Systems and Global Engineering:
A Pilot Study for High School Students and Teachers

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Abstract

This three-year pilot project is designed to engage high school classes in New Jersey and elsewhere in a geographically-distributed systems engineering design project that addresses relevant, social challenges of interest to students worldwide. Collaborating with others around the world to develop a solution to an engineering problem, students are introduced to systems-thinking, team work, effective communication and other 21st century workforce skills. This innovative project aims to increase the number of students interested in pursuing engineering as a career and to increase the pool of teachers familiar with engineering design and systems thinking. This paper presents an overview of the year one activities, including curriculum development and pilot teacher training, and shares initial findings on teacher impact as a result of teacher professional development.

Introduction

The practice of engineering is increasingly conducted in a complex, globally-distributed environment. Multiple entities must work together on a range of project components and systems that must, themselves, work together in order for the entire system to operate effectively.

Stevens Institute of Technology (SIT) has partnered with the New Jersey Technology Educators Association (NJTEA) to introduce concepts and approaches of systems and global engineering to high school technology and engineering students. As part of this three-year pilot project, students in classrooms around the world will have the opportunity to design a solution to a complex problem. Students will apply science and mathematics principles toward the development of an engineered product or system; utilize state-of-the-art industrial software to collaborate on the design; practice inventive thinking and problem-solving to develop designs; collaborate in class-based and worldwide teams; and develop and present a final product. Students will be introduced to a systems-thinking approach that encourages them to see their design effort in a larger context. They will reflect on the problem they are trying to solve, the resources that are available, and assess the desirable as well as potentially undesirable impacts their design will have in its intended environment. Local as well as worldwide collaboration will foster teamwork, innovation and invention, effective communication, and other 21st century workforce skills.

The Systems and Global Engineering (SAGE) project will develop, pilot, and disseminate, via face-to-face and online professional development, four high school level curriculum modules that elucidate systems engineering concepts and that assess different approaches to curricula implementation that will enable effective collaboration among geographically-distributed teams of students. In year one, we will pilot each of these modules and modes of collaboration in 20 New Jersey high schools and 20 U.S. and international schools.

Rationale

The current U.S. STEM workforce is facing an urgent problem. Trends reported by the National Science Board show that there are not enough students in the pipeline today to support the workforce of tomorrow. The number of students earning bachelor's degrees in engineering dropped by 30% between 1985 and 2000. In 2000, less than 5% of those earning bachelor's degrees were in engineering disciplines. In addition, females and minorities have not been completing degrees in engineering at the same rate as males and other groups[1]. The decreasing numbers of students completing degrees in engineering could have a serious effect on the science and engineering workforce of the United States unless more sufficiently prepared students, especially females and minorities, begin studying engineering in college[2].

There is a pressing need to excite and attract students to engineering. Also of critical importance in the contemporary workforce are such technological literacy skills as designing, developing, and utilizing technological systems; working collaboratively on problem-based design activities; and applying technological knowledge and ability to real-world situations[3,4]. These skills are increasingly recognized by business, higher education, and policy leaders as critical for tomorrow's workforce[5].

Further, the technical systems around us are becoming increasingly integrated, both technically as well as socially. Systems thinking and engineering gives students a toolbox and an approach to see the larger picture, both when designing technological solutions for society, as well as in considering how the different elements of a solution produce behaviors and characteristics of the system as a whole.

Thomas Friedman's book, *The World is Flat,* illustrated the globalized and interconnected world in which today's students will work. It is important that students are not only aware of this trend, but are also trained in the skills of virtual collaboration. This is not only a matter of distance, but also of culture, language, skills and many other factors. In addition, the systems and products we create have, to a larger extent than ever before, the potential for global reach. This means that better understanding of potential "foreign" user communities and environments are needed.

According to the National Research Council, employers expect those they hire to apply knowledge in *new and unusual contexts*, as well as to communicate effectively, work collaboratively, understand the perspectives of colleagues from different cultures, and continually update and expand their knowledge and skills.[6]

According to the Governor's *Economic Growth Strategy for the State of New Jersey* [7], the state ranks 29th in the nation in the number of per capita science and engineering graduate students studying in state colleges and universities. The report stresses the need for an additional investment in and reform of K-12 and higher education systems to ensure future economic growth. The National Governors Association (NGA) report, *Innovation America, Building a Science, Technology, Engineering and Math Agenda*[8], calls upon states to: develop standards and assessments in technology and engineering as well as math and science; and support the development of high quality Science, Technology, Engineering and Mathematics (STEM) curricula for voluntary use by districts.

