STEM Education as a Reformative Engine in the United States

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Introduction

Today, Science, Technology, Engineering, and Mathematics (STEM) fields contribute to the betterment of our life everyday by bringing a variety of new technologies including Smartphone, computers, nanotechnologies, bio-engineering, and renewable energy. The technologies bring convenience to our lives and help extend a life span of human beings. The advanced technologies are perceived as significant criteria that distinguish industrialized nations from developmental countries. The world competition resides in the competitiveness and the acquisition of the technological power. In the book titled "The World is Flat," Thomas Friedman (2005) concluded that the creativity could be the ultimate goal for each country to achieve in order to survive the competitive world market. He emphasized that creative technologies would be one in the future that flattens the round globe, removes the hierarchical structure of human power, and collapses the boundaries of inter-continents. He also stressed that creativity would be the biggest value and most significant criteria to be used in competition. Today, the world has already entered into an infinitive competition. This fact is not new at all. It is critical to know what is most important within the competition and how to survive through. This paper is written to respond to this imminent demand of creativity and atmosphere by introducing the U.S. STEM education with implications for Korean science education.

The power of the creativity and the infinitive competition of the world influences individuals, communities, and nations. No one can escape from the atmosphere of competition. Individuals will be assessed and judged based on the creativity of works done in their field. It is an unavoidable trend to go forward. The same principle applies to the development of a community and even a nation. The creative ideas that help develop a community, a state, and a nation deemed to be a corner stone of survival. Each country including the U.S, U.K., Finland, and Germany emphasized STEM education as a national strategy. For example, Mr. Bill Gates, CEO of Microsoft Cooperation has often been expressing his concerns to the Congress that there is a shortage of STEM brain that meets the high level of work at Microsoft. After 9.11, foreign-born Ph.D. in STEM fields continued to go back home after the completion of their doctorate due to the short-term visas. It is called "Brain Drain." Without enough number of STEM workforce, Microsoft would not be able to sustain in the U.S. In the Obama administration, an educational bill "Race To the Top" has been passed to produce 10,000 STEM teachers across the nation to compete with the advanced countries around the world (U.S. Department of Education, 2009).

Each country conceived STEM as a survival strategy. STEM became a reformative engine to reshape science education to meet the needs of a nation. The United Sates strategically uses STEM to sustain the top power by educating K-16 students. As mentioned in the above, creativity is the focus of STEM education.

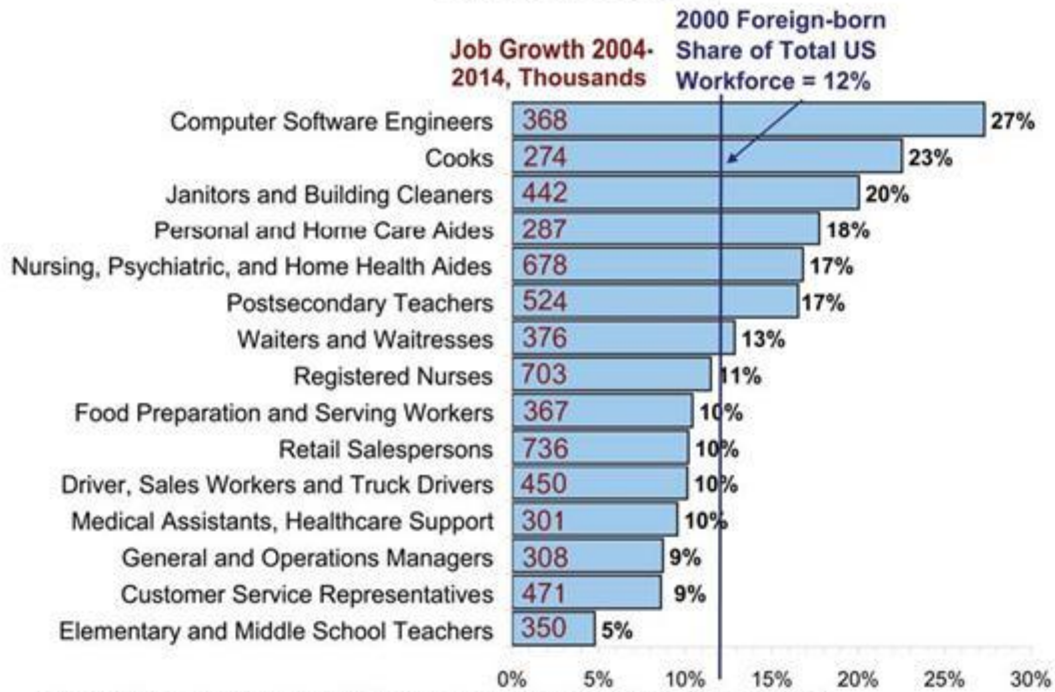
II. Background and History of STEM Education in the U.S.

STEM is an acronym of Science, Technology, Engineering, and Mathematics which was used in National Science Foundation in 1990s (Bybee, 2010). In the advent of new millennium 2000, STEM has been used as a key jargon in various reports, news media, economy, society, politics, and education. The goal of this movement is to fill up the shortage of STEM workforce needed in the United States.

1. Industry and STEM

Within this nation, the 2000 Census reported that the foreign-born STEM human resources take 12% on average in the analysis of 15 different industries. Among the industries, 27% of the entire computer software engineers in the U.S. were foreign-born people (see Fig. 1).

