AC 2009-2198: USING ROBOTICS TO EQUIP K-12 TEACHERS: THE SILICON PRAIRIE INITIATIVE FOR ROBOTICS IN INFORMATION TECHNOLOGY (SPIRIT)

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Using Robotics to Equip K-12 Teachers:

Silicon Prairie Initiative for Robotics in Information Technology

(SPIRIT)

Introduction

The Silicon Prairie Initiative for Robotics in Information Technology (SPIRIT) is a unique collaborative effort between the University of Nebraska-Lincoln (UNL) College of Engineering, the University of Nebraska at Omaha (UNO) College of Education, and the local Omaha Public Schools (OPS) system. With funding from an NSF ITEST grant, from 2006 – 2008 the initiative recruited and trained 97 math and science middle school teachers through summer workshops and follow-up sessions during the school year, with the goal of equipping teachers in hands-on engineering design principles and providing curriculum development support for STEM instruction. The centerpiece of the training was the university-level TekBot® educational robotics platform developed at Oregon State University, later replaced by the CEENBoT™ mobile robotics platform developed at UNL in the Computer and Electronics Engineering (CEEN) department. More than 9,000 students are expected to eventually participate in this model through in-school and summer programs developed by SPIRIT-trained teachers [1].

This paper will describe the objectives and methodology of the SPIRIT initiative, and report upon its initial evaluation, both quantitative and qualitative results achieved to date.

The SPIRIT Initiative's Objectives

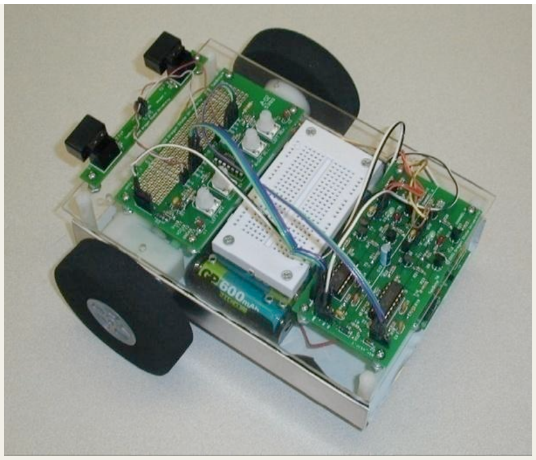
In Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future where engineering chairs discussed challenges facing STEM education in the U.S., NSF's former deputy director, Joseph Bordogna, and the National Academy of Engineering's (NAE) William Wulff suggested that the development of classroom innovations in STEM areas is critical to the country's future national competitiveness [20]. The NAE's Educating the Engineer of 2020 contains a specific recommendation for engineering schools to improve the understanding of engineering and technology literacy to improve math, science and engineering education at the K-12 level [21], which was also identified in NAE's Engineering Research and *America's Future* [22]. In a 2006 forum, Preparing for the Perfect Storm: Taking Action Together, there was a recommendation for a stronger focus on engineering design and its integration into K-12 instruction as a motivator that integrates discovery, exploration, and problem solving [23]. The SPIRIT initiative helped to support this collaborative reform effort using the context of engineering and robotics to support a motivating and flexible STEM learning environment for middle school students.

