SENSE IT – transitioning from research to retail with an ocean sensing educational program

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Abstract-.This paper describes the issues involved in progressing from the research and development stage of a pilot educational program to a finished product and a sustainable mechanism for delivering it to classrooms nationwide and beyond. The original project, a National Science Foundation (NSF)-funded Innovative Technology Experiences for Students and Teachers (ITEST) project, was designed to enrich science, technology, engineering, and mathematics (STEM) education using educational modules that teach students to construct, program, and test sensors used to monitor water quality. During the six years of the SENSE IT project, over 90 teachers across the United States implemented the modules in their classrooms with over 3,000 middle and high school students. Project evaluation results indicate that the curriculum is well received by teachers and students, can be integrated into several different subject areas and types of courses, and is effective for a wide range of students, The next stage of refining this program involves developing a sustainable commercial vehicle for producing, updating and disseminating the materials. In contrast, many such educational programs are terminated at the end of their initial R&D grant funding.

Index Terms – **Education, sensors, sensor networks**

I. INTRODUCTION

Sensors are ubiquitous in the modern world, from motion sensing light switches to environmental observatories; we are connected to our physical world in real time. The "sensor revolution" is, in effect, giving the world its first electronic nervous system [1].

Yet contemporaneously with these advances, the U.S. has fallen precipitously behind other countries in educating enough scientists, engineers and technologically trained workers to replace those now approaching retirement. This is especially true in the field of environmental sensing, for which there is a rapidly growing demand. To attract more young minds to science and technology, we must intensify efforts to teach students the science, technology, engineering and mathematics (STEM) skills necessary to work in advanced scientific and technological fields. We must provide teachers with more resources, professional development and innovative curricula through which to engage students and better teach these skills.

The education of the 21st century environmental technology workforce demands an understanding of environmental sciences and other disciplines, an ability to resolve complex environmental issues, and the ability to communicate complex ideas to a broad audience. Fostering these critical abilities will require a new set of learning opportunities. Developing and maintaining such a workforce will rely on innovative educational programs that prepare future sensor technology workforce professionals at a variety of levels and in a variety of science and engineering fields [2]. Proper leverage of information technology (IT)-enabled systems, tools, and services will be critical for addressing these training needs, having a profound impact on the practice of science and assessment, engineering research, industry, and global citizenry. However, the multidisciplinary, technology-based approach needed to ensure workforce preparedness is not always reflected in our educational programs.

To address this need, educational modules were developed that teach fundamental STEM principles through the lens of environmental science, at the same time introducing students to a new set of technologies that are becoming increasingly important in the world of environmental research. Specifically, the Student Enabled Network of Sensors for the Environment using Innovative Technology (SENSE IT) project provides students with the opportunity to learn about science, engineering and mathematics through the design, construction, programming and testing of a student-implemented water monitoring network. The objectives of SENSE IT are to*:*

1) Use environmental sensors as an engaging context to teach technology, engineering, mathematics, science, and critical workforce skills;

2) Encourage learners to look at a local problem and data with a global perspective;

3) Promote awareness of sensor network related careers and opportunities among high school teachers, students, parents and guidance counselors.

This paper provides an overview of the SENSE IT project and curriculum, the material used with students to implement the SENSE IT project in classrooms, a description of the implementation of the project and evaluation results to date and efforts to scale and potentially commercialize the program.

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II. SENSE IT

A. Overview of the SENSE IT project

Design-based activities, such as those included in the SENSE IT project, provide a rich context for learning and lend themselves to sustained inquiry and revision. SENSE IT helps students and teachers develop the deep understanding needed to apply knowledge in the complex domains of real world practice. "Children learn best if they are immersed in complex experiences and are given the opportunity to actively process what they have learned" [3]. Our Other Youth [4], reports that the majority students learn best when instruction emphasizes application. Yet only 16 percent of instruction in U.S. classrooms could be characterized as application [5]. To assist students in achieving content mastery, teachers must create learning environments that present students with challenging problems so that they can demonstrate their knowledge through application. The SENSE IT project creates the opportunity for student application of acquired STEM skills.

SENSE IT provides an infrastructure for teachers and students to construct, calibrate and deploy student developed sensors. The goals is to interest students in, and prepare them for, participation in the STEM workforce, reinforcing fundamental concepts covered in typical high school classes, while also leveraging National Science Foundation-funded and other engineering research in the field of sensor development.

Developing a sensor system for environmental measurement creates a broad technology project which can readily provide a motivating context for a variety of science, math and pre-engineering classroom curricula. Sensor systems involve an information flow of the sensed quantities from the natural environment through the physics of the transducer and the electric circuit in which it is embedded, to a computer, to programs for data gathering and analysis and IT tools for data sharing, storage and display. All of these stages require mathematical reasoning and the use of numerical and algebraic tools consistent with those typically addressed at the high school level.