Innovation and creativity is a fundamental objective in this project. Pink emphasizes the importance of innovation and creativity in achieving the "right" design: moving from a 'traditional' engineering approach to a holistic engineering design approach; and the role of the L-directed v. R-directed thinking, in which L-directed thinking represents sequential, literal, functional, textual, and analytic thinking, and R-directed thinking is characterized by simultaneous, metaphorical, aesthetic, contextual, and synthetic thinking. [9]

This project addresses New Jersey's Economic Growth Strategy priorities as well as the recommendations of the NGA report by cultivating innovation, creativity, and systems thinking. It will also address the pipeline issue by increasing the number of high school students who have first-hand experience with engineering and technology in their classrooms in an effort to increase the number of students who will go on to pursue engineering education and careers.

Curriculum Development and Teacher Professional Development Activities

The two major aspects of the first year of the SAGE pilot project have been to 1) identify and develop the four systems and global engineering curriculum modules and 2) provide professional development on those modules to selected pilot teachers. These efforts have involved a team of faculty and educators including: staff members from the Center for Innovation in Engineering and Science Education (CIESE) at Stevens who have backgrounds and work experience in professional and academic engineering, science, and mathematics environments; faculty members from the School of Systems and Enterprises at Stevens Institute of Technology; leaders and experienced technology teachers from the New Jersey Technology Education Association (NJTEA), and 20 practicing high school teachers.

A competitive application process was used as the vehicle to solicit creative and feasible ideas for the specific modules and to select lead teacher educators to assist in the module development. NJTEA members and other science and technology teachers were encouraged to submit ideas for the curriculum modules and to serve as lead teachers. Ultimately, four modules focused on global sustainability issues were selected for development:

- Introduction to the Core Concepts of Systems Engineering
- Water Purification
- Home Lighting in Developing Countries
- Biodynamic Farming

In addition to engaging students in different engineering problems, each module incorporates a different type of collaboration approach in order to determine the benefits and shortcomings of each (Table 1).

Table 1: Paradigms for Student Collaboration

Type of Collaboration	Description	Level of Interaction Benefit
Sharing	Students/classes initially work independently to complete a project or task and then share the results for further analysis by another class.	Relatively Low Analysis/Comparison
Mentorship	Students in one school are partnered with another school to complete a project or task. Partners are selected based on expertise/interest in a specific area and then mentor each other to complete a final project. Teaching a concept leads to long term retention.	Mid-level Teaching/Retention
Workflow	Students in one class are responsible for one step in the workflow of the project: design, prototyping, manufacturing, marketing, etc.	High Often used in business and industry
Interdependent Subsystems	Students/classes are responsible for the design of one component of a larger system. Most difficult to accomplish, but very true to systems thinking and engineering.	Very High Truest in terms of a systems approach

Once the topics for curriculum development were finalized, recruitment efforts to select a diverse group of pilot teachers and schools, including urban disadvantaged schools, rural schools, and high achieving suburban schools, commenced. Teachers interested in serving as pilot teachers completed an application and were required to have their principal's endorsement. Pilot teachers were selected to represent a range of school socioeconomic circumstances, achievement levels, and geographic locations. Each pilot teacher selected receives a grant of up to $1,000 for purchase of needed materials.

Pilot teachers received four days of professional development at Stevens in August, 2008 to introduce them to the four curriculum modules that will be implemented during the 2008-09 school year. The summer professional development workshop also acquainted teachers with the use of telecollaboration for teaching. A second professional development experience will provide training in the use of Pro/Engineer, a professional-grade CAD/CAE software package. Classes will be encouraged to use a CAD/CAE software tool for their designs in order to provide students with a real-world engineering design experience, and the effectiveness of using this software (or not using it) will be evaluated as part of the global collaboration aspect of the project.