Fig. 1 Foreign-born Share of the Fifteen Occupations with Largest Growth 2004 to 2014



Sources: BLS projections; tabulations of 2000 Census 5 percent Public Use Microdata Sample (PUMS).

Globally, China has already established a strong cornerstone in the areas of electric engineering and computer engineering. India has shown a strong fundamental resource of human capital in the areas of accounting and finance services. These two countries took lead in the above industries. The 500 world's richest CEOs (Fortune 500) were surveyed about STEM. The result showed that 95% of CEOs conceived that the U.S. has a serious shortage of STEM workforce, 68% believed that the U.S. has not offered a good education for STEM. K-12 is required in the U.S. education system. However, around 30% of the students (18-22 aged) are a drop-out who did not graduate from high school. And about 200,000 jobs are open every year in engineering-related industries in the United States but the higher education institutes can only produce 60,000 engineers yearly. In other words, 2/3 of the jobs in engineering are not filled. In contrast, China and India can produce about 600,000 engineers yearly respectively. Therefore, the U.S. is outsourcing the engineering-related jobs. This shortage of quality engineers is perceived not only as a culprit that makes the U.S. economy worse in the long run but also as a threat to the national security and the defense line (Heritage Foundation, 2009) because the defense technologies are developed, designed, tested by foreign-born engineers outside of the U.S. The Heritage foundation (2009) reported to the Congress that this fact would make the U.S defense security weaken.

2. Education and STEM

The American education is reported in a 'STEM Crisis' in its entirety. The school curriculum is more focused on extracurricular activities rather than on STEM. A fund-raising is business-as-usual in sports but not in Mathematics Olympia and Science Fairs. There are many sports heroes in schools while math and science gifted students are deemed as a nerd in American schools.
The students who are not good as STEM do not feel shame. Rather, they take it for granted because STEM is deemed fundamentally difficult. This little interest in STEM fields is never of assistance to the competitiveness of the U.S. A couple of the international tests (e.g., PISA and TIMSS) have seen that the U.S. students ranked at or under the average scores. For example, the U.S. students' achievement scores on PISA test ranked 17th in science and 26th in Math among the 29 OECD countries (OECD, 2010).

STEM education initiated by the perceived crisis in education and industry has started with a good reason and feasibility at the national level. People in industry, politics, and education convened together to discuss and agreed on educating STEM in K-12 to prepare for the next generation in the United States.

III. STEM Education and Successful STEM Programs

1. What is STEM Education?

STEM education is an integrated education of science and mathematics in relation to technology and engineering (Bybee, 2010; Merrill et al., 2010).

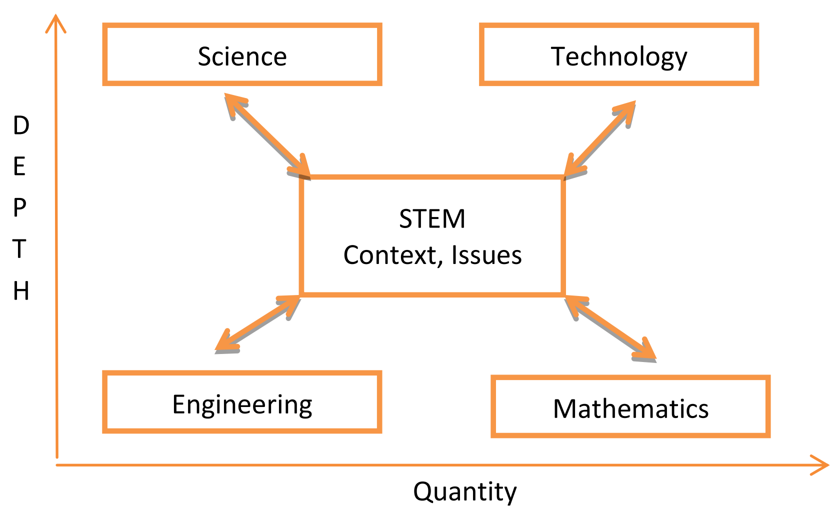


Fig. 2. The Structure of STEM (Adapted from Advancing STEM Education: A 2010 Vision (Bybee, 2010))

Thus, STEM teachers teach STEM in an integrated approach. Teaching STEM tends to be in a form of dynamic and connected way. STEM's key interest lies in how STEM is implemented in classroom settings. If each field in S.T.E.M is taught separately, then STEM is not a new concept (Sanders, 2009). STEM education teaches more than two fields of S.T.E.M in depth and quantity in an integrated fashion (see Fig. 2). STEM education focuses on problems and issues in our daily life to solve with help of technologies, engineering, and facilities and equipment to meet the human needs in innovative way.

Example of STEM Context or Issues

Wind power of renewable energy is a good example as a context for STEM education, which is used in a state-funded project of "Wind for School" (Illinois State University, 2010) as follows.
Topic: Wind Power to serve the amount of electricity demands in Chicago for a year
Content: Mathematics, Science, Engineering, and Technology
Question: How many are wind mills needed? What kinds of technologies are needed? What science and engineering are needed? What is the economic effect? What are the environmental problems (e.g., noises)?
STEM activities: Students use mathematics to build up a wind mill to solve the questions with the concept of science, engineering, and technologies. Science concepts are, in this case, the velocity of wind, electricity, energy, and sustainability. Engineering concept is used in explaining the principle of turbines, angles and spinning principles of wind blades. On the other hands, technology concept applies to technological aspects of turbines, materials of wind blades, skills. Besides, economic effects and environmental impacts are dealt in STEM education.