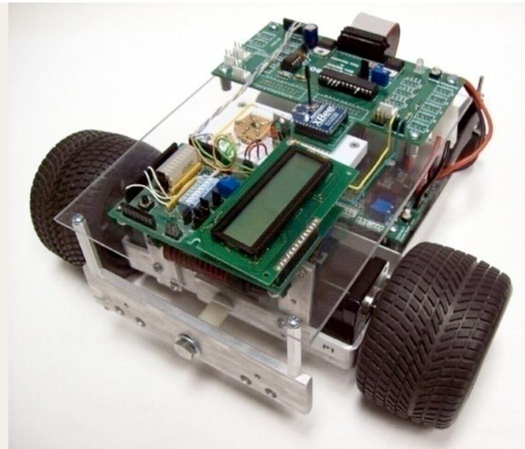
The vision of the SPIRIT initiative was to provide a model for the transformation of math and science instruction in order to ultimately promote student achievement through the use of innovative, inquiry-based robotics activities [2]. The SPIRIT project used teacher professional development as a driver to increase student success in challenging standards-based middle school math and science activities [5, 6, 7, 8], within the context of a new educational robotics technology [2]. Effective teacher professional development is well documented as a key factor in the reform of math and science instruction [9, 10], and the middle school grades are where some of most important general math and science learning occur [11]. Because curriculum reform often needs a motivating context [11, 12], and robotics can provide a motivating context for students [13], the TekBot® educational robotics platform (later replaced by the CEENBoT™ mobile robotics platform) was used to provide this context and to serve as a centerpiece for problem-based learning (PBL) activities. PBL activities, with their emphasis on active engagement of students through the context of an applied problem, have been shown to assist student learning in math and science topics in classroom settings [14, 15, 16]. Problem –based learning often employs a series of instructional steps useful in the context of learning science and mathematical problem solving [17], including having students :

1) Encounter an ill-defined problem,
2) Ask questions about what is interesting or puzzling,
3) Pursue various problem-finding strategies and respond to guided questions from the teacher,
4) Test problem solutions and analyze the results of their efforts,
5) Communicate their results and propose new problems [1].

The TekBot was a perfect venue for this learning approach, since it is engaging in its construction, consisting of off-the-shelf, real electronic parts, instead of proprietary modular components as with the LEGO MINDSTORMS® and VEX® commercially available robot kits, and it can facilitate a wide range of open-ended instructional problems from simple movement contexts (wheel circumference, revolutions, distance) to more complex application contexts (wireless technologies, video processing, sensors, microprocessors). This flexible, hands-on learning platform developed by Oregon State University was proven to be successful at the college level in inspiring interest and engaging students in university-level courses [18, 19], and it was adapted to the middle school level with this project. Out of work with the TekBot® grew a desire to improve upon aspects of the platform, and this led to the creation of a similar but more robust, significantly enhanced and expanded CEENBoT™ mobile robotics platform developed by the CEEN department of UNL. The CEENBoT™ mobile robotics platform includes features that make it more robust to the rough handling of K-12 students (e.g. quick connect cabling in place of individually-soldered conductors) while being highly expandable at the university level, and maintaining a flexible, modifiable design consisting of off-the-shelf electronic hobby store components, and is applicable to a wide range of instructional activities. Figure 1 below shows a comparison of the attributes of the CEENBoT™ and TekBot® platforms.

TekBot®	***CEENBoT™***





Attributes of the TekBot developed by Oregon State University: 5” by 7” footprint

- DC motors with plastic gear train and foam wheels
- Compact design
- Prototype circuit board useful to college and advanced K-12 students

Attributes of the CEENBoT developed by the University of Nebraska (CEEN): 6” by 8” footprint

- Stepper motors for precision control
- Full independent wheel suspension for traversing uneven indoor or outdoor terrain
- Larger capacity, quick-change power supply
- Interchangeable rubber drive tires
- Remotely controllable using a Sony PlayStation® wired or wireless remote controller
- Large prototype board for projects and more reliable connectors
- Serial-to-peripheral interface (SPI) to allow communication between multiple multiprocessors
- Flexible for K-16 educational applications to meet needs at multiple levels

Features Under Development

- Graphical Programming Interface (GPI) for K-16 users (IBM and MAC compatibility)
- Platform will accommodate GPS, on-board video camera, robotic arm, and various sensors, wireless technologies, and microprocessor platforms
- Available in a number of configurations from unassembled kits to completed modules

The four goals of the SPIRIT project were:

1. To develop an effective teacher professional development model for the integration of the TekBot® learning platform, developed by Oregon State University (and the new CEENBoT™) into middle school (grades 7-8) curriculum, as a way for teachers to better

engage students in highly motivating, interdisciplinary and standards-based STEM instruction.

