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Energy, Society, and Education, with Emphasis on Educational Technology Policy for K-12

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This paper begins by examining the profound impact of energy usage on our lives, and on every major sector of the economy. Then, the anticipated US energy needs by the year 2025 are presented based on the Department of Energy's projections. The paper considers the much-touted National Energy Policy Report, and identifies a major flaw where the policy report neglects education as a contributor to solving future energy problems. The inextricable interaction between energy solutions and education is described, with emphasis on education policy as a potential vehicle for developing economically and commercially sustainable energy systems that have a minimal impact on the environment. With that said, an earnest argument is made as to the need to educate science, technology, engineering, and mathematics (STEM) proficient individuals for the energy technology development workforce, starting with the K-12 level. A framework for the aforementioned STEM education policies is presented that includes a sustained national awareness campaign, address the teacher's salary issues, and addresses teacher quality issues. Moreover, the framework suggests a John Dewey-style "learning-by-doing" shift in pedagogy. Finally, the framework presents specific changes to the current national standards that would be valuable to the 21st century student.

KEY WORDS:

Energy usage has a profound impact on our standard of living and on every major sector of the economy. The anticipated demand for energy in the United States is increasing at a striking pace. Oil has been the major and most flexible source of energy. Lessons from geopolitical events of the last three decades demonstrate that (1) the cost and availability of oil may not always be subject to our control and (2) the cornerstone of the US' existing National Energy Policy relies on military might, and short-term fixes and may not be sustainable over the long haul. There is a need to develop sustainable, economical, and clean energy systems using technology; candidate sources may include but are not limited to solar, fusion, wind, biomass, geothermal, hydroelectric, fossil, and nuclear.

Developing energy systems using technology requires, among other things, a dedicated and highly skilled workforce of scientists and engineers. Naturally, such a workforce cannot be cultivated in a vacuum—the size and quality of that workforce depends on the quality of the science, technology, engineering, and mathematics (STEM) component of our education system at all levels, from K-12 through graduate school. Therefore, there is an inextricable interaction between energy technology development and the development of quality education.

THE EFFECT OF ENERGY ON OUR LIVES

A Qualitative Look

An energy "crunch" has the potential to severely undermine every sector of the economy and our standard of living. American prosperity, high standard of living, well being and safety depend on reliable and affordable energy.

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Following is an account regarding the effect of energy in several critical areas of the economy:

- At home and in the office, and the service industry: Energy is needed to heat and cool places of residence and offices, to provide lighting, hot water and run appliances. Imagine life without them or with these services greatly reduced!
- Manufacturing: This is generally an energy-intensive sector of the economy. In this sector, energy is needed in two forms: (1) the energy that is used to run the business and (2) the energy that is needed when raw fuel is used in manufacturing. Even for manufacturing operations that are not energy-intensive, such as in the computer and electronics industry, high-quality and reliable energy is a must.
- Agriculture: Farms need generous quantities of energy to run their machinery. Gas (fuel) is a major component in the production of fertilizers, pesticides, and other farm chemicals. Agricultural products require ample energy for their processing, transportation, storage, and final distribution. Agriculture is indeed an energy-intensive sector of the economy.
- Transportation: Airliners, rail transit, sea liners, buses, cars and trucks would all require generous quantities of energy to run. In layman's terms, without energy, there would simply be no transportation. Currently, the transportation sector accounts for about 30% of the total US energy consumption.
- The financial markets: According to the National Energy Policy Report, "rising energy costs and volatility in energy prices can have a negative effect on both individual firms and the broader financial environment, generally producing lower asset prices and higher interest rates."

The earlier statements regarding the effect of energy on our lives illustrate the desperate dependence of our modern society on energy. Clearly, a serious energy crisis would profoundly and adversely effect every sector of the economy, would have dire socioeconomic consequences, and last but not least would have grim effects on all levels of education. An energy crisis would drain resources that could be used for education, and it would add to the operational cost of schools and colleges.

A Quantitative Look: Economic Health and the Cost of Oil

Crude Oil Refiner Acquisition Costs for the years 1968–2002 were obtained from the Energy Information Agency of the Department of Energy.[2] The average cost was converted to year 2000 figures using an online inflation calculator from the US Department of Labor. [3] A plot was generated of the cost of crude oil *versus* year and is shown in Fig. 1a. The Gross Domestic Product (GDP) data were obtained for the years 1968–2002 from the Bureau of Economic Analysis of the Department of Commerce.[4] A plot was generated of the "Real" GDP *versus* year and is shown in Fig. 1b.