Examples of STEM Activity (Unit)

Title: Renewable Energy Contents Development (Center for Renewable Energy at Illinois State University, 2011)

Part 1. Energy Basics

1) Power and Energy

   In this section, students learn about the basic principles of power and energy.

   Introductory Activity: students use a hand-crank generator equipped with power and energy meters. Through this activity, students are able to see for themselves the instantaneous nature of power and the accumulative nature of energy over a period of time (for example, ask the students to crank the generator for one minute).

   The activity is followed by a classroom lesson on power, energy, and the various forms of energy (forms of potential and kinetic energy).

   At the end of this unit, students are able to answer the following questions:
   What is power?
   What is energy?
   What are the different forms of energy?

Lab or Homework Assignment: Use a Kill-A-Watt or Watt's Up meter to measure electricity consumption of various devices, calculating power and energy, unit conversion exercises.

Lab or Homework Assignment: Each student analyzes their home's electricity bill. Using a typical home electric energy breakdown template (e.g. refrigerator is typically 8% of electricity consumption, lighting is 30%, etc.), students create an energy consumption chart for their home.

2) Energy Sources

In this section, students learn about sources of energy and how they can be utilized for our energy consumption.

The classroom lesson discusses how we use different energy sources as fuel in our current society. The discussion includes the amount of each fuel source that is available for us to use.

At the end of this unit, students are able to answer the following questions:
Where does energy come from?
Why should we try to conserve energy?
How much of our electricity comes from each source?
Lab or Homework Assignment: Each student uses their own home's electric utility bill and a breakdown of the energy sources used by the utility to determine what percent of their electric consumption comes from each energy source.

3) Renewable Energy Sources

In this section, students learn what makes an energy source renewable, and an overview of various renewable energy sources. The classroom lesson discusses what makes an energy source renewable. Then, students get a broad understanding of a wide range of renewable energy systems including solar, wind, geothermal, biomass and biofuels.

At the end of this unit, students are able to answer the following questions:
What makes an energy source "renewable"?
What are some of the renewable energy options available, and how do they work?

In-class or homework assignment: Classify each energy source as renewable or non-renewable

Formative Assessment- Writing assignment: "Create your own energy grid." Suppose you have $x to spend on an energy grid system and you need to supply Z kWh of energy. How much of each energy source would you include in "your" energy grid? Why?

Teacher Reflection: based on the students' performance including their assignment reports, teachers reflect how their reports meet the objectives of the lessons.

	Engage	Explore	Explain	Extend
Energy Basics	1. Use a hand-crank generator outfitted with power and energy gauges to light a light bulb. 2. Observe what happens to the power and energy gauges as the hand-crank generator is cranked by students for one minute.	1.Bring an electricity bill from home and pick out the most relevant parts 2. Use a Kill-A-Watt or Watt's Up meter to investigate power and energy consumption of common appliances. 3. Classroom instruction on power and energy, energy sources, and renewable vs. non-renewable sources.	1. Activity: classify each energy source as renewable or non-renewable. 2. Assignment: Using a template, each student breaks down and their household energy consumption by device (A/C, lighting, etc.)	Assignment: "Create your own energy grid"

Part 2. Solar Energy

1) Solar Resource Assessment

In this lesson, students assess local weather condition and solar resource available for solar energy technologies. Students utilize a weather station located at school to measure temperature, humidity, and solar radiation.

The classroom lesson cover the description of equipment utilized for the weather condition assessment. The classroom instruction includes the terminology used in solar energy and student learns how to interpret seasonal variances of solar resource.

At the end of this unit, students are able to answer the following questions:
How can solar resource be measured using pyranometer?
How can solar radiation be converted to other forms of energy (i.e. electricity, heat source)?
What makes seasonal variances of weather condition?

Lab Activity: Students collect the data from the weather station and generate graphs with the collected data to assess local weather condition. The outcomes are shared with other schools via web interface designed for data sharing.

2) Sun Path Tracking
In this activity, the classroom instruction demonstrates a lesson used to show students a simple way of tracking the sun's path. Students observe the sun's apparent path across the sky during the day and summarize the observations for the local area. Students make a graph that demonstrates the path of the sun. The objective of this lab activity is to inform general concepts regarding solar path and subsequent intensity of solar radiation.

At the end of this unit, students are able to answer the following questions:
What determines sun's position and how can it be measured (i.e. altitude and azimuth)?
How solar radiation intensity varies with its position?
What makes seasonal temperature changes?
Why should this experiment be conducted in the southern direction?

Lab Activity: Upon completion of the assignment, each student is expected to submit the following items and report:
-The cardboard on which the sun's path was traced with all the necessary information
-A lab report

3) Solar Energy Output Estimation

In this section, students learn different types of solar energy technologies and utilize simple simulation software tool to estimate annual solar energy outputs based on local weather condition and solar energy technology implemented. Upon completion of the previous solar activities, students integrate the local weather data to estimate the solar energy generation potential.

