AC 2011-696: MEASURING THE EFFECTIVENESS OF TEAM-BASED STEM PROJECT LEARNING AMONG HIGH SCHOOL STUDENTS AND TEACHERS

Felicia Chong, Michigan Technological University
Douglas E. Oppliger, Michigan Technological University

Mr. Oppliger is a professional engineer and a lecturer in the Engineering Fundamentals department at Michigan Technological University. He is the director of the High School Enterprise program which has a mission to increase the numbers of students pursuing post-secondary degrees and careers in STEM fields. At its core, this program supports K-12 teachers who are leading teams of students in long-term STEM projects. This work is the latest in Oppliger's history of working in K-12 STEM areas. For the past 10 years he has developed and taught first-year engineering courses at the University and actively worked with high school students and teachers to increase and enhance engineering content in K-12 education. This includes consulting on K-12 engineering curriculum development for the State of Michigan. In 2004 Mr. Oppliger was awarded the Distinguished Faculty Award for Service honoring this outreach work. He has presented papers at several national conferences on engineering education. Before coming to Michigan Tech, Mr. Oppliger taught math and science at the secondary level for 11 years. Before that, he worked for 5 years as a project engineer in the marine construction industry.

Jean Kampe, Michigan Technological University

DR. JEAN KAMPE is currently department chair of Engineering Fundamentals at Michigan Technological University, where she holds an associate professorship in the Department of Materials Science and Engineering. She received her Ph.D. in metallurgical engineering from Michigan Tech, M.Ch.E. in chemical engineering from the University of Delaware, and a B.S. degree in chemical engineering from Michigan Tech. She was employed as a research engineer for five years at the Naval Research Laboratory in Washington, DC, and she held an associate professorship in the Department of Engineering Education at Virginia Polytechnic Institute and State University, working there for ten years in first-year engineering education.

Valorie Troesch, Michigan Technological University

Troesch is a Professor of Practice in the Department of Interdisciplinary Studies at Michigan Tech. She is serving as the assessment coordinator for the High School Enterprise pilot program.

Measuring the Effectiveness of Team-Based STEM Project Learning Among High School Students and Teachers

Program Overview and History

High School Enterprise (HSE) is an extra- or in-curricular school program in which students from grades 9-12 engage in active, applied STEM (Science, Technology, Engineering and Mathematics) learning. Students participate in teams organized as “virtual companies” that develop products or services as they engage in long-term projects with a STEM focus. HSE team projects are STEM-based but involve students from various backgrounds and interests. HSE teams are coached by specially-trained high school teachers called “teacher-coaches.”

Teams have access to real-world expertise and mentoring from professionals in academia and industry. HSE teams write business plans, solve real-world problems, perform testing and analyses, build prototypes, manufacture parts, operate within budgets, and manage their projects. Each spring, HSE teams showcase their work alongside college students at Michigan Technological University’s undergraduate exposition. At the conclusion of their HSE experiences, it is expected that the students will demonstrate proficiency in applied workforce skills, they will be more disposed to enter STEM careers, and they will be prepared to undertake the training and education needed to enter these careers.

HSE is premised on the principle that active, discovery-based, and team-based learning environments are effective at enabling students to apply content knowledge to problem-solving and to help prepare them to successfully pursue post-secondary STEM education. It borrows from project-based, problem-based, and inquiry-based learning models. Barrows defined six core characteristics of problem-based learning: learning must be student-centered; it must take place in small groups under the guidance of a tutor; the tutor must function as facilitator or guide; authentic problems are encountered in the learning sequence before other preparation or study; problems are used as tools to acquire the knowledge and skills to solve the problem; and new information is acquired through self-directed learning.[1] The Buck Institute for Education, which focuses on project-based learning, identifies a similar set of essential elements: “organized around an open-ended Driving Question or Challenge; creates a need to know essential content and skills; requires inquiry to learn and/or create something new; requires critical thinking, problem solving, collaboration, and various forms of communication; allows some degree of student voice and choice; incorporates feedback and revision; and results in a publicly presented product or performance”.[2]

Over the past several years, many studies have suggested that content knowledge alone is no longer adequate to prepare students for the STEM workforce and that they must also develop real-world, applied skills. K-12 instruction that focuses more on process than pure content is a recommendation that has strong support, such as stated in the Conference Board’s 2006 report. [3] Karen Bruett, director of K-12 business development for Dell, echoes the advice of many technology companies who seek a larger and well prepared STEM workforce: “Don’t focus on the technology; focus on instruction and how the tools can be applied to gather and share information with a team trying to solve the problem”.[4] In *Realizing America’s Potential,* the National Science Board recommends creating faculty and student incentives to reveal linkages between classroom-based skills and experiences and the demands on thinking and learning in the workplace.[5] Meta-analyses that have compared problem-based learning to conventional classrooms have concluded that PBL is "superior when it comes to long-term retention, skill development and satisfaction of students and teachers".[6] Based on analyses such as this and, now, on promising results from our own pilot HSE program, we believe that project-based learning can help address many of the concerns being voiced by educators and other stakeholders who are concerned with education outcomes.

HSE has received two National Science Foundation (NSF) awards to expand and fully assess outcomes of the HSE program: a $100,000 one-year grant under NSF's Innovations in Engineering Education, Curriculum and Infrastructure (IEECI), and a $1.5 million three-year award from the NSF Innovative Technology Experiences for Students and Teachers (ITEST) program began in December 2008. Using these two awards, along with significant funding from the universities and from industry sources, we lengthened the pilot to five years and added several more schools. We are now in Year 3 of this five-year pilot.

As of January 2011, there are sixteen participating high schools in Michigan, Illinois, Georgia, and Puerto Rico. These schools are diverse in locale and include rural, suburban, and inner city schools. They are also diverse in demographics, enrolling students from all income levels, first generation students, and high numbers of students from ethnic groups that are traditionally underrepresented in engineering (see Table 1). A profile of the 2010/11 host secondary institutions is provided in Table 2.

Table 1. HSE 2010/11 Team Statistics.

Total participating students	286	
Total teams	16	
Average number of students per team	18	
Student Demographics	**Number of Students**	**Percentage of Total**
Females	99	35 %
African Americans	107	37 %
Hispanics	34 (15 from Puerto Rico)	12 %
Other minorities	13	5%

Table 2. Host school profiles for 2010/11 HSE teams.