For ease of interpretation of GDP behavior, the actual plot in Fig. 1b was approximated by four line-segment approximations where the actual plot is quasi-linear during each segment: the yellow segment (1968–1973), the pink segment (1973–1977), the red segment (1978–1982), and the green segment (1982–2002). The slope of each line may be determined by computing the rise-over-the-run. The slope of each line corresponds to the GDP growth in billions of dollars per year. Hence, the following growth numbers were determined.

The four growth numbers of Table I are significant when compared to the corresponding crude oil cost of Fig. 1a, and reveal the profound impact that oil cost has on GDP growth. During 1968–1973 when oil cost was somewhat moderate, the growth was about 136 billions per year; during 1973–1977 when the oil cost rose and remained high, the growth was about 102 billions per year; during 1978–1982 when a substantial increase in the cost of oil was experienced, growth dropped to a sluggish 43 billions per year; and during 1982–2002 when the oil cost dropped significantly and remained low, growth rose to a mighty average of 244 billions per year.

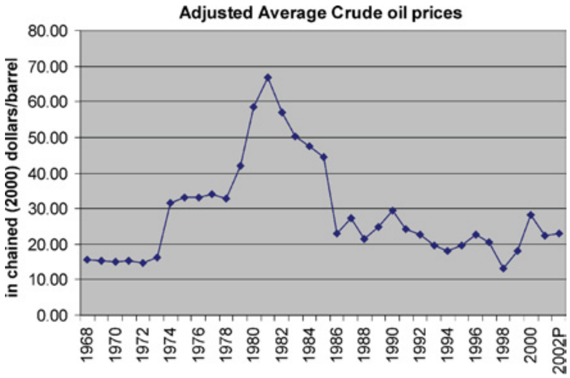
In conclusion, oil cost has a profound effect on economic growth.

The nominal (raw values) crude oil prices were obtained from the Energy Information Agency of

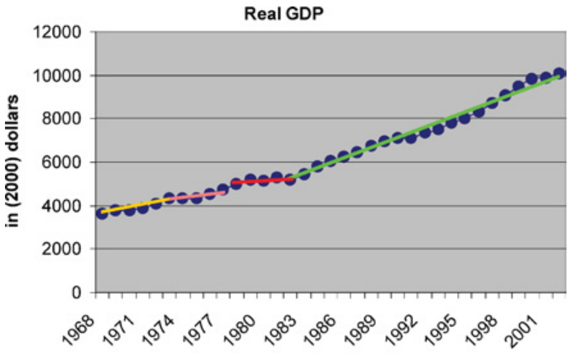
[2]U.S. Department of Energy, Information Agency. Website: http:// www.eia.doe.gov/emeu/aer/pdf/pages/sec5_45.pdf

[3]U.S. Department of Labor, Bureau of Labor Statistics. Website: http://www.bls.gov/bls/inflation.htm

[4]U.S. Department of Commerce, Bureau of Economic Analysis. Website: (http://www.bea.doc.gov/bea/dn/home/gdp.htm)



(a)



(b)

Fig. 1. (a) Average cost of a barrel of crude oil between 1968 and 2002 (in chained 2000 dollars to account for inflation.) (b) The Gross Domestic Product between 1968 and 2002 (in chained 2000 dollars to account for inflation.)

the Department of Energy for the years 1978–2002.[5] Fig. 2a shows a plot of nominal crude oil prices *versus* time.

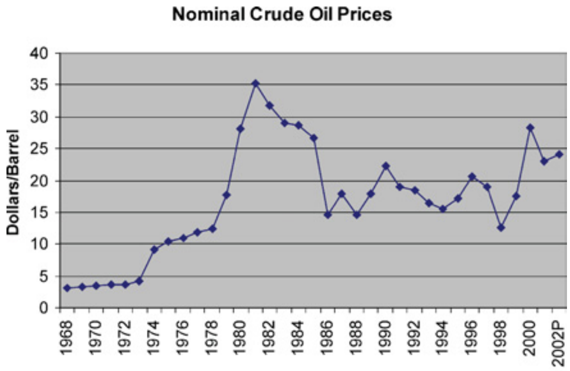
Similarly, yearly inflation data were obtained from the *Financial Trend Forecaster*[6] and were plotted *versus* time and shown in Fig. 2b.

A comparison of Figs 2a and 2b reveals an intimate relationship between the cost of oil and inflation. The two highest peaks of inflation occurred during steep hikes in oil prices, and generally, inflation and oil prices moved in the same direction—as oil prices rose, so did inflation, and as oil prices dropped, so did inflation.