At the end of this unit, students are able to answer the following questions:
How much electricity can be generated from various solar systems with different capacities?
What makes seasonal energy output variance?
How does the system orientation affect the system output?

4) Data Sharing and Networking

The last section of the solar energy program cover different methods to share the data collected and energy output quantified from different school districts. Students are involved in this activity through a web interface and the popular social networks such as Twitter and CCREE Facebook. The ISU's Renewable Energy Laboratory hosts a network server for the all the necessary data. Students from different schools compare and contrast their data sets and energy outputs. This will enhance students' understanding of solar resource and its potential as an energy source to meet our electrical demand.

Formative assessment - At the end of this unit, students are able to answer the following questions:
How do the solar resources of two locations vary each other?
What makes energy output difference between two locations?

Teacher Reflection: based on the students' performance including their assignment reports, teachers reflect how their reports meet the objectives of the lessons.

Solar Energy Program Summary Table

	Subject	Data/Information required	Equipment/Software
Activity #1	Understand solar resource available	Weather information (temperature, insolation, wind speed etc.)	Temp. sensor Pyranometer (weather station installed on site)
Activity #2	Sun Path Lab	Acquiring sun's position	Compass, cardboard, tracing tool
Activity #3	Estimating energy output from a solar photovoltaic panel	Conceptual system to calculate energy output	PVWatts & Weather info (use locally collected solar resource data from school's weather station to predict output from a solar array at *your* school)
Activity #4	Data sharing/Networking	Energy outputs from the selected school districts	Server, Web interface (Facebook & blogs)

	Engage	Explore	Explain	Extend
Solar Energy	1.Solar energy data collection from in-situ equipment 2.Sharing collected data with other school districts	1.Tracking sun's path 2.Examine local weather condition and assess solar resource available 3.Estimate electrical outputs based on solar resource assessment	1.Explain different solar technologies and their uses 2.Explain solar resource and energy output variance	1.Use computer software to evaluate several different turbine models on school property

Part 3. Wind Energy

1) Wind Resources
In this section, students learn about the resources necessary for a viable wind energy system.

To engage students and pique interest, a tour of the ISU Horticulture Center hybrid renewable energy system, a tour of a utility-scale wind farm, or a "virtual tour" of a wind turbine is arranged in cooperation with the ISU Center for Renewable Energy.

The classroom instruction portion includes a discussion of the role of height and wind turbulence in predicting energy resources, and inspect wind regimes from various parts of the country. Principles like average wind speed, Weibull curves, and wind turbine power curves are discussed in class and applied in activities.

At the end of this unit, students are able to answer the following questions:
How does turbine height impact the energy produced by a wind turbine?
What does a wind velocity profile look like?
What does a wind speed distribution look like?
How can we predict how much energy will be produced by a wind turbine?

In-class or homework assignment: Using a given wind speed distribution and wind turbine power curve, predict the annual energy output of the wind turbine.

2) What makes a good wind turbine?

In this lesson, students learn the fundamental principles of wind turbine operation and the underlying parameters that allow them to function efficiently.

The classroom instruction portion includes a discussion of the role that turbine height and rotor swept area have on energy output. Other topics include power law for predicting wind speeds and the power output equation for wind turbines. Upper-level students discuss Faraday's Law of Induction to learn how a generator operates.

At the end of this unit, students are able to answer the following questions:
Why is swept area an important parameter for a wind turbine?
How can wind speeds be predicted using the power law equation?
How can power output of a wind turbine be predicted from wind velocity and efficiency parameters?

Activity: Look inside and touch a small wind turbine (e.g. Air Breeze owned by Farnsworth Group).

Lab Activity or Competition: The students divide into team of three to four students and design and construct their own wind turbine model. KidWind turbines are the building blocks for the turbine designs. At the conclusion of the activity, the turbines are tested to see how much power can be generated by each group's model turbine (measured using a water pump and graduated cylinder, measuring pressure/pump head).

Formative assessment - Writing Assignment: If you were designing a wind turbine, what would be the most important parameters for you to consider?

Teacher Reflection: based on the students' performance including their assignment reports, teachers reflect how their reports meet the objectives of the lessons.

3) Application to local resources
In this lesson, students investigate how well a wind turbine would work in their own school's environment.

This portion of the curriculum uses data collected locally by a weather station/anemometer set up at the school. Classroom instruction includes a discussion of data quality control and a tutorial on wind energy software (Windographer®).

At the end of this unit, students are able to answer the following questions:
What is the average wind speed at the school's location for the height data was collected at?
How do the school's wind resources compare with wind resources in other parts of the state and country?
How much energy could be generated by a particular wind turbine constructed on school grounds?

Lab Activity: Each student should select three models of wind turbines of varying sizes. The students should then use Windographer® to calculate the amount of energy that could be generated by each turbine. This number should be compared to the school's overall electric energy consumption.

