

# A New Technology and Approach for Engaging Self-directed K12 Students in International STEM Learning

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## **Abstract**

How can the nation prepare young people for a rapidly changing, globally interconnected, diverse and multidisciplinary, complex, technologically driven future? One way is to use “global challenges” as an integrative, active learning theme for K12 pre-engineering learning experiences in science, technology, engineering and mathematics (STEM) placed within an informal, game-like, online learning platform. This session will report on the first two years of “The Global Challenge” program at the University of Vermont College of Engineering and Mathematical Sciences, a National Science Foundation-funded ITEST project that provides a framework supporting the major recommendations for preparing engineers for the future. Telecommunications tools used include Skype, eFolio, social networking software, and computational science tools.

## **Summary**

This paper presents a new framework for engineering education and illustrates the core ideas based on two years of a National Science Foundation ITEST Program-sponsored project, The Global Challenge, which has engaged thousands of high school students in international teams through a blend of new technologies. Evaluation research results from 2007 using a mix of qualitative and quantitative methods situate our understanding of the potential for new media (e.g., Internet as media, social networking software,

computational science tools, 3D games spaces) and for self-directed informal learning approaches to science, technology, engineering and mathematics (STEM learning) can increase the number of women and under-represented populations entering STEM majors and careers. This paper compares the findings of the project's research to theoretical and philosophical position of the National Academy of Engineering, in order to draw out how the new technologies and approaches lead to a radical reformulation of curriculum taking place outside of the traditional channels of school and educational system reforms.

## **Introduction**

The 2004 special report of the National Academy of Engineering entitled “The Engineer of 2020” (NAE 2004) presents a vision of engineering in the new century, framed by five guiding principles:

- The pace of technological innovation will continue to be rapid (most likely accelerating).
- The world in which technology will be deployed will be intensely globally interconnected.
- The population of individuals who are involved with or affected by technology (e.g., designers, manufacturers, distributors, users) will be increasingly diverse and multidisciplinary.
- Social, cultural, political, and economic forces will continue to shape and affect the success of technological innovation.

- The presence of technology in our everyday lives will be seamless, transparent, and more significant than ever.

How can the nation prepare young people for this rapidly changing, globally interconnected, diverse and multidisciplinary, complex, technologically driven engineering future?

We propose that part of the answer can be found in “global challenges” that form an integrative, active learning theme for K12 pre-engineering learning experiences in science, technology, engineering and mathematics (STEM) placed within an informal, game-like, online learning platform. This article reports on the first two years of “The Global Challenge” program at the University of Vermont College of Engineering and Mathematical Sciences, a National Science Foundation-funded ITEST project that provides a framework supporting the major recommendations for preparing engineers for the future. Observations of the program’s first years indicate how a radical re-design of engineering education is possible that operates independently from organizational change in K12 and higher education systems and that attracts and supports young people into STEM majors and careers.

### **What engineering educators need to know and be able to do**

The US needs a national K12 pre-engineering education strategy. The students of the undergraduate class of 2020 are now in the 3<sup>rd</sup> grade. When should their pre-engineering education begin? Now? What learning experiences can elementary teachers use to

prepare them and are they ready to teach engineering concepts? Should efforts wait until middle or high school? There are currently no engineering texts in widespread use in either middle or high schools. Should we wait until after high school, nine years from now, as many current recruitment and retention strategies seems to do? These questions should be addressed in a national K12 pre-engineering education strategy that accomplishes two goals:

- Inspires and motivates young people to select and stay involved in engineering and related STEM studies
- Provides a sequence of coordinated transitions that connect and deepen their preparation for rapid changes, global interconnections, diverse and multidisciplinary work teams, complex system problems and solutions, and new technologies driving the future of engineering.

Many recruitment and retention efforts focus broadly across all of science, technology, engineering and mathematics and concentrate on college entrance and retention, academic scholarship, and teaching and the workforce, not pre-college experiences. The ITEST program of the National Science Foundation is a notable and much-needed exception, but it may not be enough to turn the tide of what The Committee on Science, Engineering, and Public Policy (COSEPUP 2006) has called “the gathering storm.” The Global Challenge platform is being constructed and improved as a model of a scalable solution to the pre-college years, utilizing several bodies of research on learning and STEM education.