III. PROJECT ACTIVITIES

A. Curricula

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

In module 2 "Sensor deployment and data gathering", students learn how to interface their sensor circuits with a small computer. They use mathematical skills to calibrate the outputs of the sensors, and write programs to implement 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.

Module 3 puts the engineering activities in context, by exploring environmental science issues that provide a meaningful motivation for the development and deployment of sensors.

In module 4, 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 containing temperature, salinity, turbidity and depth sensors that have all been 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 and logged and uploaded to a PC for analysis.

B. Materials

Students construct their sensors from scratch using standard off-the-shelf electronics components. Students are led 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.

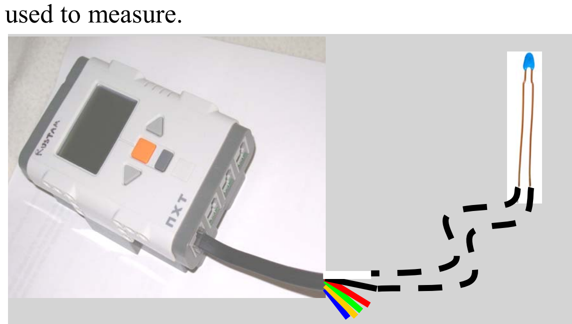

Fig. 1. Connecting a thermistor to an NXT computer to measure water temperature.

Once students have assembled a sensor, they connect it to the small LEGO NXT microprocessor (see figure 1). Students write programs on a PC and then download them to the NXT where they are executed. The NXT-G programming language is used because it is a very simple icon based programming system, which is easily assimilated by beginners with no previous programming experience.

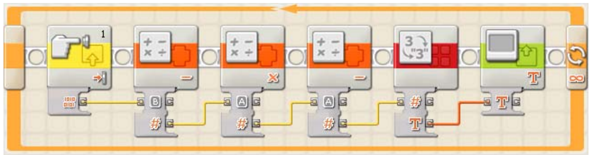

Fig. 2. A simple program in the NXT-G Mindstorms language. These programming blocks read a voltage from a thermistor circuit via an A-to-D converter, use math blocks to convert this into temperature °C by encoding the equation of a calibration curve, then convert this reading to a text string and then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

Despite its simplicity and speed of use in the classroom, this language is sophisticated enough that students can use it to take readings from A-to-D 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).

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.

IV. PROJECT IMPLEMENTATION AND IMPACT

Tracked implementation of SENSE IT in classrooms has demonstrated that, although additional time and effort are required, it is possible to have students carry out complex problem-based, hands-on projects within the scope of existing standard curricula tied to state and national learning standards.

A. Teacher Ratings

Participating teachers are positive about the benefits of SENSE IT, both in terms of engagement and what students learn. Their responses indicate that successful integration of SENSE IT is due to the flexibility of the curriculum to fit into existing courses and to meet students' wide-ranging academic levels, from upper-level high school students to middle school students, and from Advanced Placement to courses for students unable to qualify for higher-level science.

In addition, the teachers saw many other 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 felt 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.

B. Student Ratings

Students also gave SENSE IT high marks. Using a rating scale from A to F, 85 percent of high school students gave it an A or B for enjoyment and about 75 percent awarded an A or B for learning. Over 98 percent of middle school students gave it an A or B for learning and 80 percent for enjoyment. High school students liked the hands-on aspects of the project best, while middle school students liked building and working in groups.

C. Student Learning

The research results suggest that participating in SENSE IT led to higher scores on post-tests evaluating algebraic and electrical circuit knowledge for all but the more affluent and academically strong high school students. SENSE IT participation particularly benefited students in low-income schools and weaker students in all schools.

We can summarize these findings as follows:

<u>For weaker compared to stronger students</u>

- 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*.

The impact on students by SES group was less clear-cut than the impact by ability level, possibly because SES was a school-level attribute and may not have applied to the particular students in SENSE IT classrooms. However, the fact that the project had the greatest impact on the algebra and electricity scores of the weaker students was an important benefit of SENSE IT participation.

D. Participant Impact

Beyond the measured student attitudes toward considering STEM careers before and after participating in SENSE IT, some students have progressed beyond any expectations. Carrying forward lessons learned from building sensors in SENSE IT, students have gone on to win local and national science competitions. In addition, two students have pending applications for patents for sensors they designed. Expectations were exceeded on the teacher side as well. Four teachers have expanded the SENSE IT curriculum into semester-long courses and one teacher used SENSE IT as the basis for application for a national teaching award. The teacher received her award in the autumn of 2013.