	Engage	Explore	Explain	Extend
Wind Energy	1.Field trip to Illinois State University Horticulture Center 2.Field trip to a utility-scale wind farm 3."Virtual tour" of a wind turbine	1. Look inside and touch a small wind turbine (e.g. Air Breeze owned by Farnsworth Group). 2. Using a given wind speed distribution and wind turbine	1.Assignment: Using a given wind speed distribution and wind turbine power curve in Chicago, compare and explain the constructs of the distribution and	1.Design and test your own model wind turbine 2.Use computer software to evaluate several

		power curve, predict the annual energy output of the wind turbine. 3.Classroom instruction on wind energy resources, parameters, and evaluation	power curve in Wilton, North Dakota. 2. Assignment: If you were designing a wind turbine, what would be the most important parameters for you to consider and why?	different turbine models on school property

<u>Example of STEM Project</u>

<u>Title:</u>
Creating Contexts for Renewable Energy Education in High School

<u>Brief Summary:</u>
<u>Rationale:</u> Energy issues became a critical agenda for each nation now and in the future. The term, “energy, especially renewable energy” is used in news media, books, policy, reports, and school curriculum. However, the acceptance of renewable energy is not apparent due to lack of information, knowledge and understanding about renewable energy or energy in general (Liarakou et al., 2009; Krohn et al., 1999; Wolsing, 2007).
<u>Purpose:</u> ‘Creating Contexts for Renewable Energy (CCRE) education in high school’ project will deliver a professional development workshop for 20 secondary science teachers in a school district to meet three goals: (G1) To enhance teachers’ content knowledge and to improve teaching practices, (G2) To improve secondary school students’ achievement scores in science, and (G3) To increase the understanding and application of scientifically-based educational research through action research.

<u>Method:</u> The proposed project will focus on two areas of renewable energy including solar and wind energy. Each area will have 3-5 activities in which teachers and students will perform measurements of several parameters out in the field once a week for 2 1/2 years. When measuring the data in the areas of solar and wind energy, participants will precisely follow the protocols that will be designed and tested by the ISU’s Renewable Energy Center. As participants collect data from the field, they send it to a web-based data bank that will be stored at ISU and be utilized for the purpose of research as part of their action research. In this case, participants will use the Social Network Services technology called *CCREEfacebook* by using a Smart Phone to have easy and fast access in communicating with data. All data will be presented on a web in a form of GIS using a Google map that will show data points accurately in a time series so that all the participants use for their action research.
Evaluation: TIMSS and PISA instruments, ISAT will be used to assess students’ achievement; DSAMST instruments for evaluating teacher content knowledge; RTOP for teaching practices.

Evaluation:
G1. Students' achievement scores will be measured through TIMSS, ISAT, & PISA.
G2. Teachers' content knowledge will be evaluated by *Diagnostic Science Assessments for Middle School Teachers* [DSAMST] developed by University of Louisville. For teachers instructional practices evaluation, we will use (a) the *Inside the Classroom: Interview and Observation Analytic Protocol*, (c) *Local Systemic Change Through Teacher Enhancement questionnaire* (c) the *Understanding by Design* self-assessment and (d) the *teacher's journal entries*. For the implementation fidelity of the workshop program, Reformed Teaching Observation Protocol (RTOP) instrument will be utilized.
G3. Educational research will be evaluated by Research Competition: A yearly Research Symposium will be held at ISU as a result of completing *Action Research.* Each team from each school will be presenting their research result at a meeting where friends, professors, students, teachers, and principals are all invited to attend.
External Evaluation: External evaluator will measure the quality of program activities by using *(a) Professional Development Activity Log* (PDAL), (b) the *teachers' journal entries* and (c) the *Understanding by Design* (UbD) standards checklist.

Our CCRE project creates instructional materials including lesson plans using a 4Ex2 inquiry model and measurements using protocols over 2 year and a half period, which will be both utilized in science class and for research. In addition, the scope and depth of science curricular in the CCRE project will be aligned with Illinois Learning Standards, Teacher Professional Development Standards so that all the activities are inclusive around the standards for students learning and teachers' improvement of teaching practices. Lastly, the CCRE project will utilize technologies to promote students collaboration and their cyberlearning including RE measurement probeware, *CCREE facebook*, a web-based data bank for RE measurements, netbook, & Smart phones to upload collected data and *Cybercollaboration* right at the data site. These activities are carefully aligned with the National Educational Technology Standards by a STEM Technology Committee to make students learning relevant and meaningful.

Scope of the CCRE Project (see Example of STEM Activity (Unit)**)**: Teachers and students will participate in the following activities during the *Renewable Energy Partnership (REP)* program in which ISU science educators and scientists in two colleges including College of Education, College of Applied Science and Technology.
(1) Solar Energy (put here scientific content knowledge to be used, technologies - computer software, labware, networking and collaboration utilities, web-based resources, on--line gaming, virtual learning environments, and portable digital media as well as scientific tools like sensors for data capture or laboratory studies).
(2) Wind Energy (core content knowledge and technologies)
Activity of the CCRE Project: Over 2 1/2 years (once a week), students and teachers will be out in the field to measure the parameters identified in the above activities and do the following:
(1) Enter the data from their unique school location into the *web-based data bank* that will accumulate it in a time series. Fig. 3 is an example of water data. We will develop a similar GIS web-based data bank as Fig. 3 through this project. The data will be stored in a computer server at Illinois State University and will be accessible by any of the individuals in the program.
(2) Extract the data to use for the purposes of teaching and action research.
The following web is a model that we are developing for data presentation on a web (see Fig. 3).

http://www.communitymap.net/chatham/
(3) Students and teachers are connected with scientists through a Social Network Service (SNS) technology called *CCRE facebook* that will be developed for collaboration, discussion, and Q&A. SNS will promote an active discussion and collaboration about inquiries that require in-depth content knowledge and topics in soil, hydrology, and atmosphere areas. This model of learning community is adopted by NSF and USDoE to increase students' achievement.