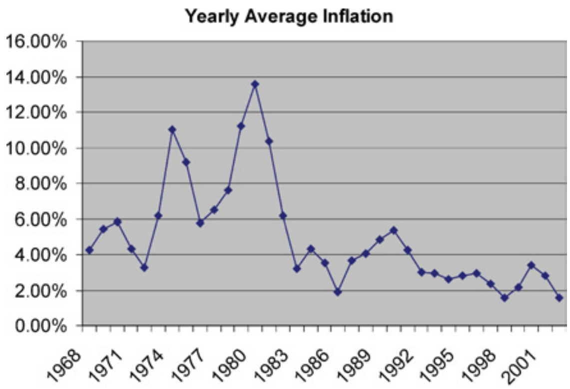
Table I. Yearly GDP Growth

Color code	Duration	Yearly GDP growth in billions of dollars
Yellow	1968–1973	136
Pink	1973–1977	102
Red	1978–1982	43
Green	1982–2002	244

In summary, based on available data and the comparisons delineated earlier, of the large number of factors that affect the economy, the cost of oil appear to be a dominant factor: the cost of oil directly and profoundly affects economic growth and inflation, and is a good predictor of both. In light of this finding, it is reasonable to argue that developing technology for sustainable, efficient, clean, and economical energy, would not only avert the impending economic crisis with all its grim consequences, but in fact may spur an unprecedented economic growth.



(a)



(b)

Fig. 2. (a) Actual cost of a barrel of crude oil between 1968 and 2002. (b) Yearly inflation figures between 1968 and 2002.

[5]U.S. Department of Energy, Energy Information Agency, table 5.19. Website: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec5_45.pdf

[6]Financial Trend Forecaster, Inflation Data. Website: http:// inflationdata.com/inflation/inflation_rate/HistoricalInflation.aspx?dsInflation _currentPage=1

OFFICIAL PROJECTIONS AND THE CURRENT POLICY

According to the Energy Information Administration of the US Department of Energy, total US gross oil imports are projected to increase from 11.5 million barrels per day in 2002 to 20.7 million barrels per day in 2025.[7] Also by the year 2025, the projected consumption of natural gas will grow by over 50%, oil by over 70%, and coal by over 50%, while nuclear and hydro would remain unchanged; and non-hydro renewables would increase by a minute percentage.[8] In addition, demand on oil by vast countries like China and India would produce additional pressure on supply with a resulting step-up in oil prices. For example, Newsday (August 15, 2004) reports that in China private auto sales grew from 22,000 in 1999 to nearly 2 million this year; last year alone, China's automobile sales increased by a staggering 69%.

The much-heralded National Energy Policy Report[9] by the National Energy Policy Development Group to President Bush (May 2001) makes repeated references to the solution of future energy problems by "our unmatched technological know-how" without elaboration or substantiation—as if technological know-how develops in a vacuum. The report does not make any connection between the desperately needed energy technology and education. The development group was composed of a group of *Who's Who* in the administration, including most cabinet members, except for the secretary of education. Moreover, throughout the report, among the multitude of tools cited to respond to the problem of increasing energy need, education is hardly mentioned. The main tools cited in this report include modernizing the energy infrastructure, modernizing energy conservation, and increasing the energy supply by reconsidering regulatory restrictions and allowing for oil and gas exploration in previously restricted areas.

The National Energy Policy Report asserts the following"...we must use technology to reduce demand for energy, repair and maintain our energy infrastructure, and increase energy supply," yet the report does not mention education, as if technology develops in isolation and is disconnected from education.

The report neither mentions the successful experiences of other nations nor recommends emulating those experiences. For example, in the United States, nuclear power accounts for 20% of the country's electricity generation, compared to over 80% in France. For the last few decades, the French have pursued a policy of aggressive R&D of nuclear power plant design and nuclear waste processing. Their method is to utilize a standardized nuclear power plant design with a focus on continuous improvements of the standard design.

Coal accounts for more than 50% of US electricity generation. There are estimates that the United States has enough coal to last for another 250 years. The problem with coal is that it is one of the worst offenders in terms of producing carbon dioxide[10] and sulfur dioxide.[11] There is an urgent need to develop *clean*-coal technologies, but the report does not acknowledge any link between clean-coal technologies development and education.

In summary, the National Energy Policy Report contains a great deal of public relation and rhetoric. Lost in the official rhetoric presented in the report is the issue of how to solve our current and future energy problems using sustainable, environmentally sound, morally sound, technological solutions.

WHY SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) EDUCATION?