High School and Location	**Rural**	**Urban**	**Low Income**	**High Minority**	**At Risk**
BRIDGE Alternative H.S., Hancock, MI	X		X		X
Horizons Alternative H.S., Calumet, MI	X		X		X
Hancock, H.S., Hancock, MI	X		X		
Chassell H.S., Chassell, MI	X		X		
Traverse City H.S., Traverse City, MI					
Arthur Hill H.S., Saginaw, MI		X	X	X	X
Utica Community Schools, Utica, MI					

Cass Tech H.S., Detroit, MI		X	X	X	X
Melvindale H.S., Melvindale, MI		X	X	X	X
Dollar Bay H.S., Dollar Bay, MI	X		X		
University Prep H.S., Detroit, MI		X	X	X	X
Cranbrook Schools' Horizons-University Upward Bound, Blooomfield Hills, MI		X	X	X	
Tech High, Atlanta, GA		X	X	X	X
Benjamin E. Mays H.S. Atlanta, GA		X		X	X
Manuel Toro H.S., Puerto Rico		X	X	X	X
University of Chicago Woodlawn Charter H.S., Chicago, IL		X		X	

To provide additional support to these teams, the program has united a strongly committed set of partners that include three universities, the American Society of Mechanical Engineers (ASME), and several other industry, government, and foundation sponsors. Assessment of the HSE program is led by an external evaluation team from the Science and Mathematics Program Improvement (SAMPI) Center at Western Michigan University.

By creating a partnership and communication network between universities and HSE teams, HSE students are being exposed to post-secondary STEM education throughout their HSE experience. For instance, in addition to showcasing their work at college campuses (hence receiving valuable feedback from college students), HSE teams such as Chassell, BRIDGE, Horizons and Tech High work closely with, and are mentored by Michigan Tech and Georgia Tech engineering students.

HSE teacher-coaches acquire important skills through their HSE training and experiences in the program. They are immersed in an integrated structure in which they learn how to implement project-based learning, how to manage a team working on a project outside their area of expertise, and how to generate and sustain enthusiasm for STEM learning among the team participants. In addition to leading students in planning and completing their projects, teacher-coaches also attend online meetings where they are networked with their peers and the HSE program director, participate in annual summer training workshops, and take part in program assessment.

In brief, HSE is a framework that allows teacher-coaches to implement and sustain long term team-based STEM projects. The HSE program model (see Figure 1) offers ongoing support for the teams by providing:

- program director organization and expertise, e.g., an open communication link with the teacher-coaches, where they can regularly seek technical and logistics support.
- assistance in seeking university and industry partner expertise and mentoring, e.g., college student mentors, funding and resources by companies like AT&T, Ford and IBM,
- opportunities to display and promote team work, e.g., yearly college exposition and HSE Web site
- teacher-coaches professional development, e.g., continuing education credit for summer workshop participation,

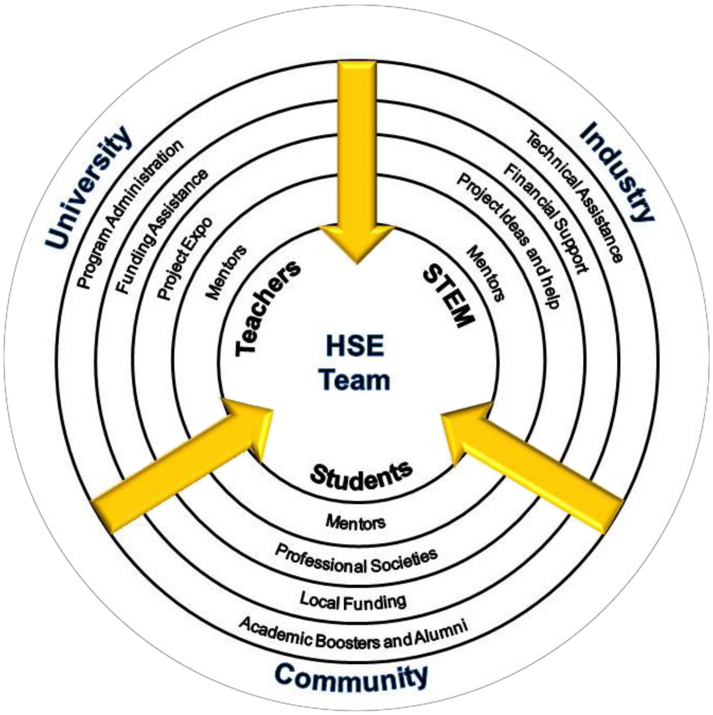


Figure 1 - High School Enterprise Program Model

- cyber-infrastructure, e.g., HSE Web site to archive resources and project information, regular online meetings to network with teacher-coaches and facilitate peer support.

This model is unique and attractive to high school teachers mainly due to its flexibility, i.e., its ability to accommodate different types of long term team-based STEM projects and to operate in different types of high schools (e.g., alternative, public, charter, magnet). Depending on implementation type (extra- or in-curricular program), students can earn school credit for their work. In all cases, students self select to participate in HSE, and there is no pre-requisite knowledge or inclination imposed on their participation by the HSE program. This is a strength of the program that participation by any student, based on interest alone, is allowed. Since there is no pre-requisite knowledge for HSE participation, self selection here does not imply that HSE reaches only students who are predisposed to enter STEM fields or even to enter higher education, and this is evidenced by HSE functioning in two alternative high schools as well as it does in the more traditional secondary institutions served in the HSE pilot phase (see Table 2 above).

It is also important to emphasize that this program does not require each of the 16 high school team to learn/apply the same STEM materials, e.g., how to solder, use CAD or assemble underwater remotely operated vehicle (ROV) components. Instead, teacher-coaches are encouraged to teach to their strength by choosing projects that are not only within their field of expertise, but are also appropriate for the context of their school environment or location. Students are then expected to make use of appropriate technologies to design, implement, and present projects, thus building their STEM skills, in addition to developing teamwork skills, increasing content knowledge, enhancing science and other process skills, improving communication/presentation abilities, and acquiring innovative mindsets. For instance, the HSE team in Manuela Toro Morice High School in Puerto Rico focuses on building underwater robots. Since the teacher-coach has experience in building robots, and since they live on an island, where water is a pervasive element in their lives, it is appropriate for the team to be involved in a project that is closely relevant to them. This of course gives the students an invaluable opportunity to develop intellectually and allow them to work with other students to learn about the environment outside of their traditional classroom.

Therefore, HSE projects cover a wide range of STEM topics, which include design and construction of ROVs, fuel cell vehicles, electric go-carts, earthquake shake-tables, wearable computer products and landscaping a school garden. Unlike competition-based programs, such as FIRST Robotics, HSE teams are not required to participate in competitions. (For example: some teams participate in competitions but this is only a part of their year-long project.) They are expected to do independent research and discovery pertaining to their STEM topics. This allows students to work in an environment where they can learn through their mistakes in order to find solutions and ultimately succeed with a project for which they have a passion and ownership.