Benefits for students and teachers: Teachers are invited to ISU's Renewable Energy program for two full weeks during two summers. Participants will be provided:

- a graduate course (action research -3 credit hours paid through the grant)
- a Renewable Energy probeware or technologies and equipment for measuring the parameters
- a CCRE station in each school
- a certificate of CCRE teacher (we offer a certificate to participants upon completion of the summer workshop)
- a Smart phone to send collected data as fast as possible and to check data at other data points.
- Stipend

Instructional Strategies for Implementation:
-Project-based science approach to teach science
-*4Ex2* Inquiry Model of teaching
-Middle and High School level

Expected outcomes: For students:
-Students science achievement scores will be increased.
-Reasoning skills will be developed.
-Motivation will be increased.
-Science attitudes will be increased.
-Ability to apply will be increased

Expected outcomes: For teachers:
-Teachers science content knowledge will be increased.
-Teachers pedagogical knowledge (instructional practices or curricula knowledge) will be increased.

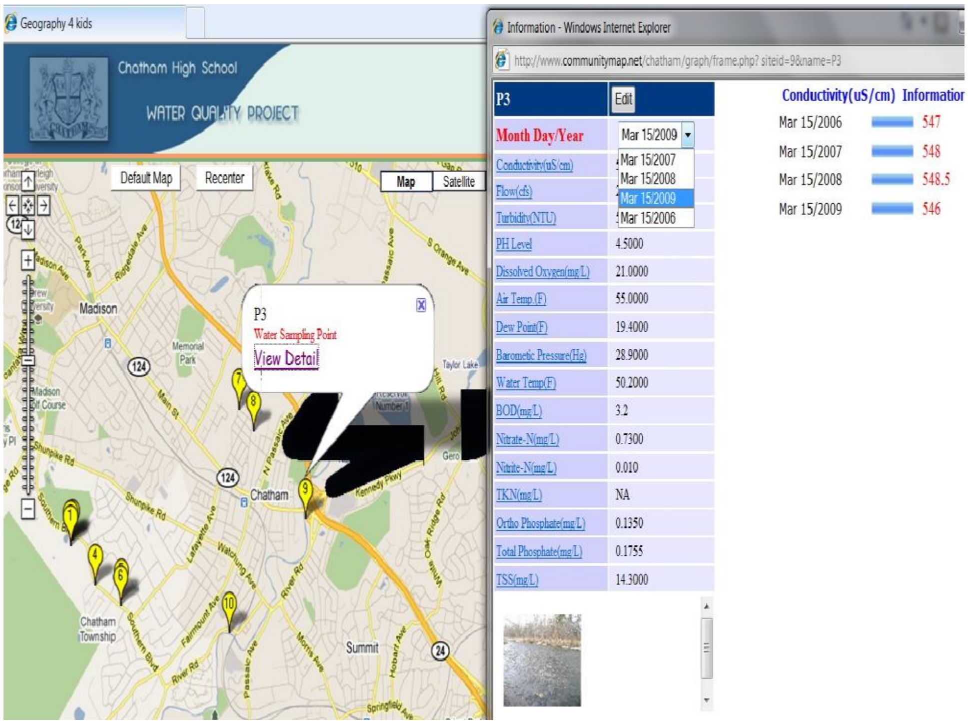


Fig. 3. An example of data presentation on a web that the project will develop.
Note: The image in Fig. 3 is not directly related to renewable energy. However it is a model of data presentation on a web that will be produced throughout the project.

Theoretical Framework of *4E* x *2 Instructional Model* for Inquiry Learning:

As an instructional model of inquiry-based investigation, we will adopt the ***4E* x *2*** model to teach Wine Energy, Solar Energy, and Scientific Inquiry (Marshall et al., 2009) because it provides a dynamic research-based framework designed to promote deep, content-rich teaching that integrates inquiry teaching, formative assessment, and reflective practice.

4E x 2 Instructional Model. Student achievement increases when teachers effectively incorporate three critical learning constructs into their teaching practice: (1) inquiry teaching (NRC, 2000), (2) formative assessment (Black & William, 1998), and (3) teacher reflection (National Board for Professional Teaching Standards, 2006). The *4E* x *2* Instructional Model (Fig. 4), which provides the framework for this proposal, integrates these learning constructs into a single dynamic model that guides the transformation of instructional practice. **Inquiry teaching** provides a solid and essential strategy for learning mathematics and science (Bransford, Brown, & Cocking, 2000).

Currently, the 5E Instructional Model is an approach that has been widely adopted by science educators (Bybee, 2002), but this model assessment is often perceived as summative (the 5th and final *E*), not formative, and thus left to the end of instruction. Also, teacher reflection is not explicitly integrated and thus becomes neglected. The proposed *4E* x *2* Instructional Model adopts the core of the 5E Model (Engage, Explore, Explain, and Extend) while integrating and explicitly linking formative assessment and teacher reflection to each phase of Inquiry teaching as shown in Fig. 4. Research evidence suggests that the *4E* x *2* Model is effective in transforming instruction and improving learning in science (Marshall et al., 2009).