During the pilot testing phase, each of the 20 teachers will receive classroom visits by a member of the project team in order to observe how the materials are being implemented in a classroom environment. At the completion of the piloting effort, teachers will be asked to complete a survey and to submit recommendations for improvements to the materials.

Evaluation of Teacher Professional Development

Pilot teachers completed an Internet-based survey prior to and at the conclusion of the summer professional development institute. Teacher perceptions of the workshop and feedback were requested on a daily basis via a paper-based questionnaire in addition to the pre- and post-workshop surveys. The findings presented here are based only on the Internet-based survey results. Due to attendance issues at the summer institute, only 18 participants completed the survey, and some participants neglected to answer all of the questions.

While technology educators were specifically targeted for participation in the SAGE project, the pilot teachers teach a wide variety of subjects, in some cases, in addition to technology. Figure 1 shows the responses the participants provided when asked what subjects they teach. The majority, 11 of the 17 pilot teachers who completed this part of the survey, responded that they teach technology but engineering and various science courses were also common responses. Four teachers wrote in responses that had not been provided on the survey. Three of these were architecture-related courses. The total number of courses taught exceeds the number of respondents because teachers could provide more than one response.

The four-day pilot teacher workshop consisted of four major activities. Teachers were asked to rate how valuable each of the activities was to them. More than 70% of the respondents stated that each of the four activities was very valuable as shown in Figure 2. All of the respondents stated that the overview of systems engineering was very valuable. Teacher responses to the items related to self-efficacy (to be discussed near the end of this section), suggest that systems engineering is the topic in the project with which teachers have the least familiarity and confidence. It is reasonable, then, that they would find this aspect of the workshop very valuable in preparation for teaching modules that incorporate systems engineering as a primary component.
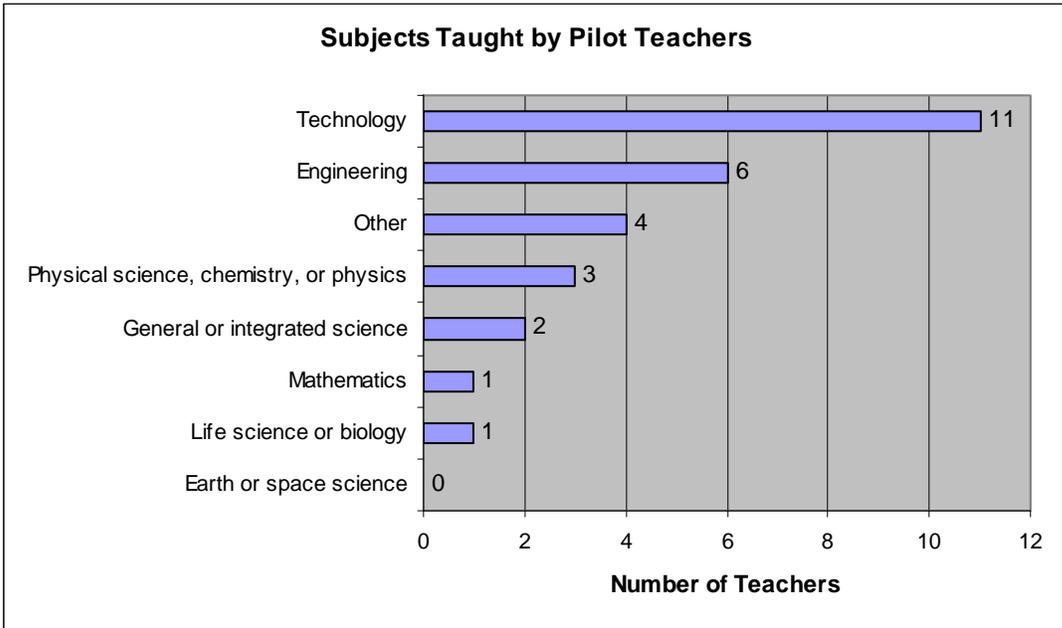
Figure 1: Graph representing the pilot teachers' response when asked what subjects they teach. Total exceeds number of respondents because more than one response was accepted. (N=17)
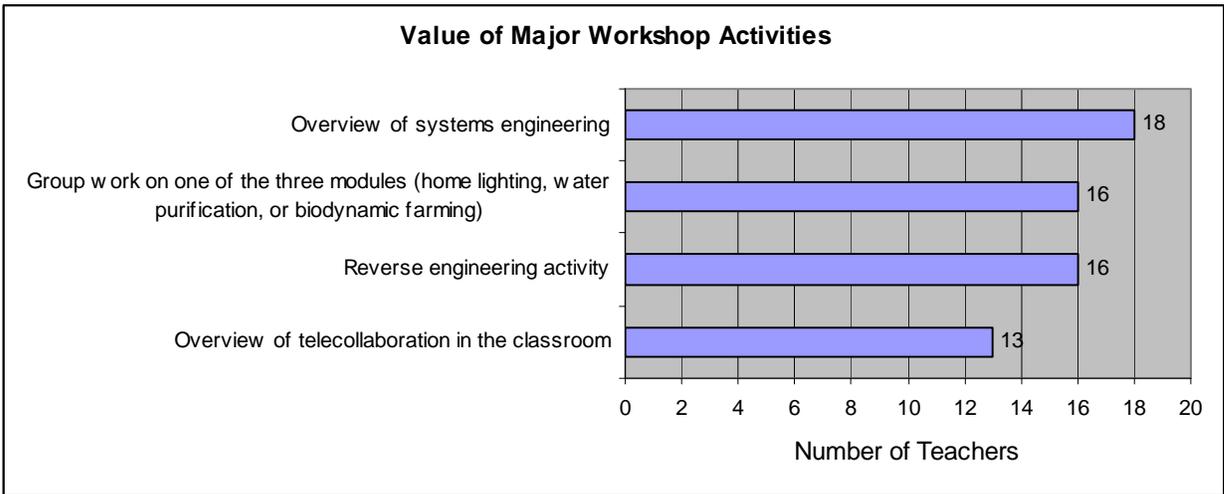