2. To train and equip science and math teachers in grades 7 and 8 in engineering design principles by the use of the TekBot® platform (and the new CEENBoT™), and to help them plan for the integration of this platform into their curricula.
3. To increase student success rates (as reflected by criterion referenced testing) in science and math, including the disaggregated performance of underrepresented minority children within the classes of the participating teachers.
4. To help narrow the typical 15-25% gap in middle school student success rates between African American, Hispanic, and Native American students and their Caucasian classmates in the classes of the participating teachers.

The SPIRIT Initiative's Methodology

From 2006 through 2008, math and science middle school teachers were recruited from the Omaha Public School (OPS) systems, and several other Omaha-based school districts (to a lesser extent) to participate in the SPIRIT project. OPS served as a strong K-12 school district partner for the SPIRIT initiative. Located in metropolitan Omaha, the seat of Nebraska's largest population, OPS educates 50,000 students in urban and suburban neighborhoods, including 11 middle schools serving 6,800 students. Educators of middle grade students include 114 science teachers and 120 math teachers [1]. OPS also serves most of Nebraska's minority student population, with 52% minority students in OPS. This includes 80% of Nebraska's African American students, 60% of the state's Hispanic American students, and 35% of the state's Native American students. The SPIRIT initiative targeted the diverse population of OPS where increasing student achievement in math, science and technology was consistent with the district's goals. The OPS district also possessed a strong standards-based criterion referenced testing process which was used with SPIRIT's curriculum development and project evaluation process [1]. Furthermore, the targeted curriculum content was designed to map closely to OPS's existing standards and testing [1].

Each summer, teachers were trained in an intensive 2 week summer workshop, along with five follow-up Saturday sessions during the school year. In the summer workshop, teachers were trained in STEM content knowledge as well as awareness of engineering design principles. UNL engineering faculty facilitated technical sessions on topics including: the definition of engineering, typical activities of an engineer, the imperative to reach underrepresented students in STEM, the engineering design process compared to the scientific method, soldering 101, circuit analysis laws, motors, circuit simulation tools, and components of the TekBot® (used in 2006 and 2007) and CEENBoT™ (used in 2008) robotics platforms, including assembly instruction. Teachers were empowered to embrace engineering for themselves with the hands-on experiences of constructing their own robot from a bag of electronic parts during the 2 weeks in the summer, and adding additional functionality in fall follow-up sessions. Under the direction of UNO education faculty, the teachers designed STEM lessons to address middle school math and science standards using educational robotics strategies to implement in their classrooms. They presented their lesson ideas along with a completed robot on the last day of the workshop. An optional 3rd week followed, where teachers could help facilitate students in building the same robot platform in an unrelated middle school summer enrichment program at UNO called Aim for the Stars. These optional hours provided teachers with perceptions of how students interacted with the robotics technology as feedback for their own lesson development plans.

After the summer, follow-up sessions were held on Saturdays that were spread throughout the school year. These 5 hour sessions consisted of building additional modules to add to the robotic platform such as an infrared wireless remote controller, and a circuit to count wheel revolutions. The sessions included technical background information, ideas for educational integration and lesson development support. Summer workshop and fall follow-up session materials are accessible at http://www.ceen.unomaha.edu/TekBots/Secondary/.

Of the 97 teachers that participated in the workshops, 37 (38%) were male and 60 were (62%) female. Four teachers were African American (4%) and the rest were white. The SPIRIT project leadership team consisted of a group of 17 engineers and educators. In this group, 2 were female (11.7%), the rest male. There were 2 from underrepresented groups, one African American and one Hispanic American in the leadership team, who were also female (an engineering professor and an engineering graduate student). Of the remaining 15 males, 14 were white and one was Asian American.

The SPIRIT Initiative's Evaluation: Quantitative and Qualitative Results

In the follow-up sessions, and throughout the three years, a learning community was established that brought engineers, university educators, district administrators, and teachers together to further both STEM achievement and local educational goals.