Program Goals and Objectives

The goal of the HSE is to equip high school students with the knowledge, skills, and dispositions that will motivate more of them to consider STEM careers and will prepare them for success in pursuing those careers. More specific program objectives follow.

Objective 1. All HSE participants develop and strengthen the eleven essential applied skills identified by U.S. employers in The Conference Board's 2006 report, *Are They Really Ready to Work?*[3] These are the eleven skills cited in that report: critical thinking/ problem solving; oral communications; written communications; teamwork/collaboration; diversity; IT (information technology) application; leadership; creativity/ innovation; lifelong learning/self direction; professionalism/ work ethic; and ethics.

Objective 2. HSE participants are strongly motivated to pursue STEM careers, are more likely to enroll in and complete STEM and IT post-secondary education and training, and enter the STEM workforce in greater numbers than do non-HSE participants.

Objective 3. Teacher-coaches are educated and equipped with the skills and resources to develop, implement, coach, and sustain HSE teams.

Objective 4. HSE teams are sustained through robust and committed partnerships with industry, universities and colleges, foundations, informal science education organizations, community-based organizations, and other units as appropriate to the particular HSE implementation.

Objective 5. HSE is a tested, documented, and sustainable national model, which is proven to help grow the U.S. domestic STEM workforce and which is adaptable to any secondary institution.

Objective 6. Enterprise concepts are introduced to middle and elementary students.

Program Assessment and Evaluation

As stated earlier, Science and Mathematics Program Improvement (SAMPI) Center at Western Michigan University is responsible for assessing and evaluating the HSE program. The following results and summaries are obtained from the report (for the period September 2007 through June 2010) prepared by the external evaluation team.

Students who participate in HSE usually do so over multiple years, and team projects are selected and structured to be long-term. Students are continually entering the program and, after HSE has been in place for a number of years, a much larger number of students will be graduating and exiting the program. To track students for evaluation purposes, each group of new students who join a team in the beginning of an academic year (or, in case of a newly formed HSE team, the first group of students to participate on that team) is assigned to a "cadre." All students who were on HSE teams at the beginning of the 2008-2009 school year constitute "Cadre I." All students who joined an existing or new team at the beginning of the 2009-2010 school year constitute "Cadre II." All students who joined an existing or new team at the beginning of the 2010-2011 school year constitute "Cadre III," and so on. Each student is assigned a unique code that identifies his/her cadre, school, and other demographic information. This allows us to make comparisons on outcomes across multiple factors (e.g., teams, schools, number of years of participation, gender, ethnicity).

HSE teacher-coaches are also included in the program evaluation. They, too, are assigned to cadres that correspond to their HSE participation start: Cadre I teachers started in AY 2008-2009 (the first year of HSE funding from NSF), etc.

SAMPI has employed the following assessment methods to determine the impact of the program on participating teachers and students:

- A comprehensive pre-test survey of all new students beginning HSE participation and an annual post-test survey of *all* students in the program. The survey covers a wide range of topics such as self-assessment of various workforce skills, technology skills and use, attitudes toward STEM, and college and career intentions. This survey consists of scaled response items.
- Surveys of teacher-coaches (upon starting to coach a team and annually thereafter) that covers a range of skills needed by teachers to coach HSE teams (e.g., IT knowledge and usage and preparedness to use selected instructional strategies).
- Teacher-coach summer workshop questionnaire completed annually by teacher-coaches.
- Annual debriefing interviews with teacher-coaches.
- Expo survey (open-ended questions) of students who participate in the university research Expo.
- Direct assessment of student expo presentations and posters.
- Site visits and teacher-coach interviews conducted by the project evaluators.
- Data collection on student demographics.

Cadres I and II students and teacher-coaches have participated in all assessment activities to date. Cadre III students and teacher-coaches have participated in pre-test assessment only, and as we have no data on program impact due to insufficient time in the program, results for Cadre III are not included here.

A. Evaluation Results: HSE Students

- Pre/post Student Survey

At the beginning of their participation in the program, students were asked to complete a survey about their skills and knowledge. Cadre I students completed the same survey at the end of the second year of their participation; Cadre II students completed it at the end of the first year. Here are a few of the highlights:

I. Student Workforce Skills

Cadre I students were asked to rate the following applied work skills on a 5-point scale, with 1 = very weak skills and 5 = very strong skills. Ratings were done at both the beginning of the program in 2008 and again in Spring 2010. Pre/post mean scores and pre to post mean changes are shown in Table 3 for work skill items.

Table 3. Workforce Skills for Cadre I students

Pre n = 65; 2 yrs n = 52	**Pre Mean Score**	**Post Mean Score**	**Mean Change**
a. I can use math and science concepts and knowledge to solve problems.	3.87	4.10	+0.23
b. I am good at analyzing information	3.98	4.02	+0.04
c. I can verbally communicate my ideas clearly and effectively	3.67	3.98	+0.31**
d. I speak well in front of groups, such as my class	3.30	3.48	+0.18
e. I can write about my ideas so others can clearly understand them	3.62	3.67	+0.05
f. I work well as a member of a team	4.26	4.37	+0.11
g. I work easily with people who are different from me	3.67	4.06	+0.39*
h. I can use computers to help solve problems	4.13	4.12	-0.01
i. I know how to use the strengths of others to achieve common goals	3.94	3.94	0.00
j. I can help others develop their skills	2.78	3.77	+0.99
k. I can come up with original ideas to solve problems	3.65	4.17	+0.53
l. I am able to learn new things and develop new skills	4.43	4.41	-0.02
m. I have good work habits—arrive on time, work well with others, make good use of my time	4.09	4.31	+0.22
n. I act in a responsible way for the benefit of others	4.24	4.35	+0.11

*Difference from pre to post is statistically significant at alpha $\leq$ .05
**Difference from pre to post is statistically significant at alpha $\leq$ .10

Cadre II students were asked to rate the following applied work skills on a 5-point scale, with 1 = very weak skills and 5 = very strong skills. Ratings were done at both the beginning of the program in Fall 2009 and again in Spring 2010. Pre and first year mean scores and pre to post mean changes are shown in Table 4 for work skill items.