Figure 2: The number of teachers responding "very valuable" when asked about the value of each of the major workshop activities. (N=18)

Pilot teachers were then asked to what extent their awareness or knowledge of specific relevant topics was increased as a result of participating in the workshop activities. Again, systems engineering ranks at the top of the list, with 16 of the 18 teachers completing this part of the survey stating that their knowledge of this topic increased considerably. Figure 3 shows data for this item, but is limited to teachers responding that their knowledge was increased considerably. Teacher knowledge of the engineering design process and general engineering concepts were not as often cited as having been increased considerably, although more than 75% of the teachers stated that their

knowledge of these topics increased considerably or moderately. This apparent discrepancy can be explained by the fact that six of the teachers teach engineering courses and therefore would likely have been quite knowledgeable about general engineering concepts before the workshop but not necessarily knowledgeable about systems engineering, which is a more specialized area of study that is only beginning to receive broader consideration in undergraduate engineering courses and programs.
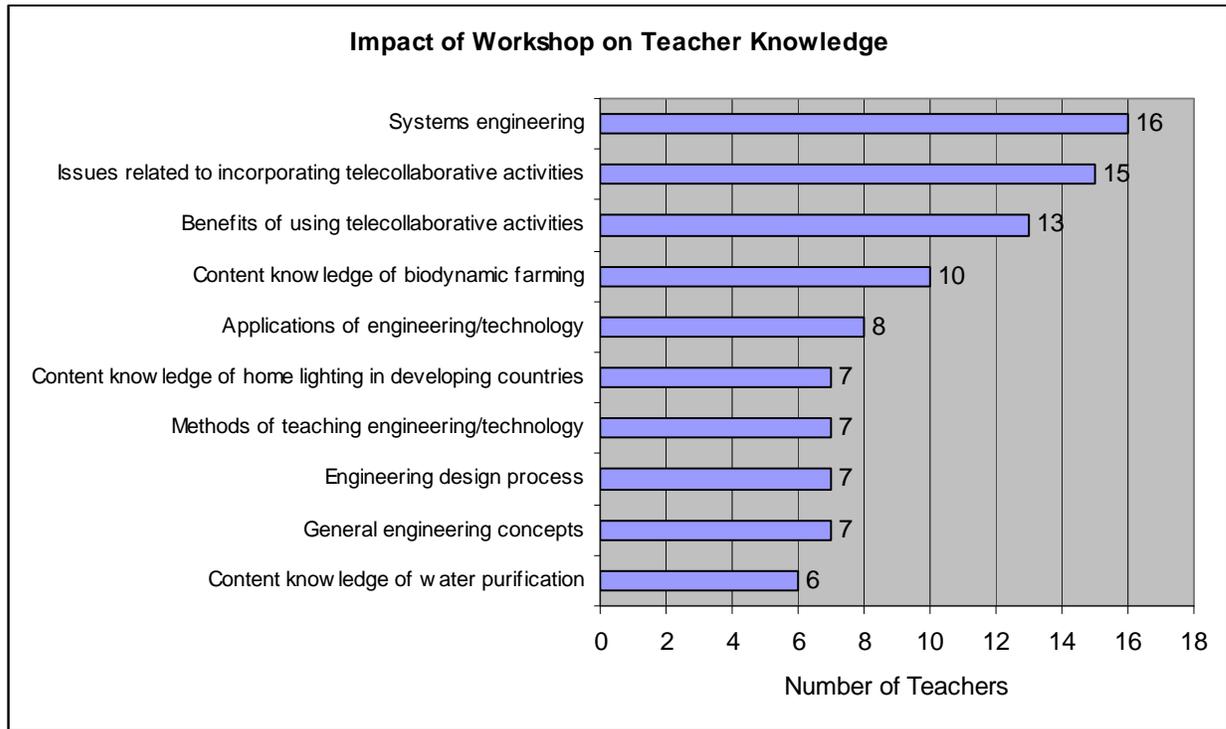
Impact of Workshop on Teacher Knowledge

Topic	Number of Teachers
Systems engineering	16
Issues related to incorporating telecollaborative activities	15
Benefits of using telecollaborative activities	13
Content knowledge of biodynamic farming	10
Applications of engineering/technology	8
Content knowledge of home lighting in developing countries	7
Methods of teaching engineering/technology	7
Engineering design process	7
General engineering concepts	7
Content knowledge of water purification	6

Figure 3: The number of teachers stating that their knowledge of each of the listed topics was increased considerably as a result of workshop activities. (N=18)

Also, the three content knowledge items received fewer responses corresponding to a considerable increase in knowledge, which appears to suggest a weaker area of the workshop. This result is to be expected due to the arrangement of the workshop, however, and is not necessarily indicative of a weakness in the workshop. While all teachers received an overview of each of the content areas on which the three design-based modules are