Every framework for energy production and use involves the re-engineering of existing technologies and the development of new ones. For example, in solar (Ellis, 1977), geothermal (Ellis, 1977), renewable (Sarensen, 1979), energy from waste (Larry and Tillman, 1977), fuel cells (Larminie and Dicks, 2003), energy conversion (Kenney, 1984), wind (Gipe, 1995), and hydro energy technology (Gulliver and Arndt, 1990), attempts are being made to achieving economically and commercially sustainable energy systems that have a minimal impact on the environment *via* usage of science and technology.

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[7]U.S. Department of Energy, Energy Information Agency. Website: http://www.eia.doe.gov/oiaf/aeo/figure_44.html

[8]U.S. Department of Energy, Energy Information Agency. Website: http://www.eia.doe.gov/oiaf/aeo/figure_2.html

[9]National Energy Policy Report; a Report of the National Energy Policy Development Group to President Bush. Website: http://www.whitehouse.gov/energy/

[10]U.S. Department of Energy, Energy Information Agency. Website: http://www.eia.doe.gov/oiaf/aeo/figure_116.html

[11]U.S. Department of Energy, Energy Information Agency. Website: http://www.eia.doe.gov/oiaf/aeo/emission.html

Each and every energy source that may be useful to society requires sophisticated science and engineering in the extraction, conversion, and end-use of the said energy. For example, the science and technology of thermodynamics lie at the heart of virtually every energy efficiency analysis and design; electrical science and technology lie at the heart of generating, transporting, and using electrical energy; the list goes on and on. In addition, the development of energy technology systems is subject to political, social, economic, and environmental constraints, which require the developer to exercise higher order technical and scientific skills and engineering ingenuity in order to meet the functional requirements while complying with those constraints. The formation of science and technology professionals who would carry the development of energy technology systems takes place in our schools and universities. The quality of that skilled workforce depends on the quality of our entire education system, K-12 through graduate school.

Education is a key factor for technology development—including technology for efficient, clean, and economical energy generation, transportation, storage, and use. Any attempt at dealing with our impending energy issues has to focus on education as a major prerequisite for the solution.

The huge increase in energy need that is expected within the next 20 years requires leadership for immediate and sustained action on a number of fronts, the most important of which is the formation of science, technology, engineering, and mathematics (STEM) professionals through *education*.

"STEM" EDUCATION AND THE POOR STATE OF AFFAIRS IN THE K-12

Please note: The more inclusive acronym "STEM" is relatively new, and many studies that address STEM issues are in the literature generally under the narrower titles of science and mathematics.

The history of STEM education in the K-12 has been a story of mixed successes and failures, of accomplishments and of chronic problems. Following Sputnik (1957), there was a serious and urgent effort to upgrade STEM education, and the effort was successful to a good degree, particularly with regards to launching satellites, having astronauts orbit the earth, etc. as these areas were priorities as far as the government and the public were concerned. Eventually, some of the momentum was lost and a new set of skills and abilities became necessary. During the last two decades, major examinations of the K-12 were undertaken. Hence, over the years, a number of alarms have been sounded regarding the quality of mathematics and science in K-12 education: for example, the *A Nation at Risk* report (National Commission on Excellence in Education, 1983), the National Commission on Mathematics and Science Teaching for the 21st Century report *Before It's Too Late*, and *The Condition of Education 2002* report (The National Commission on Mathematics and Science Teaching for the 21 Century, 2000). The shortage of qualified teachers in mathematics and science at the national level was brought into focus by the National Association of State Boards of Education report (U.S. Department of Education, 2002). Groups that have been historically under-represented in STEM specialties continue to be significantly under-represented (National Association of State Boards of Education, 2002). There has been evidence documented by the US Department of Education of US students' achievement scores being at or lower than international averages in science and mathematics—indicating that the scientific competence of US students needs improvement (U.S. Department of Education, 1992). One third of 4th, 8th, and 12th graders performed at the lowest level on the National Assessment of Educational Progress (NAEP) mathematics assessment (U.S. Department of Education, 2002). There is a persistent achievement gap between white students on one side and African-American and Hispanic students on the other side when it comes to mathematics and science (U.S. Department of Education, 2001).

A FRAMEWORK FOR A MULTI-FRONT SOLUTION

This section gives a design of a framework that would improve STEM education in K-12 for the purpose of eventually enriching the 21st century pool of STEM professionals who would provide technical solutions to society's problems—including the impending energy problem.

The framework suggests a national awareness campaign and establishes its guidelines, addressing teacher issues from salary to teacher quality and professional development, a Dewey-style instruction strategy, and a framework for specific changes to the current national standards and expectations (modeled after *ABET EC2000 accreditation standards*[12]).