The evaluation of the SPIRIT project focused on the teacher development aspects of the summer workshops due to being funded as a NSF teacher professional development grant. The external evaluator of the project was Dr. Mike Timms, the Managing Director of NSF's Center for the Assessment and Evaluation of Student Learning (CAESL), which has evaluated numerous NSF teacher professional development workshops. Dr. Timms helped to design several instruments to look at teacher professional development, including a pre-post perceptions instrument, a workshop observation instrument, a daily feedback form, and a classroom walk-through instrument, all of which are available on the SPIRIT website. Dr. Timms also observed several days of the workshops along with a sample of the teacher's final curriculum presentations.

The results of teacher perception instruments showed that teachers perceived that they had increased their understanding of STEM-related topics and strategies, with a particular growth in engineering and robotics. [4] The results were derived from the survey that was administered at the beginning of the training workshop (pre-survey) and again at the end (post-survey). Several series of questions measured teachers' perceptions about project-based learning (PBL) and STEM subjects, participants' experiences and expectations of the SPIRIT project, and several open-ended questions. The reliability of the subscale for teachers' perceptions about PBL and STEM measured 0.75 on Cronbach's Alpha, which is a moderate level of reliability [4]. In the first set of questions, teachers ranked their experience level with PBL and STEM topics. The scale indicated their familiarity with the topics and whether or not they valued them as beneficial to their students, with 1 being the least, and 4 the most.

Changes in Teacher Perceptions from SPIRIT Trainings									
	Cohort 1 (2006)			**Corhort 2 (2007)**			**Corhort 3 (2008)**		
General Experience in	**Before**	**After**	**Change**	**Before**	**After**	**Change**	**Before**	**After**	**Change**
Engineering	1	2	1	1	2	1	1	3	2
Electronics	1	2	1	2	2	-	1	3	2
Robotics	1	2	1	1	3	2	1	3	2
Programming	2	2	-	2	2	-	1	2	1
Computers	2	3	1	3	3	-	2	3	1
Cooperative Learning	3	3	-	3	3	-	2	3	1
PBL	2	3	1	3	3	-	3	2	1

In all three years, teachers reported an increase in experience in robotics and engineering, which were major themes of the workshop [4]. There was some variability during the years, with Cohort 1 (2006) reporting a 1 point increase in the areas of engineering, electronics, robotics, computers and PBL, and Cohort 2 (2007) reporting a 2 point increase in robotics and a 1 point increase in engineering only, while Cohort 3 (2008) reported a 1or 2 point increase in each of the areas that was surveyed, including programming and cooperative learning. This variability can be attributed in part to the level of experience of teachers in the groups, e.g. Cohort 3 had a large number of beginning teachers with 64% having 6 years experience or less [2]. This contrasted to the previous two years where the experience levels of the teachers primarily fell into two categories: a group with 7 years or less, and a group with 20 years or more, with a median of 5 years teaching experience [2]. In addition, the teachers in Cohort 2 entered the workshop with higher levels of perceived experience in electronics, computers, PBL and cooperative learning as indicated by their pre-survey ratings [2]. The workshops were also continually modified to respond to feedback from previous years. For example, in 2007 and 2008, additional computer simulation exercises and new lesson formats were provided based on feedback from the first and second years [2].

Open ended-questions also were available on the teacher professional development instruments to solicit comments from teachers on what they liked about the workshops and what they thought could be improved in the workshops. The comments from the open-ended questions mirrored the perceived increases in experience when teachers commented about what they liked about the workshops [4]. For each cohort the comments were coded into eight categories, with the relative percentage of their responses calculated for each category [4].