The broad framework for a radical re-making of engineering education includes:

- Recommendations for policy (NAE 2004; COSEPUP 2006; Fox 2003)
- Curriculum change (Bransford 2007; Roselli and Brophy 2006; Fox and Hackerman 2003; Grasso 2002; NRC 1999)
- Clarity of expectations for engineers (Taraban et al. 2007; Reisslein, Sullivan, and Reisslein 2007; Roselli and Brophy 2006)
- More rigorous research (Borrego 2007).

To activate these ideas a new model of learning is informed by the National Research Council report on “How People Learn” (Bransford, Brown, and Cocking 2000) and the emerging field of games and simulations-based learning, which outlines how to take advantage of highly motivating self-directed learning environments (Gibson 2006; Prensky 2001; Aldrich 2005; Mayo 2005). The Global Challenge is situated within this new model of learning as an informal curriculum for pre-engineering STEM learning experiences for high school students.

### **The policy perspective**

The largest pre-engineering effort in K12 in the US is perhaps the \$73 million dollar ITEST program of the National Science Foundation, which funds thirty-five youth-based projects and forty-one comprehensive projects that include teachers. Only 13% of the programs include an engineering focus, according to the national Learning Resource Center (EDC 2007). There is currently no national focus on global systems science in

K12, or engineering, or on helping produce scholarship pathways for pre-college youth. The Global Challenge puts these three areas together in a new way, with policies designed to allow the program to evolve as a model for addressing pre-engineering and pre-college STEM education through a complex global problem-solving game.

The Global Challenge takes place primarily online at the initiative of the student. A student anywhere in the world registers herself, finds a male partner (or vice versa) and finds any adult to work with. This policy led to 460 students (51% females) forming into teams, including representation from twenty countries. An initial 2,600 students from fifty countries registered and inquired about the program, indicating that web-based recruitment was viable. The 398 students who gave ethnicity information showed that a balance of cultural backgrounds was represented (Figure 1).