[12] Accreditation Board of Engineering and Technology. Website: http://www.abet.org/

As a solution is framed, it should be recognized that changes would not bring measurable response within weeks, a year, or an election cycle. Years or even decades of effort are needed to educate the public, build facilities for education, train faculty, and support students through an educational pipeline of 16 years or more. Any solution requires a sustained long-term commitment.

The National Awareness Campaign

A national awareness campaign is proposed, to be led by the US Department of Education and which would enlists help from the states' departments of education, business, professional and civic organizations, entertainment industry, and the public at large. It would focus on the following:

1) Educating the public in general and educators in particular on the impact of increased energy cost or diminishing energy supply on the economy and on society. As explained earlier in this paper, "Economic growth is tied directly to energy cost"; this important fact must become widely known. Developing technology for sustainable and economical energy may spur an unprecedented economic growth.
2) The need for understanding energy issues by introducing them as an integral component of the next generation's education.
3) Enlightening both parents and children with regard to the opportunities in energy-related STEM careers.
4) Enlightening the parents and children with regard to science and mathematics ability in K-12 as being the pathway to energy-related STEM careers.
5) Enlightening the public in general that advances in technology, global competitiveness, and generation of affordable and efficient consumption of energy depend on most, if not all, students achieving proficiency levels in mathematics and science that are higher than is currently required.

The public needs to be informed as to how a strengthened math and science education would contribute to softening the economic and environmental impact of the impending energy crisis. Moreover, strengthened math and science education would ultimately contribute to increased prosperity.

As a result of the awareness campaign, parents who were successful in life while they performed poorly in mathematics will become aware that their offspring would unlikely be successful without the mathematical literacy. Projections through the year 2010 by the US Department of Labor indicate that *15 out of 20* of the fastest growing occupations require substantial mathematics or science preparation (U.S. Department of Labor, 2000).

The awareness campaign will fight the social stigma of being good in mathematics—equated with being a "nerd"—and seeks to reverse it to one of a glorified social standing among the young.

In an economy that is highly dependent on technology and where productivity is driven higher and higher, the need for math and science competent young generation is great, as mathematics and science are key factors for technology development.

It has been reported by the National Commission on Mathematics and Science Teaching for the 21st century that productivity has increased by an average of 2.6% per year (1996–2000); with that rate, and all other things being equal, the standard of living would double in about 25 years (see footnote 3). The tricky expression here is "all things being equal"; as the analysis presented earlier in this paper has shown, energy cost is a wild card and energy cost is the *Achilles heel* of the economy: inflation increases and GDP slows as a result of higher energy cost (and the converse is true). Therefore, it becomes doubly imperative that the public in general, policy makers and educators in particular become aware of the mechanism by which increased energy cost or diminishing energy supply would adversely affect the economy and society; equally important is that these groups become aware that improved STEM education provides the safeguard from energy-related problems, and spurs economic growth and improved standard of living.

The awareness campaign would convey the message *that in the United States today, mastering mathematics has become more important than ever*. Educators also must be enlightened with regards to a critical juncture in a student's mathematics education. In a white paper entitled *Mathematics Equals Opportunity* by the US Department of Education (U.S. Department of Education, 1997), the following statement is made: "Students with a strong grasp of mathematics have an advantage in academics and in the job market. The 8th grade is a critical point in mathematics education. Achievement at that stage clears the way for students to take rigorous high school mathematics and science courses—keys to college entrance and success in the labor force.

However, most 8th and 9th graders lag so far behind in their course taking that getting on the road to college is a long way off." In the same paper, it is indicated that the key to understanding mathematics is taking algebra or courses covering algebraic concepts by the end of the 8th grade. Achievement at that stage gives students an important advantage in taking rigorous high school mathematics and science courses. However, many 8th and 9th graders may already be behind in their course selection to get on the road to college. Hence, the awareness campaign should target parents, students, educators and policymakers with the message that mastering mathematics is a gateway to college, and that some young kids may be closing doors very early on further education and better careers. The campaign will aim to enlighten parents and students with respect to opportunities in energy-related STEM careers. There is evidence that individuals in STEM-related careers would have ample opportunities and a lower unemployment rate. For example, the National Science Board; *Science and Engineering Indicators 2004 predicts the following:* "If the trends identified in *Indicators* 2004 continue undeterred, three things will happen. The number of jobs in the US economy that require science and engineering training will grow; the number of US citizens prepared for those jobs will, at best, be level . . ." (National Science Board, 2004).