What Teachers Liked about the SPIRIT Workshops			
	Percentage of Comments		
Categories of comments on what teachers liked	**Cohort 1**	**Cohort 2**	**Cohort 3**
Building of the robots	28%	27%	30%
Interaction with others (faculty, students, teachers)	23%	25%	10%
Help with teaching (exchange of ideas, lesson plans, etc.)	20%	22%	18%
Learning about STEM courses and career opportunities	3%	6%	2%
Learning about engineering	15%	6%	18%
Friendliness and helpfulness of workshop staff	8%	5%	15%
Learning about new resources	3%	5%	0%
Learning about robotics	3%	4%	7%

In all three cohorts, teachers made comments about enjoying the experience of building the robots and about how they were impressed by and learned from the hands-on laboratory sessions of the workshops [4]. They noted that they gained a better appreciation of engineering in general and the career opportunities available to students [4]. The teachers enjoyed the diversity of experience of the workshop presenters and the enthusiasm they brought to the subjects [4]. In all three years, they also praised the aspects of the workshop devoted to helping them develop lesson plan ideas and felt that sharing them and learning from others in the workshop was very helpful in planning instruction for their students [4]. The sessions gave them “concrete examples for applying in the classroom” [4].

Participants also provided feedback on the aspects of the workshops they felt could be improved for future workshops. Teachers in all cohorts made suggestions that have been coded and classified into five categories.

Suggested Improvements for the Teacher Workshops			
	Percentage of comments made:		
Comments on what teachers thought could be improved.	**Cohort 1**	**Cohort 2**	**Cohort 3**
More time: Robot construction, electrical theory, electronics, running robot, problem solving, working together	41%	51%	32%
Less time on lectures about engineering	6%	19%	18%
Content of the sessions	21%	14%	18%
Quality of the sessions	9%	9%	5%
Structure of the sessions	24%	7%	27%

The percentage of SPIRIT teachers from minority ethnic groups was 4%, which was lower than anticipated, however recruiting a higher percentage of minority teachers from the Omaha metropolitan area where only approximately 3-4 % of teachers are from minority groups proved to be a challenge [2]. The 62% female teachers was a viewed as a generally positive outcome as one aim of the project was to influence female students to participate in STEM topics, and having female teachers incorporate robotics and STEM into their future teaching will hopefully have a positive long-term impact [2]. The presence of female engineers in the SPIRIT leadership team also seemed to resonate with many teachers as an image of an engineer they rarely encountered, and one that many wished to expose to their students. Moreover, several female teachers informally commented that they were never encouraged as children to consider a career in engineering even though they possessed high aptitude in math and science. After being exposed to the SPIRIT workshop, these teachers felt they could have pursued a career in engineering, which might likely influence how they will mentor female students to consider an engineering career.

Students in the classrooms of SPIRIT teachers, where they implemented one or more activities derived from the workshop, scored above district and school averages in STEM topics [4]. An initial investigation of 29 groupings of math and science student criterion referenced (CRT) test scores reported by Omaha Public Schools were examined and compared with averages [4]. Of the 29 groupings of students, 21 scored about their school averages, and 23 scored about district averages. Although this was an encouraging result, particularly because many of the groupings were taken from some of the traditionally poorest performing schools in OPS, the project evaluation process discovered that it was impossible to use CRTs to compare across teachers, and to provide a controlled study for the teacher themselves due to the following three problems:

1) Because teachers can have their students retake the CRTs as desired, there is a significant testing difference for comparisons,
2) CRTs vary widely across districts, and thus, it is difficult to use these instruments across districts to examine student achievement, and
3) The timing of the CRTs also vary widely from teacher to teacher, and district to district, making the process of a CRT-based pre-test to post-test evaluation a significant challenge.

Due to limitations of CRTs in measuring student impact from teacher integration of SPIRIT activities, additional work is underway to plan and perform more controlled studies using improved instrumentation. To replace CRTs, a new instrument has recently been developed to examine student achievement within the classroom of select SPIRIT teachers in the form of a 37-item, paper-and-pencil, multiple-choice assessment, covering a variety of STEM topics. This instrument is available on the SPIRIT website along with its reliability and validity ratings.

The SPIRIT project has also been working closely with OPS and area school districts to set up various control groups of students (not using educational robotics), to compare to the classrooms of SPIRIT-trained teachers who incorporate STEM activities with new groups of students each year. The control group effort is using the following strategies:

1) Control group teachers are selected from the peers of a SPIRIT teacher at the same school.
2) The control teacher gives the same content pre-test/post-test instrument within the same time increments as the SPIRIT teachers.
3) The control teachers undertake instruction for the same mathematics and science topics in their usual teaching strategies.
4) As a reward for participation in the control group process, the control class receives a three-hour robotics event facilitated by SPIRIT educators and engineers, after the data is collected.