based, they then selected one of the three modules (content areas) for implementation in their classrooms and focused their work during much of the workshop on that specific topic. It would be unlikely, then, that more teachers than had selected a particular module would have responded that their knowledge of the content area covered by that module had increased considerably.

While teachers' perceptions of workshop activities and their self-reported impact on teacher knowledge of content and pedagogy were overwhelmingly positive, an efficacy scale score was used as a more reliable measure of workshop impact. At the beginning and at the end of the workshop, teachers were presented 11 statements, some of which were presented in the negative form (to increase reliability of this measure), regarding their confidence in the classroom. Teachers responded as to their level of agreement to

each statement. Each statement corresponds to an efficacy scale that is related to one of three focal areas in the workshop:

- Content knowledge (1 statement)
- Telecollaboration (3 statements)
- Engineering (7 statements)

An efficacy scale score was calculated for each teacher in each of the three focal areas for both the pre- and post-workshop surveys. The pilot teachers' level of confidence increased significantly in all three of the focal areas as evidenced by p values ≤ 0.010. Results of the paired t-test are shown in Table 2.

Table 2: Results of paired t-test for teacher efficacy in the three focal areas of the workshop (N=16)

Pair	t	Significance
Content pre/post	3.955	.001
Telecollaboration pre/post	3.822	.002
Engineering pre/post	2.930	.010

During the workshop, pilot teachers were actively involved in exploring the web pages where the modules appear (http://www.stevens.edu/ciese/sage) and carrying out activities that appear on those pages just as students will when the modules are implemented in their classrooms. In the post-workshop survey, teachers were asked to rate several attributes of the module that they investigated in depth. All of the attributes received ratings of 4 or 5, with 5 being the highest rating, by virtually all of the teachers as shown in Figure 4. The organization of the material on the pages received the highest rating and clarity of directions and content received the lowest. It is expected that modifications will be made in the web pages as the pilot advances toward classroom implementation.