The awareness campaign should highlight the global competition for STEM-related talent that will almost certainly intensify in this decade and the next, generating more aggressive recruiting of talented graduates, and thus creating greater opportunities for STEM graduates. So far, the United States has been a winner on the recruiting front. Historically, the majority of foreign-born STEM graduates of US universities were recruited by US firms, settled in the United States and eventually became productive US citizens. The numbers of those individuals in substantial: According to the National Science Board, *Science and Engineering Indicators 2004* (National Science Board, 2004), drawing on data on science and engineering occupations from the 2000 US census, roughly 17% of bachelor-degree holders, 29% of masters-degree holders and 38% of doctorate holders are foreign born. This phenomenon highlights three things that are germane to the subject of this paper: (1) STEM-related education at US higher education institutions is highly desired; (2) The crux of the American STEM knowledge-bank rests not only on native talent, but on a substantial migrant population, that contribute talent, scientific ingenuity and technical sophistication to the US science and technology enterprise; and (3) This has, to some extent, *masked and shelved the serious problems in K-12 math and science education by filling the much needed talent gap and has prevented sending the US science and technology enterprise into a crisis mode.*

Address the Teacher's Salary Issue

Teachers' salaries are low compared to other college graduates' and are not compatible with the vital services they provide. A study by the American Federation of Teachers, AFL-CIO published in 2002, indicate that the earned average yearly salary of teachers was $43,250 in comparison with $74,920 for engineers (American Federation of Teachers, 2002). The same study shows that in 2001–2002, recent college graduates were getting offers of yearly salaries averaging more than $40,000, while the average salary for beginning teachers was about $30,719. Clearly, teacher salaries are not competitive and this impedes efforts by school districts to attract new teachers and retain them. Furthermore, there are data that suggest very different mobility patterns by teaching fields and gender. A study on *Teacher Mobility, Pay, and Academic Quality* by Podgursky *et al.* (2002) at the University of Missouri-Columbia concludes with the following: *It is well-known that math and science teachers have higher attrition rates than other fields. However, for both men and women, the attrition of high ACT ability math and science teachers is higher than in other teaching fields. Among women, math and science teachers are much less sensitive to pay differences than are elementary school teachers. This means that much larger pay increases will be necessary to reduce the attrition of high-ability math and science teachers as compared to elementary school teachers.*

The phenomenon of teacher attrition in math and science warrants further study, if it is to be combatted effectively. For the time being, however, if the average salary gap cannot be completely closed, other creative incentives may be used by districts, such as decreased student/teacher ratio, added aides' support, differential pay, recognition awards, effective professional development, and overall improvement in working conditions.

Address the Teacher Quality Issue

There is evidence that high-quality teachers affect student academic achievement (Sanders and

Rivers, 1996). A science teacher, for example, who has not majored or minored in the subject matter he/she is teaching will likely deliver diminished instruction in that subject. A substantial number of mathematics and science teachers lack a major or a minor in their field, this is especially true for middle schools (Seastrom *et al.*, 1987).

There is also evidence that while 44 states require candidates for secondary licenses to take some type of licensing test, there are only 29 that require them to take those tests in the subject area they will teach (The Education Trust Inc., 1999).

The grasp of the core concepts and structure of a discipline that one studies in college is a critical foundation for teaching: if that foundation is weak, no instructional cleverness can make up for it. The recommendation is that math and science teachers must have been majored in math and science in college, and must be certified in those disciplines.

Pre-service and in-service STEM education for K-12 is a major challenge for institutions of higher education. These institutions will have to blend STEM knowledge with pedagogical methods and effective practices. This is something that is lacking at the present time. STEM faculty in higher education institutions have the content knowledge but many lack the methods of conveying that content in a *usable knowledge* format to future K-12 teachers.

A Dewey-Inspired Effective Instruction Strategy that May be Nicely Adaptable to the "Next Generation STEM Rich Curriculum"

A primary activity in K-12 education (and often in higher education) has been the transfer, to future generations, of disciplinary facts and ready-made knowledge that were painstakingly gained by past generations. The often-stated goal of this practice is to provide the student with a broad knowledge base. The *No Child Left Behind*[13] achievement standards appear to cater to this philosophy. This goal is a Herculean task given the vast amount of existing knowledge, and consequently a typical curriculum is crammed with courses that instruct the student in disciplinary facts (algebra, geometry, physics, life science, etc.). This is a serious problem as the curriculum has become over-packed, and it will be over-packed even more if sophisticated STEM and energy topics are incorporated into the curriculum. Another serious problem is that this aforementioned activity supports analysis, not synthesis. The "analysis muscle" of a typical student tends to be developed—in contrast to the "synthesis muscle" which tends to be weak and floppy. 21st century skills that are vital to the knowledge-based economy require both the "analysis muscles" and the "synthesis muscle." These include designing solutions, "connecting the dots," designing experiments that advance thoughtful inquiry, and synthesizing patterns from seemingly chaotic data.