Table 4. Workforce Skills for Cadre II students

Pre n = 74; 1 yr n = 43	**Pre Mean Score**	**Post Mean Score**	**Mean Change**
a. I can use math and science concepts and knowledge to solve problems.	3.82	3.90	+.08
b. I am good at analyzing information	3.94	4.17	+.23
c. I can verbally communicate my ideas clearly and effectively	3.92	4.07	+.15

d. I speak well in front of groups, such as my class	3.63	3.55	-.08
e. I can write about my ideas so others can clearly understand them	3.96	4.00	+.04
f. I work well as a member of a team	4.40	4.45	+.05
g. I work easily with people who are different from me	4.04	4.15	+.11
h. I can use computers to help solve problems	4.20	4.37	+.17
i. I know how to use the strengths of others to achieve common goals	4.14	4.05	-.09
j. I can help others develop their skills	3.79	4.03	+.24
k. I can come up with original ideas to solve problems	4.10	4.15	+.05
l. I am able to learn new things and develop new skills	4.59	4.55	-.04
m. I have good work habits—arrive on time, work well with others, make good use of my time	4.35	4.54	+.19
n. I act in a responsible way for the benefit of others	4.44	4.56	+.12

Note: There were no mean pre to post statistically significant differences.

Summary:

- Cadre I: Of the 14 items, the pre-to-post mean change was positive for ten items and no change for four items. Four of the positive items were statistically significant pre-to-post, including "I can verbally communicate my ideas clearly and effectively," "I work easily with people who are different from me," I can help others develop their skills," and "I can come up with original ideas to solve problems."
- Cadre II: Of the 14 items, the pre-to-post mean change was positive for ten items, negative for two items, and no change for two items. No pre-to-post mean changes were statistically significant. This is possibly because these students had been in the program for only one year at the time of the post-test survey.

II. Student Technology Skills:

Cadre I students rated their technology skills on the scale 0 = Do not use; 1 = Beginner: Cannot use without help; 2 = Independent: Can use without help most of the time; 3 = Expert: Can teach others to use the tool. Pre-program and end-of-second year mean scores and mean pre to post changes are shown in Table 5 for technology skill items.

Table 5. Technology Skills for Cadre I students

Pre n = 65; 2 yrs n = 52	**Pre Mean Score**	**Post Mean Score**	**Mean Change**
a. Computers	2.44	2.50	+.06
b. The Internet	2.72	2.73	+.03
c. Digital still camera	2.50	2.59	+.09
d. Digital movie camera	1.94	2.14	+.20

e. Scanner	2.00	2.10	+.10
f. I-Pod or other hand-held device	2.63	2.71	+.08
g. Email	2.76	2.67	-.09
h. Text messaging	2.43	2.62	+.19
i. Social networking	1.89	2.56	+.67*
j. Video calling/conferencing	1.20	1.50	+.30
k. Word processing software	2.57	2.58	+.01
l. Spreadsheet software	2.09	2.13	+.04
m. Graphing calculators	1.93	2.14	+.31
n. Database software	1.32	1.71	+.39**
o. PowerPoint software	2.50	2.45	-.05
p. Blogs	1.19	1.63	+.44**
q. Podcasting	.58	1.21	+.63*
r. Modeling software	.88	1.46	+.58*
s. Computer game development software	.76	1.15	+.39**
t. Robotics programming software	.54	1.27	+.73*

*Difference from pre to post is statistically significant at alpha ≤ .05
**Difference from pre to post is statistically significant at alpha ≤ .10

Cadre II students rated their technology skills on the scale 0 = Do not use; 1 = Beginner: Cannot use without help; 2 = Independent: Can use without help most of the time; 3 = Expert: Can teach others to use the tool. Pre-program and end-of-second year mean scores and mean pre to post changes are shown in Table 6 for technology skill items.

Table 6. Technology Skills for Cadre II students

Pre n = 74; 2 yrs n = 43	Pre Mean Score	Post Mean Score	Mean Change
a. Computers	2.48	2.50	+.02
b. The Internet	2.77	2.76	-.01
c. Digital still camera	2.51	2.50	-.01
d. Digital movie camera	2.34	2.29	-.05
e. Scanner	2.11	2.29	+.18
f. I-Pod or other hand-held device	2.75	2.74	-.01
g. Email	2.73	2.69	-.04
h. Text messaging	2.76	2.81	+.05
i. Social networking	2.70	2.71	+.01
j. Video calling/conferencing	1.83	2.05	+.22
k. Word processing software	2.25	2.33	+.08
l. Spreadsheet software	2.01	2.31	+.30**
m. Graphing calculators	1.90	2.21	+.31*
n. Database software	1.59	1.93	+.34*
o. PowerPoint software	2.52	2,55	+.03
p. Blogs	1.88	1.85	-.03
q. Podcasting	1.41	1.48	+.07
r. Modeling software	1.14	1.48	+.34**
s. Computer game development software	1.23	1.62	+.39**

t. Robotics programming software	1.03	1.48	+.45*

*Difference from pre to post is statistically significant at alpha≤ .05
**Difference from pre to post is statistically significant at alpha≤ .10

Summary:

- Cadre I: Of the 20 items, the pre-to-post mean change was positive for 15 items, negative for four items, and no change for one item. Seven of the positive items were statistically significant pre-to-post, including “social networking,” “database software,” “blogs,” “podcasting,” “modeling software,” “computer game development software,” and “robotics programming software.”
- Cadre II: Of the 20 items, the pre-to-post mean change was positive for 11 items, negative for one item, and no change for eight items. Six of the positive items were statistically significant pre-to-post, including “spreadsheet software,” “graphing calculators,” “database software,” “modeling software,” “computer game development software,” “ and “robotics programming software.”

III. Student Technology Use:

Cadre I students were asked to rate their use of technology in and out of school on the scale 0 = Don’t know how; 1 = Do not use; 2 = Sometimes I do; 3 = I do this often. Pre-program and end-of-second year mean scores and mean pre to post changes are shown in Table 7 for technology use items.

Table 7. Technology Use for Cadre I students

Pre n = 65; 2 yrs n = 52	Pre Mean Score	End Yr 2 Mean Score	Mean Change
a. Gather info from Internet or CD	2.74	2.73	-.01
b. Store info on database or spreadsheet	2.06	1.87	-.19
c. Summarize or analyze data by using database or spreadsheet software	1.74	1.87	+.13
d. Communicate w/teachers, students or friends using email, Blogs, Podcasting	2.50	2.63	+.13
e. Create presentation using Power-Point for your class/other audience	2.44	2.50	+.06
f. Create movie using digital video camera for your class/other audiences	1.89	1.75	-.14
g. Create displays of information such as charts, graphs, maps made with computers, scanners, digital cameras	2.19	2.23	+.04
h. Write/publish stories, newsletters, reports/other with the computer	2.17	2.29	-.13
i. Create pictures or design posters using technology	2.32	2.42	+.12
j. Use technology to practice skills	2.32	2.42	+.10
k. Summarize or analyze data by using a database or spreadsheet	1.94	1.98	+.04
l. Collect data in science or other	2.13	2.04	-.09

investigations			
m. Develop scientific models showing how complex systems actually work	1.40	1.83	+.43*
n. Use mathematics to make models about issues/problems related to the environment, business, health, etc.	1.64	1.77	+.13
o. Design interactive computer games	1.23	1.44	+.21
p. Program robots w/computer software	1.21	1.54	+.33*
q. Analyze numerical data and create displays of the results	1.55	1.98	+.43*

*Difference from pre to post is statistically significant at alpha≤ .05
**Difference from pre to post is statistically significant at alpha≤ .10

Cadre II students were asked to rate their use of technology in and out of school on the scale 0 = Don't know how; 1 = Do not use; 2 = Sometimes I do; 3 = I do this often. Pre-program and end-of-second year mean scores and mean pre to post changes are shown in Table 8 for technology use items.