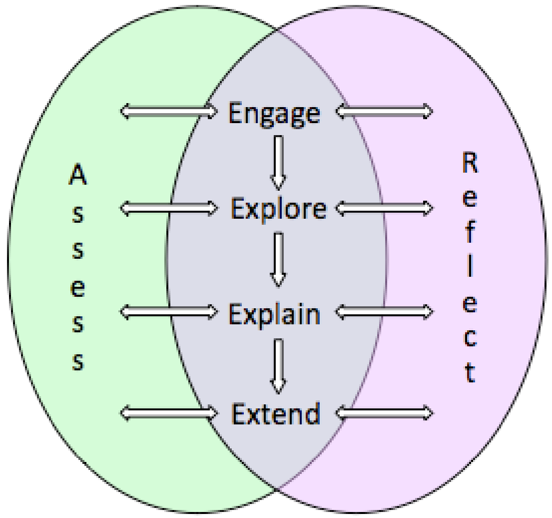


Fig. 4. Framework for the *4E* x *2* in Instructional Model

Instructional Method:

1. Co-Teaching: Co-teaching is two or more people sharing responsibility for teaching some oral of the students about a subject. Co-Teaching is an integration of collaboration, consultation, and cooperation in learning. Key elements are sharing recourses, cooperative responsibility, co-planning, seamless instruction, and co-evaluation.
2. Project-based Learning
3. Problem-based Learning
4. Inquiry-based Learning
5. Integrated Curriculum

2. Why STEM Education?

Rationale of STEM education in the U.S. is two-fold as follows.
(1) Producing jobs and workforce in STEM
The ultimate goal of STEM education is to produce more jobs and expert workforce in America (ITEA, 2009). As noted in the above sections, the U.S. is in shortage of STEM workforce, which becomes a rationale of STEM education. The modern industry requires more complicated knowledge and skills to produce creative and innovative items (Lacey et al. 2009). Moreover, the decisions of individuals and societies also often require the comprehensive understanding of STEM fields. A couple of reports stressed that the U.S. requires STEM education in order to sustain the leadership in world economy and a continuing advancement in domestic economy. However, around 75% of the 8^{th} graders in the U.S. failed in math achievement (Schmidt, 2011). In addition, the labor workforce of the U.S. industry is lacking knowledge and skills in mathematics and problem solving (NGA, 2007).

(2) International Competitiveness in Economy and Education
STEM is conceived as a fundamental strength of the U.S. economy. Without enough STEM workforces, the U.S. economy will not be standing on a strong foot in the future. To strengthen

the U.S. economy, STEM education is a must from K and all the way up (Brophy, Klein, Portsmor, & Rogers, 2008; Congressional Research Service, 2006; National Science Board, 2007). STEM supporters stressed that if students who received STEM education are highly likely to enter the STEM field as their career (Brophy et al., 2008; Suddreth & Itamura, 2007).
In addition, STEM students develop their ability of problem solving, critical attitude, and creative and analytic ability, and their ability to connect school curriculum and real life (National Science Board, 2007). These skills and abilities are ones that the 21st century requires students to adapt to a rapidly changing world.

3. Purposes of STEM Education (NRC, 2011)

(1) To produce advanced students pursuing STEM field careers and to increase a number of women and minority students who are involved in STEM area.
The U.S. faces an imbalance of academic achievement among the low SES and minority group of students including Hispanic and African American, which becomes a political burden (Wilson et al., 2007). The increase of STEM workforces in these groups would be of great assistance to construct a strong society.
(2) To produce STEM experts
The modern society requires more STEM workforces that help resolve a complex problem in everyday life. The demand surpasses the supply. This STEM workforce is an indication of nation's strength and element that increase the competitiveness.
(3) To increase STEM literacy of students at all levels
STEM literacy is an imminent goal to be achieved for all students regardless of their majors. The concept of STEM literacy is necessarily needed in the decision making of individuals, culture, and economic productivity. It applies to students at all levels. STEM literacy is a framework of assessment that was used in the 2006 PISA test. The core concept of the test is as follows (OECD, 2006).
-Acquire the knowledge of S.T.E.M. and use that knowledge to identify issues, learn new knowledge, and apply it to STEM-related problems.
-Understand the features of STEM disciplines as forms of human endeavors including the processes of inquiry, design, and analysis.
-Realize how STEM fields shape our understandings and knowledge about the material, cultural, and intellectual world.
-Live and engage in STEM-related issues with the knowledge and skills in S.T.E.M. as informed and concerned citizens.

4. Criteria of Successful STEM Schools

(1) STEM Achievement Scores of Students
Students' achievement score become an appropriate measure of successful STEM school. One thing to be careful, however, is that students' achievement score is not the only data to determine a success of STEM school. Therefore, teaching strategy, school program, structural conditions, and students' participation in the lesson should be additional resources to use in explaining what it means to be successful.

(2) STEM-Concentrated Schools

This criterion helps school be a better school in STEM. However, it is not easy to determine a successful school and program of STEM because the definition of a success may be different depending on different situations of schools, different students, and different conditions. But it is worth reviewing STEM schools so that we can draw an image of successful STEM schools. 90 schools are noteworthy because they concentrate on STEM fields (http://www.ncsssmst.org). The following schools are a good example.