Next Steps

The results of this pilot project will form the basis for a modular curriculum that will be disseminated, via workshops, presentations, and articles in relevant journals and magazines, to other high schools throughout New Jersey and nationwide. These modules will form an important resource in a major statewide initiative that CIESE is leading in New Jersey to ensure that all K-12 students experience engineering as an integral component of their K-12 education, not merely as an elective or extracurricular activity.

In conjunction with the pilot test, CIESE will also develop an online short course for each of the modules, comprised of 3-5 sessions, that will be used to supplement face-to-face teacher professional development and also for online, asynchronous professional development. This optional online course will serve to prepare teachers from a wide geographic spectrum and with a wide diversity of backgrounds to implement any of the global engineering modules.
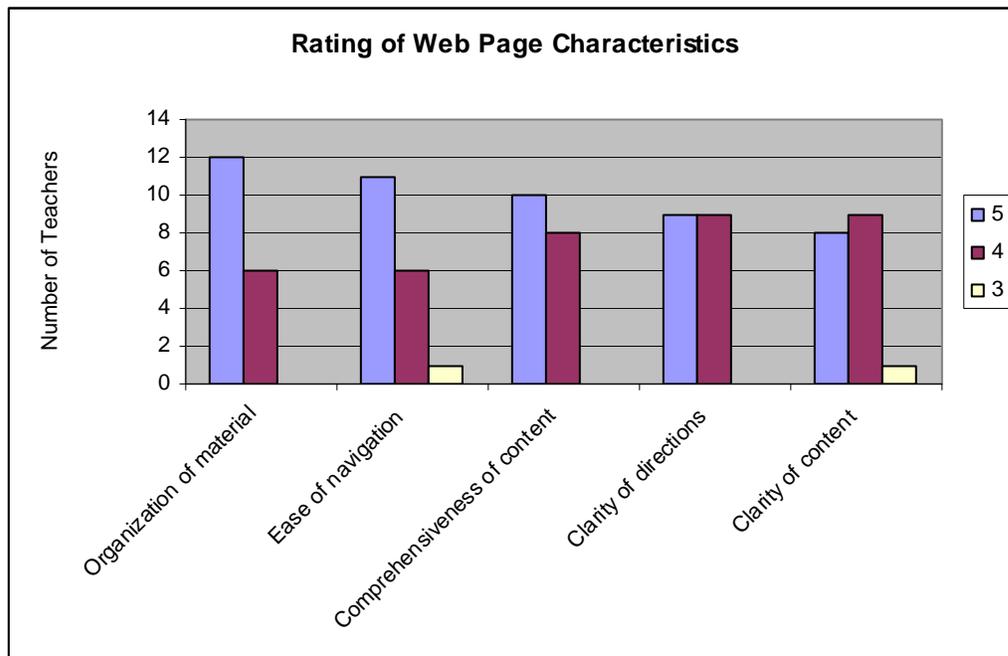
Rating of Web Page Characteristics

Figure 4: Teacher ratings of the web pages for the content-based modules. Numerical ratings from 1 (lowest) to 5 (highest) were assigned by teachers. (N=18)

Conclusion

The SAGE project is still in the early stages of development and implementation, having been initiated less than a year ago, but substantial strides have been made in the development of the curriculum modules and pilot teacher training leading up to classroom implementation beginning in the fall of 2008. Evaluation of these early efforts indicates several strong points of the program, including:

- Teacher preparation for teaching key components of the modules
    - Systems engineering
    - Telecollaboration
    - Content-specific topics
- Web page development that is well organized and easy to navigate. It is expected that refinement of these pages will occur as the project matures.

As the project progresses, additional data collected via Internet-based teacher surveys and classroom visitations will provide information regarding the impact of the project; specifically, on teacher classroom practices as a result of implementing one or more of the SAGE modules.

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