Table 8. Technology Use for Cadre II students

Pre n = 74; 2 yrs n = 43	**Pre Mean Score**	**End Yr 2 Mean Score**	**Mean Change**
a. Gather info from Internet or CD	2.72	2.62	-.10
b. Store info on database or spreadsheet	2.17	2.24	+.07
c. Summarize or analyze data by using database or spreadsheet software	1.80	1.98	+.18
d. Communicate w/teachers, students or friends using email, Blogs, Podcasting	2.50	2.43	-.07
e. Create presentation using Power-Point for your class/other audience	2.44	2.50	+.06
f. Create movie using digital video camera for your class/other audiences	1.96	1.95	-.01
g. Create displays of information such as charts, graphs, maps made with computers, scanners, digital cameras	2.15	2/12	-.03
h. Write/publish stories, newsletters, reports/other with the computer	2.22	2.14	-.03
i. Create pictures or design posters using technology	2.14	2.40	+.27**
j. Use technology to practice skills	2.34	2.43	+.09
k. Summarize or analyze data by using a database or spreadsheet	1.88	1.98	+.10
l. Collect data in science or other investigations	2.15	2.17	+.02
m. Develop scientific models showing how complex systems actually work	1.64	1.79	+.15
n. Use mathematics to make models	1.72	1.95	+.23

about issues/problems related to the environment, business, health, etc.			
o. Design interactive computer games	1.42	1.55	+.13
p. Program robots w/computer software*	1.45	1.64	+.19
q. Analyze numerical data and create displays of the results	1.69	1.83	+.14

*Difference from pre to post is statistically significant at alpha $\leq$ .05
**Difference from pre to post is statistically significant at alpha $\leq$ .10

Summary:

- Cadre I: Of the 17 items, pre-to-post mean change was positive (+.05 change or more) for ten items, negative (-.05 or more) for four items, and no change (less than + or - .05) for three items. Three of the positive items were statistically significant pre-to-post; "Develop scientific models showing how complex systems actually work," "Program robots with computer software," and "Analyze numerical data and create displays of results."
- Cadre II: Of the 20 items, the pre-to-post mean change was positive (+.05 change or more) for 11 items, negative (-.05 or more) for one item, and no change (less than + or - .05) for eight items. Two of the positive items were statistically significant pre-to-post: "Create design posters using technology" and "Program w/computer software."

▪ End School Year Student Questionnaire

Students were also asked to complete a survey at the end of their spring Expo experiences. They were asked to reflect on their experiences over the previous year. Here are a few of the highlights:

I. Career Intentions:

At the end of their first year in HSE, 70% (32 of 46 surveyed) of Cadre I and 61% (34 of 56 surveyed) of Cadre II students indicated that they are considering STEM careers. Longitudinal data will continue to be collected for these students so we can learn if attitudes about career intentions in STEM are changing.

II. Perceived Value of HSE:

In spring 2009, 44 of 45 responding students said they would encourage other students to participate in HSE or a similar project. In spring 2010, all 73 responding students stated that they would encourage other students to participate in HSE.

III. Judged Assessment of HSE Team Work:

HSE teams have been presenting their projects on campus at X University's Undergraduate Expo in the spring since 2008. The external evaluator (SAMPI) conducted direct assessment of the student team project posters and presentations. Oral presentations were judged on introduction, content, text, graphics, oral presentation skills, scientific rigor of the project, and writing mechanics and quality. Poster presentations were judged on purpose, content, text, graphics, scientific rigor, and writing mechanics and quality. Data shows that presentation scores for first-time teams tend to be low, while the mean scores improve for teams that return and present again. Scores for returning teams in these two areas were about 20% higher than for first year teams.

IV. Student Reaction:

Based on student surveys at the end of each school year and opportunities of SAMPI evaluators to interact with student team members during annual school site visits, it is clear that most students find the HSE experience rewarding and useful. They like being involved in student-driven long-term projects; working with their peers (although many find teamwork challenging); and developing their communication skills (within their team and in preparing for and presenting at the Expo). Many are hopeful this experience will be a "plus" in applying for college admission.

B. Evaluation Results: HSE Teacher-coaches

Teacher-coaches completed surveys at the beginning of the program and at the end of each year of their participation:

- At the end of June 2010 there were four Cadre I teacher-coaches, teaching students in one or more grades 9-12; teaching experience ranges from one to 25 years; they teach a variety of STEM-related subjects, including computer science, Engineering, Biology, Physics, and Mathematics. There are seven Cadre II teachers, with students in both middle and high school; teaching experiences ranges from less than one year to 25 years; they teacher STEM-related subjects, including Earth Science, Biology, Chemistry, Physics, Engineering, Computers, General Science, and Robotics. Five (5) teacher-coaches have been selected for Cadre III and have participated in the summer workshop.
- Among Cadre I teacher-coaches, about half said they personally had done a long-term team project in college or since college, half have facilitated high school or other student teams in conducting long-term projects, half incorporate team projects as part of their normal curriculum (before HSE). More than half of Cadre II teachers said yes to each of the items above.

I. Teacher-coaches Technology Skills:

At the beginning of their participation in HSE and at the end of each school year in which they participate, teachers are asked to complete a survey of their perceptions of the skills and knowledge. The tables below show survey results. NOTE: The number of teachers completing the surveys is small; readers are cautioned not to generalize from the data. No pre/post analysis for statistical significance was done because of the small numbers in the population. This data DOES NOT fully represent the effects of the program on teacher participants.