This author proposes the following strategy: A student experience that would strengthen the "synthesis muscle" is an experience in which the student uses the theories and body of knowledge that have been constructed during his/her various coursework to synthesize a new technical solution to a societal problem. This may be accomplished by integrating more design, simulation, and laboratory (real and virtual) experience into the curriculum. Hence, developing the "synthesis muscle" would require undertaking new activities and new practices that include stronger discovery and learning-by-doing components in the curriculum. The new design and synthesis activities can take place in full-fledged term-long courses at various levels in the curriculum where the student devotes an entire semester to designing a solution to a (large) problem, and/or performing laboratory work associated with existing courses whereby the student performs design (solutions to smaller problems) in the laboratory on a weekly basis instead of having the student repeat prescribed standard experiments according to predetermined procedures that have been performed countless times by previous generations of students. Here, the word "laboratory" is used in a generic form: the "laboratory" may be physical or virtual, may be computational or simulation, may be work with a mentor face-to-face or at a distance, or may mean some other form of learning-by-doing. New internet, communication, and laboratory technologies would also provide powerful leverage in this endeavor.

Naturally, given the already over-packed curriculum, infusing these new activities would have to occur at the expense of other existing activities that are composed of transferring those disciplinary facts and ready-made knowledge to future generations that were painstakingly gained by past generations. The solution described here would ease the adverse effects of the problems outlined earlier (overfeeding the student "ready-made" knowledge, and the over-packed curriculum), would enhance the

[13] U.S. Department of Education, No Child Left Behind Act. Website: http://www.ed.gov/nclb/landing.jhtml?src=pb

student's ability to synthesize solutions, and would provide a new, superior, powerful pedagogy, that is learner-centered and not teacher-centered or test-driven.

This aforementioned dilemma has been alluded to by John Dewey, albeit using a different vocabulary, in *Experience and Education* (Dewey, 1997), where he distinguished between "traditional" education and "progressive" education. On the traditional model of education he states, *"the subject-matter of education consists of bodies of information and of skills that have been worked out in the past; therefore, the chief business of the school is to transmit them to the new generation."* The traditional model is teacher-driven rather than learner-centered. Knowledge and skills are commodities to be delivered by the teacher to the student. On the other hand, Dewey's idea of "progressive education" was described by him as follows, *"that there is an intimate and necessary relation between the processes of actual experience and education."* Dewey rejects knowledge of the past as the *end* of education; rather, it is a *means*. Moreover, he emphatically argued against the traditional model of teaching the findings of science where the material is presented as ready-made ideas to believe in. He argued that it is not enough merely to repeat that all findings of science are hypothetical or theoretical. Instead, the student should come to see the theory in the context of a meaningful inquiry. John Dewey writes that science education has failed because it "*has been so frequently presented just as so much ready-made knowledge, so much subject-matter of fact and law, rather than as the effective method of inquiry into any subject matter."*

Dewey's theory of inquiry—which he has variously called the method of inquiry, complete act of thoughts in *How We Think* (Dewey, 1991), or critical or reflective thinking—when stripped of his general philosophical perspective, may be reframed as the familiar scientific method or the familiar design process. Dewey's five-step process of inquiry consists of the following: "(i) a felt difficulty; (ii) its location and definition; (iii) suggestion of possible solutions; (iv) development by reasoning of the bearings of the suggestion; (v) further observation and experiment leading to its acceptance or rejection; that is, the conclusion of belief or disbelief." Those five steps are similar to the steps of a typical design process; for example, Barry Hyman in his book *Fundamentals of Engineering Design* describes the steps in the design process model as follows: recognizing the need, defining the problem, planning the project, gathering information, conceptualizing alternative approaches, evaluating the alternatives, selecting the preferred alternative, communicating the design, and implementing the preferred design.

This is a powerful method for educational improvement that has been used and tested in higher education, particularly in the engineering and applied sciences. In higher education, this effective learning model has been in increased use as it has come to be seen to foster the development of knowledge and skills that are needed in the 21st century. With the appropriate content tuned to suit the K-12 levels, it would be a rational move to utilize this powerful method in K-12 education, for it might yield important learning benefits, and it would provide the appropriate "training of the mind" that would be invaluable as individuals go on to college.