Several of these classroom studies are currently underway and others are being conceptualized.

The initial results of the SPIRIT initiative laid a foundation for continuation by its learning community to engage in a follow-up project appropriately named SPIRIT 2.0, funded by a Discovery K-12 NSF grant (2008 – 2012). The aim of SPIRIT 2.0 is to build upon the successes and products of SPIRIT and to extend the SPIRIT learning community to a national scale in order to accomplish the following goals [4]:

1. To develop a Grades 5 – 8 educational robotics curriculum to enhance student learning concepts using the flexible TekBot® (and new CEENBoT™) robotics platform.
2. To refine the instructional effectiveness of the curriculum in an extended development process, using peer editing, expert review, pilot testing, and field testing.
3. To integrate a series of interactive and focused assessments into the curriculum to help teachers determine what STEM concepts students are learning.
4. To extend the TekBot® learning platform into a newly developed CEENBoT™ platform for use with the curriculum, including detailed technical enhancements, hardware tuturials, software guides, and a Graphical Programming Interface (GPI).
5. To create a cyber-infrastructure support environment, including a flexible sequencing of lessons, materials, assessments, technical information, and online diagnostics.
6. To begin to scale the project, by use of two summer workshops with national educators (in person and via distance learning), to help teachers learn to use the curriculum.

Several products (STEM lesson modules, tutorials, videos) that have resulted from initial lesson development and classroom pilots by SPIRIT teachers are currently available at: http://www.ceen.unomaha.edu/TekBots/SPIRIT2/. SPIRIT 2.0 encompasses the control group effort being implemented in order to permit a better evaluation of how SPIRIT teacher professional development impacts student achievement. Control group agreements with seven of the Omaha-area school districts have already been established to this end.

The CEENBoT™ is the learning platform at the center of the SPIRIT 2.0 initiative. It is being enhanced with additional educational features (e.g. a GPI programming interface) by the UNL department of Computer and Electronics Engineering, with input from the SPIRIT 2.0 leadership team. As part of SPIRIT 2.0, these products will continue to be refined, tested and distributed nationally in the coming years.

Conclusion

The Silicon Prairie Initiative for Robotics in Information Technology (SPIRIT) set out to create a revitalized model for empowering middle school teachers and students in STEM education, based on inquiry-based educational robotics strategies. In the three years of the project, 97 middle school teachers were trained in an intensive teacher professional development program involving a 2 week summer workshop and follow-up sessions throughout the school year. At the center of this initiative was the university-level TekBot® educational robotics platform developed at Oregon State University, later replaced by the CEENBoT™ mobile robotics platform developed at UNL. Both platforms were adapted to the middle school environment in this project. Teachers were empowered to embrace engineering for themselves with the experience of building a robot from a bag of electronic parts, which also led to their perceived increases in understanding of STEM-related topics and strategies, with consistent growth in engineering and robotics. Students in the classrooms of SPIRIT teachers also showed promising initial results by scoring above district and school averages in STEM subjects.

A learning community was formed over the project's duration that brought engineers, university educators, district administrators, and teachers together. The work of the learning community has been expanded to the SPIRIT 2.0 project, which intends to continue to refine the assessments and educational products of the first initiative and develop a full grades 5-8 educational robotics curriculum for national distribution.