Teachers were asked to rate their technology skills on the scale shown in Tables 9 & 10:

Table 9. Technology Skills for Cadre I teacher-coaches (numbers in cells are frequency of ratings pre-program, end first year, end second year)

Technology Pre n = 8, 1 yr n = 5, 2 yrs n = 6	I do not use Pre/1 yr/2 yrs	**Beginner:** Cannot use without help Pre/1 yr/2 yrs	**Independent:** Use without help most of the time Pre/1 yr/2 yrs	**Expert:** Teach others to use the tool Pre/1 yr/2 yrs
a. Computers	-/-/-	-/-/-	4/3/2	4/2/4
b. The Internet	-/-/-	-/-/-	4/2/2	4/3/4
c. Digital still camera	-/-/-	-/-/-	6/4/3	2/1/3

d. Digital movie camera	-/-/-	3/-/-	3/5/3	2/-/3
e. Scanner	-/-/-	2/-/-	3/4/5	3/1/1
f. I-Pod or other hand-held device	-/-/3	2/2/1	4/3/3	2/-/-
g. Email	-/-/-	-/-/-	3/1/2	5/4/4
h. Text messaging	1/1/2	1/1/-	2/1/3	4/2/1
i. Social networking	3/3/3	2/1/-	2/-/3	1/1/-
j. Video calling/conferencing	4/-/-	2/1/2	2/4/4	-/-/-
k. Word processing software	-/-/-	1/-/-	3/2/2	4/3/3*
l. Spreadsheet software	1/1/1	2/-/-	1/2/3	4/2/2
m. Graphing calculators	1/1/1	2/-/1	2/4/3	3/-/1
n. Database software	3/1/3	1/2/-	3/2/2	1/-/1
o. PowerPoint software	-/-/-	2/-/1	2/2/1	4/3/4
p. Blogs	3/1/3	4/2/1	-/2/1	1/-/-*
q. Podcasting	2/2/3	4/1/1	1/2/2	-/-/-
r. Modeling software	3/1/2	4/2/2	1/2/1	-/-/1
s. Computer game development	4/3/5	3/1/-	1/2/2	-/-/-
t. Robotics programming software	3/1/2	4/2/2	1/2/1	-/-/1

* 1 no response

Table 10. Technology Skills for Cadre II teacher-coaches (numbers in cells are frequency of ratings pre-program and end first year)

Technology Pre n = 8, 1 yr n = 5	I do not use Pre/1 yr	**Beginner:** Cannot use without help Pre/1 yr	**Independent:** Use without help most of the time Pre/1 yr	**Expert:** Teach others to use the tool Pre/1 yr
a. Computers	-/-	-/-	2/1	6/4
b. The Internet	-/-	-/-	1/-	7/5
c. Digital still camera	-/-	-/-	3/2	5/3
d. Digital movie camera	-/-	2/1	2/3	4/1
e. Scanner	-/-	-/-	2/1	6/4
f. I-Pod or other hand-held device	1/-	1/2	3/1	3/2
g. Email	-/-	-/-	1/-	7/5
h. Text messaging	2/1	-/-	2/2	4/2
i. Social networking	2/2	2/-	-/1	4/2
j. Video calling/conferencing	-/-	3/-	2/4	3/1
k. Word processing software	-/-	-/-	2/1	6/4
l. Spreadsheet software	-/-	2/-	1/3	5/2
m. Graphing calculators	1/1	3/1	2/2	2/1
n. Database software	-/-	1/1	4/4	3/-
o. PowerPoint software	-/-	-/-	2/-	6/5
p. Blogs	3/1	-/2	1/1	3/1

q. Podcasting	3/1	1/2	1/1	3/1
r. Modeling software	3/1	1/2	1/1	3/1
s. Computer game development	2/2	5/3	1/-	-/-
t. Robotics programming software	2/1	4/2	1/1	1/1

Summary:

- In assessing their technology skills, Cadre I said they had stronger skills in use of the computer, the Internet, digital still and movie cameras, scanners, email, word processing software, spreadsheet software, graphing calculators and PowerPoint software. They indicated they were still learning about hand-held devices, text messaging, social networking, video calling/conferencing, database software, blogs, podcasting, modeling software, computer game development, and robotics programming software.
- In assessing their technology skills, Cadre II said they had stronger skills in the use of the computers, the Internet, digital still and movie cameras, scanners, hand-held devices, email, text messaging, social networking, video calling/conferencing, word processing software, 6 spreadsheet software, database software, and PowerPoint software. They indicated they were still learning about graphing calculators, blogs, podcasting, modeling software, computer game development, and robotic programming software**.**

II. Teacher-coaches Technology Use:

Teachers were asked to rate how often they do particular technology-supported activities on a 4-part scale as shown in Tables 11 & 12:

Table 11. Technology Use for Cadre I teacher-coaches (numbers in cells are frequency of ratings pre-program, end first year, end second year)

Technology Pre n = 8, 1 yr n = 5, 2 yr n = 6	**I do not do** Pre/1 yr/2 yrs	**Sometimes I do** Pre/1 yr/2 yrs	**I do this often** Pre/1 yr/2 yrs	**I don't know about this** Pre/1 yr/2 yrs
a. Gather info from Internet or CD	-/-/-	1/-/-	7/5/6	-/-/-
b. Store info on database or spreadsheet	1/1/1	2/3/1	5/1/4	-/-/-
c. Summarize or analyze data by using database or spreadsheet software	1/1/1	3/2/1	4/2/4	-/-/-
d. Communicate w/teachers, students or friends using email, Blogs, Podcasting	-/-/-	1/1/-	7/4/6	-/-/-
e. Create presentation using Power-Point for your class/other audience	1/-/-	2/2/1	5/3/4	-/-/1
f. Create movie using digital video camera for your class/other audiences	4/2/1	2/3/2	2/-/2	-/-/1

g. Create displays of information such as charts, graphs, maps made with computers, scanners, digital cameras	2/-/-	3/2/4	3/3/2	-/-/-
h. Write/publish stories, newsletters, reports/other with the computer	2/1/1	3/4/2	3/-/3	-/-/-
i. Create pictures or design posters using technology	3/-/1	4/4/4	1/1/1	-/-/-
j. Use technology to practice skills	-/-/1	4/3/3	4/2/2	-/-/-
k. Summarize or analyze data by using a database or spreadsheet	1/-/1	2/3/3	5/2/2	-/-/-
l. Collect data in science or other investigations	1/1/-	5/2/5	2/2/1	-/-/-
m. Develop mathematical models of environmental, business, or other data	3/2/3	3/3/3	1/-/-	-/-/-
n. Develop scientific models showing how complex systems actually work	4/2/4	3/2/2	1/1/-	-/-/-
o. Design interactive computer games	6/4/6	2/1/-	-/-/-	-/-/-
p. Program robots w/computer software	6/2/4	1/2/-	1/1/1	-/-/-
q. Analyze numerical data and create displays of the results	2/1/2	5/2/2	1/2/2	-/-/-

Table 12. Technology Use for Cadre II teacher-coaches (numbers in cells are frequency of ratings pre-program and end first year)