Framework for Specific Changes to the Current National Standards that Would be Valuable to the 21st Century Student

This framework calls for a significant and sustained research effort that would yield a better understanding of what are the best methods to achieve the priority learning objectives and expected student outcomes shown later. These objectives mirror the skills expected of the 21st century student.

Expected Learning Objectives and Student Outcomes

Schools must demonstrate that graduates have the following:

a) an ability to apply knowledge of mathematics and science to solve real-life problems or to conduct an intelligent inquiry;
b) an ability to design and conduct experiments in a variety of STEM disciplines as well as to analyze and interpret data;
c) an ability to analyze and understand systems or processes that use STEM to serve a societal need;
d) an ability to function on a multidisciplinary team in a face-to-face or cross-distance setting;
e) an ability to identify, formulate, and solve problems using STEM;
f) an understanding of civic and ethical responsibility;

g) an ability to communicate effectively using distributed media;
h) the broad education necessary to understand the impact of STEM solutions in a global/societal context;
i) a recognition of the need for and an ability to engage in lifelong learning;
j) a knowledge of contemporary issues, including energy issues;
k) an ability to make decisions and synthesize solutions based on incomplete information and real-life constraints;
l) an ability to critically filter information and to determine credibility of information; and
m) an ability to use the techniques, skills, and modern technology tools necessary to function and succeed in the 21st century.

Based on the learning outcomes a-through-m shown earlier, research should give schools initial suggestions regarding the design and implementation of the "next-generation, STEM-rich curriculum". Each outcome addresses one area of knowledge or ability and should be supported by one or more components of the curriculum. Every effort should be made to move away from the "bean counting" pedagogy where each STEM subject is taught within each "silo" of the discipline in a fragmented, inefficient and artificial manner. In fact, by default, the outcomes delineated earlier would require a curriculum whose components are interrelated. Moreover, these outcomes lend themselves to project-based, interdisciplinary learning by doing; for example, a project on harnessing the energy of the sun may deal with the intersection of knowledge ranging from the science of photovoltaic, to materials technology, to climate and geography, to economics, and to civic responsibilities.

A Mechanism for Continuous Improvement

Once the STEM rich curriculum has been established based on the expected student outcomes delineated earlier, schools should strive for further curriculum improvement through a well-designed outcomes assessment process. This assessment process would include (in addition to the high-stakes tests) feedback from the local communities, universities who are receiving the high school graduates, employers, and the government. Local communities and employers can provide invaluable feedback. For example, a small business in the community that provides summer internships would provide useful feedback with regards to the skills and abilities that the student interns have. Universities can provide invaluable feedback regarding the academic preparation of its freshmen (the high schools' recent graduates) by monitoring their performance. Ultimately, a closed-loop feedback system has to be implemented. Assessments such as the ones mandated by the *No Child Left Behind* act are of the open loop nature and lack the critical feedback loop. The scientific method tells us that the closed-loop structure is inherently more reliable and stable, is more accurate, provides for easier cause-and-effect observation, and encompasses a critical and comprehensive self-correcting mechanism. Figure 3 is a graphical depiction of the proposed closed-loop model.

Under the proposed framework, it is no longer sufficient for the schools to simply satisfy the literacy thresholds mandated by NCLB. Rather each school, based on the outcomes delineated earlier (or an improved version of the same), should have an assessment process in place involving the key constituents (parents, community, business, universities, etc.), document the results of assessment based on outcomes, and show evidence that the results are applied to continuously develop and improve teaching and learning.

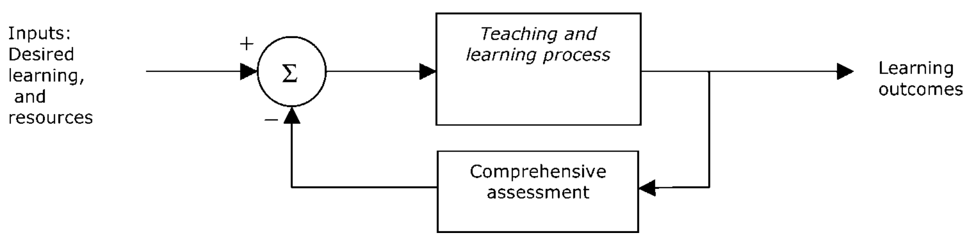

Fig. 3. A teaching and learning system modeled as a closed-loop system with negative feedback. The system has an inherent self-correcting mechanism whereby the actual outcomes are continuously measured, compared to the desired outcomes and appropriate corrective action is undertaken.

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