V. PROGRAM RECOGNITION AND AWARDS

SENSE IT has been recognized by several professional education societies and organizations. The American Society for Engineering Education (ASEE) featured SENSE IT as an innovative program which incorporates engineering skills within middle and high school science classrooms. The National Science Teachers Association highlighted SENSE IT in their Association newspaper, NSTA Reports as a leading program which teaches students to work with data sets. The National Environmental Education Foundation's National Environmental Education Week named SENSE IT a Greening STEM Innovator for connecting STEM to the environment in a unique and creative way. And finally, SENSE IT was highlighted on Live Science (livescience.com). Live Science features groundbreaking developments in science, space technology, health and the environment.

VI. FUTURE DEVELOPMENT

Unfortunately many innovative educational projects funded by NSF and other organizations terminate at the end of the grant time frame, clearly not an efficient use of grant funding. To make such projects sustainable long term, the initial educational pilot programs need to be transformed into a finished product, and a financially self sustaining mechanism must be created which is capable of continuing to deliver these products to classrooms longer term.

To challenge NSF researchers to think beyond their research results and toward broader adoption of STEM education and learning innovations, NSF's Innovation Corps Learning Program encourages researchers to take discoveries and promising practices from education research and development and promote opportunities for widespread adoption, adaptation, and utilization.

Getting the best evidence-based practices out to potential adopters where those practices can benefit large numbers of students or learners, rather than just in a few classrooms or informal learning organizations, requires an entrepreneurial approach. There are a number of analogous elements between trying to bring product discoveries to market and getting learning innovations into broad practice that NSF can leverage to help promote widespread use of promising educational learning practices. Through I-Corps L, the tools of science can benefit education researchers by helping them to identify approaches that are effective in STEM teaching and learning [6].

In June 2015, Eidos Education received additional funding from the NSF from the Innovation Corp for Learning (ICorp-L) program to explore potential areas of growth and commercialization of the SENSE IT program. Taking results and lessons learned from the pilot studies funded through the NSF ITEST grant described in this paper, the ICorp-L exploration involves identifying the aspects or products potential customers might be willing to pay for, identifying potential customer segments and market size, developing a revenue model and potential partnerships to scale and sustain the SENSE IT program across the U.S.

For example, during the pilot program, three obstacles emerged which are hampering larger scale implementation of the SENSE IT project in classrooms across the country. The first is the inability of teachers to easily access and assemble the required materials to construct the sensors, the second is the cost of tools and materials, and the third obstacle is that many teachers lack the required subject matter expertise to successfully lead students through the sensor construction, calibration and deployment process.

To address materials acquisition, we propose and are currently testing the interest for building sensor construction kits and making them available for purchase by teachers, schools districts and informal groups. Kits will contain the materials required to construct a specific sensor (temperature, conductivity, turbidity or depth). To address cost, we would purchase materials in bulk, lowering the total costs incurred by a single teacher assembling materials; we would investigate lower-cost options for the microprocessor required for sensor calibration, data logging and communications. We are also investigating options to rent equipment to classrooms to reduce a school's overhead expense to participate in the project. To increase teacher's confidence with the curriculum we are developing instructor professional development workshop options and an on-line educator professional development on demand as a subscription service.

There are plans for additional sensor development and additional platforms, such as LEGO EV3, Raspberry Pi, Arduino and PicoBoard, microprocessors used in educational settings and DIY (Maker) groups. This transition and adaptation of the existing materials will also position SENSE IT materials to be used in the undergraduate classroom and for research projects.

SENSE IT also hopes to partner with other marine technology focused programs. Currently SENSE IT is partnered with a marine technology education program located at the University of Rhode Island and partnered with several other groups on proposals to fund future applications of SENSE IT.

VII. CONCLUSION

SENSE IT promotes inquiry based learning strategies through challenging hands-on projects. It also promotes student awareness of the interdisciplinary nature of modern engineering and the interdependence of diverse areas of science and math. The applied themes of environmental stewardship and sensor systems provide:

1) a motivating and meaningful scenario for learning a wide range of core math, science and technology topics and workforce readiness skills, 2) awareness of the ubiquity of sensors in our world while demonstrating the link between biological, physical and social sciences, 3) a scenario to encourage learners to look at local water quality and environmental issues and data with a global perspective and 4) an opportunity to engage students in the use of sensors for environmental monitoring and potential careers involved with environmental monitoring and management.

As we grow the program and network of SENSE IT adopters, we also plan to administer similar evaluation tools to continue understanding the impact of SENSE IT materials on students and teachers. The refinement SENSE IT materials will continue to ease classroom implementation issues and increase the numbers of teachers and students exposed to hands-on, real world learning experiences.

VIII. Acknowledgment

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