References

1. Chen, B., Grandgenett, N.F. (2005). Project Proposal: The Silicon Prairie Initiative for Robotics in Information Technology (SPIRIT). An Information Technology Experiences for Students and Teachers (ITEST) Proposal for the National Science Foundation Project #0525111.
2. Grandgenett, N.F., Chen, B., Timms, M. (2008). Project Report: The Silicon Prairie Initiative for Robotics in Information Technology (SPIRIT). A final evaluation report for the National Science Foundation Project #0525111, October 31, 2008. Accessed on January 21, 2009 from http://www.ceen.unomaha.edu/TekBots/SPIRIT2/Reports/.
3. Grandgenett, N.F., Chen, B., Ostler, E. (2007). Project Proposal: The Silicon Prairie Initiative for Robotics in Information Technology 2.0 (SPIRIT 2.0). A Discovery K-12 Proposal for the National Science Foundation Project #0733228.
4. Grandgenett, N.F., Chen, B., Ostler, E., Timms, M. (2008). Project Report: The Silicon Prairie Initiative for Robotics in Information Technology 2.0 (SPIRIT 2.0). An evaluation report for the National Science Foundation Project #0733228, December 20, 2008. Accessed on January 21, 2009 from http://www.ceen.unomaha.edu/TekBots/SPIRIT2/Reports/.
5. ISTE (International Society for Technology in Education. (1999). National Educational Technology Standards for Students – Connecting Curriculum and Technology. Eugene, Oregon: ISTE.
6. ITEA (International Technology Education Association). 2000. Preparing students for a technological world. Pp. 1-10 in Standards for Technological Literacy. Center for the Study of Technology, Reston, Virginia: ITEA.
7. National Council of Teachers of Mathematics. (2000). Principles and standards for school mathematics.
8. National Academy of Sciences (1996). National science education standards. Washington, DC: National Academy Press.
9. Loucks, S.F., et al. (2003). Designing professional development for teachers of science and mathematics. Thousand Oaks, CA: Corwin Press.
10. Richardson, V. (1994). Teacher change and the staff development process. New York: Teachers' College Press.
11. Adams, K., Brower, S., Hill, D., Marshall, I. (2000). The components of effective mathematics and science middle school: Standards, teaching practices, and professional development. A Texas State study indexed within the ERIC document service, ED 449032.
12. Greenwald, N.L. (2000). Learning from problems. Science Teacher, v67 n4 p28-32. Apr 2000.
13. Heer, R.L., Traylor, T.T., Fiez, T.S. (2003). Enhancing the Freshman and Sophomore ECE Student Experience Using a Platform for Learning. IEEE Transactions on Education, 46(4), November 2003.
14. Cusick, J. (2001). Practicing science: The investigative approach in college science teaching. NSTA Press, Arlington, VA.
15. Van Heuvelen, A. (1991). Learning to think like a physicist: A review of research-based instructional strategies. American Journal of Physics, 59(10), pp. 891-897, 1991.

16. Weber, J. Puelo, N. (1988). A comparison of the instructional approaches used in secondary vocational and nonvocational classrooms. Journal of Vocational Education Research, 13(4), pp 49-67.
17. White, H.B. (2001). Problem based learning. Biochemistry and Molecular Biology Education, 29(1), 24-25.
18. Sash, R., Detloff, H., Chen, B., Grandgenett, N., Duran, D. (2006). "Work in Progress: Retention of Freshmen Computer and Electronics Engineering Students," in Proceedings of IEEE/ASEE 36th Frontiers in Education Conference, San Diego, CA, October 2006.
19. Gajic, V., Heer, D., Thompson, T, Traylor, R., Frost, G., Fiez, T.S. (2004). Introducing a mechatronic platform to freshman mechanical engineering students. Paper presented at the American Society for Engineering Education Annual Conference, 2004.
20. Bordogna, J., Wulff, B. (2006). Rising Above the Gathering Storm: Energizing And Employing America for a Brighter Economic Future. A Presentation to Chairs of Engineering Departments. Washington, DC.
21. National Academy of Engineering. (2005). Educating the Engineer of 2020: Visions of Engineering in the New Century. Washington, DC: The National Academies Press.
22. National Academy of Engineering. (2005). Engineering Research and America's Future: Meeting the Challenges of a Global Economy. Washington, DC: National Academies Press.
23. Coppola, R., Malyn-Smith, J. (2006). Preparing for the Perfect Storm—A Report on the Forum Taking Action Together: Developing a National Action Plan to Address the "T&E" of STEM. Reston, VA: International Technology Education Association.