($p < .01$), and the students whose teachers discussed the pre-test results did significantly better than those whose teachers did not, $F(1, 539) = 12.62$, $p = .000$ ($p < .001$). In this case, however, the difference between those who did not was larger for the weaker students.

The same was the case for algebra at the middle school level: the stronger students again did significantly better than the weaker students, $F(1, 167) = 7.43$, $p = .007$ ($p < .01$), but the students whose teachers discussed the pre-test results did significantly better than those whose teachers did not, $F(1, 167) = 4.68$, $p = .032$ ($p < .05$), although this was more the case for the stronger students.

For electricity at the middle school level, however, there was no significant difference in electricity scores between weaker and stronger students ($p > .05$), and also no difference between the students whose teachers discussed the pre-test results and those whose teachers did not ($p > .05$).

In summary, discussing the results made a significant difference for both stronger and weaker students. It made a bigger difference for high school algebra than middle school algebra and almost equalized the difference between stronger and weaker students for electricity at both levels.

V. Conclusion

Overall, SENSE IT demonstrates that it is possible to have students carry out complex hands-on projects within the scope of existing standard curricula. SENSE IT gives students an opportunity to acquire and then use STEM skills while at the same time providing a real-world application of science (particularly environmental science), technology (pre-engineering and computing) and mathematics, all tied in a holistic way within the overarching theme of water quality. As a result, the project promotes awareness of the interdisciplinary nature of modern engineering and the interdependence of diverse areas of science and math. Teacher and student participants found this approach rewarding. The theme of environmental stewardship and sensor systems provides: 1) a motivating and meaningful scenario for learning a wide range of core math, science, pre-engineering and technology topics, 2) an engaging link between biological, physical and social sciences and 3) a cutting-edge example of science and engineering research, delivered directly into the classroom in a particular area of growing importance and workforce need.

Research results indicate that the participating teachers were positive about the benefits of the SENSE IT curriculum for their students, both in terms of how it engaged them and in terms of what they had learned. Teacher responses indicate that this success was in part because they were able to adapt the curriculum to fit into their existing courses and to meet their students' academic levels. In other words, the strength of the curriculum was that it could be—and was—integrated into a wide range of courses with a wide range of students—from upper level high school students to middle school students, from academically advanced students to academically challenged students, from Advanced Placement courses to courses for those students who could not qualify for higher level science. The results also suggest that participating in SENSE IT led to higher post-test scores for almost all students, and that SENSE IT participation particularly benefited students in low SES schools and weaker students in all schools.

Although SENSE IT can be taught by teachers in many subject areas, the strong correlation between teacher and student results indicate that teacher preparation is necessary if strong student results are desired. This means that professional development is necessary for teachers not already well versed in the content knowledge and skills embedded in the SENSE IT curriculum.

The SENSE IT initial project was designed to develop and test the concept of integrating the construction of sensors into existing courses. This required a time-consuming approach which is not practical or sustainable when addressing the issue of scale. To address issues with the SENSE IT project materials and professional development experienced over the three years, we have requested a no-cost extension during 2012. The purpose of the project extension is to have an opportunity to streamline the classroom materials and professional development process to make the project available to more teachers at a lower cost per teacher.

The extension plan includes reaching out to new teachers through regional science centers for face-to-face workshops, followed up with online webinars and instruction--for a total of ten hours of professional development associated with each sensor. The recruited teachers will be able to decide which sensor they would like to build and implement in their classroom. The teachers will be provided with the necessary equipment and will be required to report data to the project evaluator. In addition, the classroom materials will be condensed to potentially increase the number of teachers willing to use the materials, compress the professional development experiences to increase the likelihood of teacher interest, and provide more explicit instruction for students as to the role that sensors play in everyday life.

VI. Acknowledgement

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