School Names	Web Addresses
Thomas Jefferson High School of Science and Technology, a stand-alone school in Virginia	http://www.tjhsst.edu
North Carolina School of Science and Mathematics, a residential school for grades 11-12	http://www.ncssm.edu/
Illinois Mathematics and Science Academy, a residential high school	https://www3.imsa.edu
Brooklyn Technical High School, a stand-alone school	http://www.bths.edu/

Successful Story 1: North Carolina School of Science and Mathematics (NCSSM)
NCSSM is a public STEM school that provides grades 11-12 with a two-year school system and a residential model. Since 1987, NCSSM became part of the public school system. Only 10th graders are eligible for applying. Admission criteria are centered on math and science interests, standardized test scores, school academic achievements, essay, giftedness, records of competition, extracurricular activities, etc. Application and tuition fees are all waived.

1. Characteristics of School
NCSSM students are to take 4-5 courses per semester. Over three semesters, students are to take 5 courses in math, 6 courses in science, 2 courses in social studies, 6 courses in foreign languages, and 1 course in physical and health science. One of the most worth noting is that students conduct research with a mentor in the subject area in which they are interested. Over the 2 years, 65% of the students participated in a research program and a mentoring program. All of the NCSSM students complete 2,200 hours in social service.

2. The Demographic Information of Students
The entire students' population of NCSSM is 680 in which 68% are Caucasian with 11% African American, 1% Hispanic, 22% Asian and Pacific, and 1% American Indian.
3. Others Facts
99% of the graduates enter the college. More than 900 high school students throughout the entire state of North Carolina are provided the NCSSM curriculum and 2,000 students are benefited by connecting to NCSSM lessons through video conference.

5. Successful and Effective STEM Lessons

The effective teaching is summarized as follows. The effective teaching is defined as increasing students' experience and interests at an early stage, helping students to discover what they know, engaging them in science activities so that they keep their interests (NRC, 2010).
Key Element 1: Consistent Curriculum and Standards.

Key Element 2: Exemplary teachers who are able to teach a subject area in depth level.
Key Element 3: Offering quality STEM education qually.

In sum, the characteristics of successful STEM schools are two-fold:
First, students conduct research on their own. Second, students receive mentoring during the period of their study. Students are directly involved in their research, gathering data, interpreting and discovering new facts and proving the hypothesis. The development of creativity tends to be promoted during this process of research.

IV. Solutions of STEM Issues (Heritage Foundation, 2009).

The solution is not as simple as it seems. Figuring out a solution will take time and a systemic approach.
(1) Offering STEM Education to all students regardless of gender, academic degree, and race.
(2) Inviting a good teacher and providing quality training.
Salary increase became debatable when inducting a good teacher. Without the salary level appropriate to the other jobs, however, quality teachers are likely to move to other jobs. Another issue is how much passionate the teachers are about teaching. Students tend to learn more from passionate teachers. In the U.S., many teachers do not have an appropriate teaching certificate about a subject area that they teach.
(3) Choosing schools. Students are able to choose schools that they like to attend regardless of their home location. This idea is to drive a competition among schools so that students have a broader option to choose a better school. As a negative consequence, school principals and teachers tend to teach to the test.
(4) Differentiating STEM teachers' salary. This idea is to close the salary gap between the industry and the school.
(5) Offering a teaching certificate to STEM majors.
This idea is to produce more STEM teachers who may be offered a teaching certificate as they complete 32 hours of teaching methods and pedagogy-related courses.
(6) Introducing inquiry-based instruction.
(7) Attracting the STEM gifted students of U.S citizens. Offering a stipend to students of the top 1-2% would be appealing.
(8) Attracting foreign brains. Foreign-born Ph.Ds. in STEM areas are induced by revising H1-B visa policy.

V. Conclusion and Recommendation

This paper has reviewed the history and background of American STEM education, its goal and content and rationale, the criteria and characteristics of a successful STEM school. In addition, it explained how the Unites States orchestrated its efforts of many organizations to help schools better teach STEM fields and how the research agenda was developed and operated in K-16. The review of the paper came to a conclusion as follows:
First, regarding the creativity through STEM education, the U.S. school introduced two elements including (1) research and (2) mentoring system. Inquiry-based STEM education requires an innovative and creative method in solving problems. Meeting a good teacher and a mentor during K-16 is one of the most important elements recommended by the Creativity Manifesto

(Torrance, 2002). Second, a research project tends to be a long process to produce new knowledge after a robust research question is established. This long process creates new knowledge through creative endeavors. When we agree that STEM education is an imminent thing to do in school, the following two recommendations are made for STEM education.
First, STEM curriculum should first be developed.
As reviewed in the paper, STEM education is a topic that many people are lacking understanding (Bybee, 2010; Keefe, 2010; Brown et al., 2011). To increase the knowledge of STEM education, STEM curriculum development is an immediate thing to do. Specifically, the curriculum must meet the needs of Korean students with the appropriate materials that are developed within the Korean contexts. Second, a task force would be formed to develop a nation's strategy, model, goals, and content that provide a guide and assistance to each of the research centers and universities as they conduct research on Korean version of STEM education.

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