Technology Pre n = 8, 1 yr n = 5	**I do not do** Pre/1 yr	**Sometimes I do** Pre/1 yr	**I do this often** Pre/1 yr	**I don't know about this** Pre/1 yr
a. Gather info from Internet or CD	-/-	-/1	8/4	-/-
b. Store info on database/spreadsheet	1/-	1/4	6/1	-/-
c. Summarize or analyze data by using database or spreadsheet software	1/-	3/3	4/2	-/-
d. Communicate w/teachers, students, etc. using email, Blogs, Podcasting	-/1	-/1	7/3	1/-

e. Create presentation using Power-Point for your class/other audience	-/-	3/2	5/3	-/-
f. Create moving using digital video camera for your class/other audiences	4/1	3/1	1/2	-/1
g. Create displays of information such as charts, graphs, maps made with computers, scanners, digital cameras	1/-	3/4	4/1	-/-
h. Write/publish stories, newsletters, reports/other with the computer	2/-	2/3	4/2	-/-
i. Create pictures or design posters using technology	3/1	1/2	4/2	-/-
j. Use technology to practice skills	1/-	3/1	4/4	-/-
k. Summarize or analyze data by using a database or spreadsheet	2/-	2/4	4/1	-/-
l. Collect data in science or other investigations	1/1	2/2	5/2	-/-
m. Develop mathematical models of environmental, business, or other data	1/1	7/2	-/2	-/-
n. Develop scientific models showing how complex systems actually work	4/1	4/2	-/2	-/-
o. Design interactive computer games	7/3	1/1	-/1	-/-
p. Program robots w/computers	5/3	3/-	-/2	-/-
q. Analyze numerical data and create displays of the results	2/1	4/2	2/2	-/-

Summary:

- Cadre I: 12 were rated as medium to high use; 5 were not used or only occasionally used (these included digital video, developing mathematical models, scientific models, interactive computer games, and robotics).
- Cadre II: 14 were rated as medium to high use, 3 were not used or only occasionally used (these included digital video, developing scientific models, designing interactive computer games, and robotics).

III. Preparedness to Facilitate Selected Instructional Strategies:

Teachers were asked to rate on a 4-point scale, with 1 = not adequately prepared and 4 = very well prepared. The table below shows mean ratings for pre-program, end of first year, and end of second year. Mean score ratings are shown in Tables 13 & 14:

Table 13. Instructional Strategy Preparedness for Cadre I teacher-coaches

CADRE I	MEAN RATINGS		
Fall 09 n = 8, Spring 09 n = 5, Spring 10 n = 6	Fall 2008 (Pre-Program)	Spring 2009	Spring 2010
a. Problem-solving among students	3.63	3.80	3.33
b. Making connections among IT and STEM topics	3.00	3.40	3.33
c. Making connections within and among STEM topics	3.25	3.40	3.33
d. Making connections from STEM topics to real-world situations	3.50	3.40	3.50
e. Leading a class or group of students using investigative strategies	3.38	3.60	3.33
f. Managing a student group engaged in hands-on/project-based work	3.63	3.80	3.67
g. Helping students use information technology (IT) to conduct investigations	2.88	3.20	3.00
h. Helping students use technology to present findings from investigations	2.25	2.40	2.17
i. Helping students use IT to design programs and systems	3.13	3.00	2.17
j. Helping students take responsibility for their own learning	3.50	3.60	3.83

Table 14. Instructional Strategy Preparedness for Cadre II teacher-coaches

CADRE II	MEAN RATINGS	
Spring 09 n = 8, Spring 10 n = 5	Spring 2009	Spring 2010
a. Problem-solving among students	3.25	3.50
b. Making connections among IT and STEM topics	3.25	3.60
c. Making connections within and among STEM topics	3.50	3.40
d. Making connections from STEM topics to real-world situations	3.13	3.60
e. Leading a class or group of students using investigative strategies	3.25	3.00
f. Managing a student group engaged in hands-on/project-based work	3.38	3.60
g. Helping students use information technology (IT) to conduct investigations	3.00	3.60
h. Helping students use technology to present findings from their investigations	2.63	2.60
i. Helping students use IT to design programs and	3.00	3.20

systems		
j. Helping students take responsibility for their own learning	2.88	3.60

IV. Summer Workshops:

Teacher-coaches participated in summer workshops at Michigan Tech University in summer 2009 and 2010 as part of their preparation to work with their students on long-term team projects. Their responses to items on an end-of-session evaluation questionnaire were very positive. They were asked to rate the value of the workshop topics/activities on a 5 point scale (1 = low rating and 5 = high rating). Of the 8 items rated by participants in 2009, all received 4.00 or above, 6 above 4.50; in 2010, of 7 items, all were above 4.00, 4 above 4.50. They indicate opportunities to network with other teacher-coaches, as well as with project staff and other project-affiliated experts as very useful.

V. Teacher-coaches Reaction:

Cadre I and II teacher-coaches have consistently favorable comments about the HSE program. Despite an added work load for them, they find the program very motivating for students. Teacher-coaches have chosen to participate for a variety of reasons. Many see HSE as a way for them to learn new instructional strategies, especially techniques associated with “project-based learning.” For some, it is an opportunity to enhance their project-based programming; for others it is an opportunity to learn how to design and implement project-based learning. For those who already were using this approach to learning, there are opportunities to interact with other teachers and university faculty staff on project-based learning. They also like opportunities to network face-to-face and electronically with the other teachers involved in HSE, as well as with project staff and faculty experts. The opportunity to spend time at Michigan Tech at both the summer workshop and the annual spring Expo is well received. They also appreciate the financial and human resource support from the University.

C. Evaluation Results: School Site Visits

In Spring 2010, SAMPI evaluators conducted site visits at schools of participating teams to learn about how teams develop and implement their projects. Site visits included observation of team activities, informal discussions with students, teacher interviews, and gathering or review of relevant documents or materials being used to complete projects. Of the five Cadre I schools, site visits were conducted at four of them (one school had withdrawn from the program during the first year of the project). Of the seven Cadre II schools, site visits were conducted in three and phone interviews in three; neither a site visit nor phone interview could be arranged in one of the schools.

Here is a vignette that provides insights into how a typical HSE team operates:

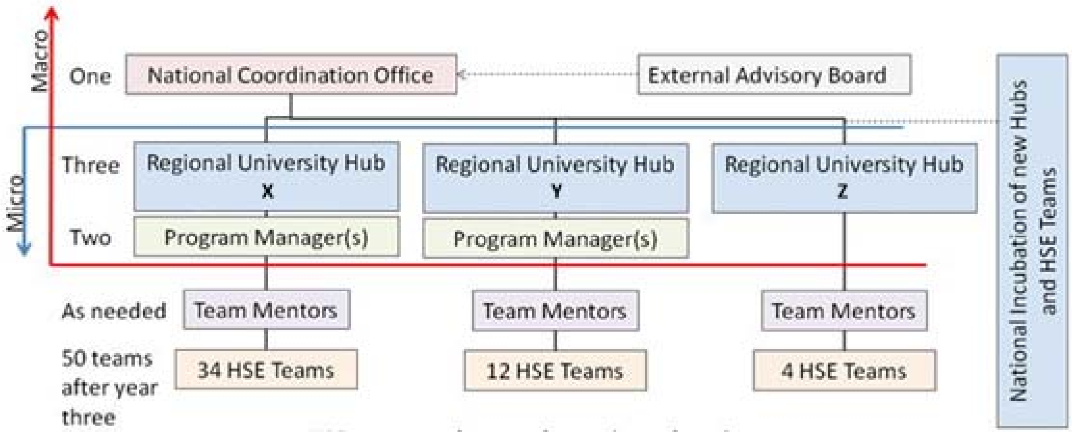
Arthur Hill High School

This team is transforming a neglected area next to the school (which students refer to as the “cove”) into an inviting landscaped environment. Over a four-year period (freshman to senior), this team will design a landscape, develop a model, prepare specifications, clear the area, obtain plants and other supplies, and create the new landscape. This project is providing students with a variety of opportunities to develop knowledge, skills, and interests not available through the normal curriculum. This team was selected randomly from all freshmen in the school and meets once each week for two hours, including during the summer. They will continue as a team through their high school careers. Expectations are that students will be actively involved in the project. The teacher allows only two absences per year. Students (with parents in attendance) made a successful presentation about the project to the school board. With approval from the school district to undertake the project, students have been clearing the area of brush and debris. At the time of the evaluator visit, students were working on their plans for revitalizing the site. They have been using Sketchup software to prepare drawings. Students have accessed various Internet sites and learned to use Google Earth. They have also created a three-dimensional model of the plan. They have also been documenting their activities with digital photos and preparing PowerPoint presentations. The teacher-coach said she has learned a lot about PowerPoint, how to publish documents, and using the Sketchup software. "I have also learned about the process of leading a large project and understanding sequential learning for this four-year project." Asked to identify the best part of the project, the teacher said, "The kids—they are all charged up."

Program Scale-Up

The evaluation results from SAMPI indicate that HSE strengthens workforce skills and STEM knowledge and has the strong potential to motivate students to pursue post-secondary STEM education. Hence, HSE has applied for additional funding in order to launch a national model that consists of at least 50 HSE teams and more than 1000 students. A national office will be established with three university hubs at Michigan Tech, Georgia Tech, and Universidad del Turabo in Puerto Rico.

A scaled-up High School Enterprise program will provide both the macro-level (regional/national) and micro-level (local school team) framework that is essential for enabling the successful implementation and sustainability of project-based STEM learning programs in K-12 schools. This framework will constitute a research test-bed for investigating two aspects of the HSE scaled-up model. At the micro-level (teams and schools), longitudinal studies will determine and measure whether HSE, when scaled-up, is effective to motivate and prepare students to successfully pursue post-secondary STEM education; whether HSE continues to attract and retain high participation by students from groups that are underrepresented in STEM; and whether significant improvements in academic STEM and workforce skills occur in participant students. At the macro-level (national, scaled-up program), research will assess both the essentiality of specific components in the HSE program framework and the sustainability of the HSE program at scale. Figure 2 depicts the proposed HSE scale-up organizational structure and the delineation of the macro and micro levels of the study.



HSE team numbers each year in each region

Year	1	2	3	4	5
Region					
Michigan	18	23	34	34	34
Georgia	4	8	12	12	12
Puerto Rico	1	2	4	4	4

Figure 2 - High School Enterprise Scale-Up Structure

The pilot HSE program was highly effective at recruiting these students: 35% of all HSE student participants are female and 54% are from minority groups, principally African-American and Hispanic. Teams are from a broad range of schools that represent multiple geographic regions, varying income levels, and urban-suburban-rural areas. By focusing on the metro-Detroit area, the metro-Atlanta area, and Puerto Rico, the scaled-up HSE project will continue to be widely inclusive and diverse. In the pilot program, one-half of the teacher-coaches were women or from minority groups. The scale-up HSE program intends to maintain the diversity of the teacher-coaches so that diverse students have diverse STEM role models as HSE teacher-coaches.

Conclusion

HSE creates a culture of active discovery-based learning that can be centered on an in-school or extracurricular experience according to the needs of the school. Furthermore, HSE can complement other programs (e.g., Project Lead the Way) by providing a flexible implementation of long term team-based STEM learning that facilities the goals of the other programs. It is designed as a self-sustaining program to bring resources into the school from industry, the local community, and academia. By linking HSE teams with higher education, students are exposed to post-secondary STEM education throughout their HSE experience, which then creates the expectation that they will continue STEM study after high school. Assessment results indicate that HSE is indeed a proven success in many different geographical and socioeconomic environments. More importantly, HSE is able to recruit and retain high number of underrepresented groups in STEM such as young women and minorities. Therefore, HSE has the potential be a transformative project-based national educational model that significantly improves applied workforce skills and increases post-secondary STEM enrollment and graduation.

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References

1. Barrows, H. S. (1996). Problem-Based Learning in Medicine and Beyond: A Brief Overview. *New Directions for Teaching and Learning*, 68, 3.
2. Buck Institute for Education Project Based Learning for the 21st Century. (n.d.). *What is PBL?* Retrieved from http://www.bie.org/about/what_is_pbl.
3. Casner-Lotto, J. & L. Barrington (2006). *Are They Really Ready to Work*? *Employers' Perspectives on the Basic Knowledge and Applied Skills of New Entrants to the 21st Century U.S. Workforce*. Retrieved from http://www.conference-board.org/pdf_free/BED-06-Workforce.pdf
4. Fletcher, G. H. (2007). Curriculum-based Reform: An Eye on the Future. *T.H.E. Journal (Technological Horizons in Education).* Retrieved from http://thejournal.com/articles/2007/07/01/curriculumbased-reform--an-eye-on-the-future.aspx
5. National Science Board, National Science Foundation. (2003). *The Science and Engineering Workforce: Realizing America's Potential.* Retrieved from http://www.nsf.gov/nsb/documents/2003/nsb0369/nsb0369.pdf
6. Strobel, J. & Van Barneveld, A. (2009). When is PBL More Effective? A Meta-synthesis of Meta-analyses Comparing PBL to Conventional Classrooms. *Interdisciplinary Journal of Problem-based Learning*, 3(1), 44-58.