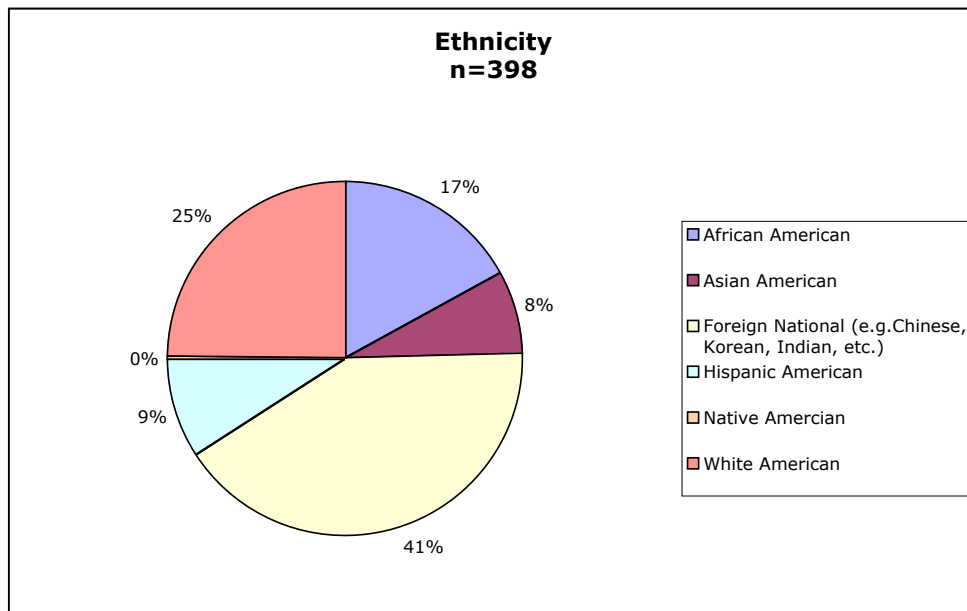


Figure 1. Ethnic balance in the Global Challenge 2006-2007 program

The program leverages existing online resources in STEM, including “Ask a Scientist” projects, interactive applications in global systems science, and telecommunications tools such as Skype ([www.skype.com](http://www.skype.com)) and eFolio ([www.my-efolio.com](http://www.my-efolio.com)). This policy makes extensive use of existing resources and avoids duplication of efforts. Students work in small teams for six to eight months for approximately 120 hours to produce a solution to global warming with impact on the future of energy. Undergraduate engineering students, project staff, and scientists mentor the students, a policy that extends the reach of experts well beyond the classroom and allows the Global Challenge to be utilized by classroom teachers as an extension or enhancement activity.

To meet the congressional ITEST requirement to provide intensive summer learning experiences, the program’s primary policy is to identify existing summer institutes and provides support to young people for applying, traveling and meeting tuition costs. This policy allows scaling to all states and avoids the expenses of reproducing another small, intensive summer session for a handful of students. We are actively studying the effect of this approach to determine impact on student learning and retention.

The Global Challenge’s added value to pre-college STEM education models also comes from the creation of new small-team challenges (self-directed learning, units of study) focused on complex system problems prevalent in global challenges. Our long-term goal is to create game-like learning experiences out of each team challenge and to place much of the learning experience into a physically realistic virtual world, to take advantage of game and simulation-based learning characteristics. A partnership with Microsoft, the

Lawrence Hall of Science at UC Berkeley, the Boston Museum of Science and many others is beginning to lay out that path to the future.

In addition to the scalability of its synthesis of existing resources and the game-like platform for self-directed learning, the Global Challenge focuses on creating a long-term financial incentive and support structure to any high school-aged student in the world. Private fundraising meets the world needs, while both public and private funds concentrate on U.S. students.

## **Curriculum Change**

Borrego (Borrego 2007) points out that “the field of engineering education (if it can be considered a field) has not yet developed its first paradigm,” but at the same time there has been “a gradual shift from focusing on course and curriculum innovations to assessment and institutionalization.” Fortunately, the recent efforts in curriculum change for post-secondary engineering education have begun to turn up several promising themes, which when combined with what we know about informal learning, can provide guidance for a radical re-thinking of pre-engineering experiences for K12 students. The ideas are radical in the sense that the learning experiences need not be delivered at school, or with teachers, or with physical facilities. They are also radical in that the focus shifts from teaching to learning, with the primary motivation coming from the student, not the curriculum materials or an entertaining teacher.

A quick summary of the core curriculum idea of the Global Challenge is that U.S. students who are attracted to the idea of “saving the world on their way to college” work on creative solutions to global challenges with a team of their own choice, on a solution of their own choice, at personally selected times and places with international partners and adults of their own choice. For their hard work, they are rewarded with team success and a college scholarship fund that they build for themselves during their high school years. Along the way, they engage deeply with STEM content with a focus on engineering a much-needed solution that will benefit the world (Table 1).

Table 1. “Patent office” ideas from the 2006-2007 Global Challenge

Passive Refrigerator	The passive refrigerator is made up of two components: a hole in the ground that is insulated and filled with two-liter plastic bottles full of saltwater, and an icebox that is also heavily insulated. Connecting the two is a pipe system that transfers the cold energy from the bottles to the refrigerator using a sugar antifreeze solution.
Intelligent Distribution of Temperature and Lighting Control	Sensors and prisms are utilized in a system to address three problems with home heating: 1. energy wasted warming up unused parts of the house, 2. "lights and appliances" left on needlessly, and 3. redistributing direct light where needed.
Adaptable Insulation	Big temperature differences and strong airflow combined with poor insulation result in heat loss and wasted energy in homes. This patent concerns increasing the insulation in the winter and decreasing it in the summer, saving a lot of energy.
Chemical Reactions with Greenhouse Gases	A layer of a certain chemical compound will be painted onto the outside of a house that will react with oxygen and hydrogen or water (rain) to form another chemical compound X. Compound X will then go up into the atmosphere and reacts with carbon dioxide to form a substance that is not harmful to the society, and at the same time, gets rid of carbon dioxide.
Algae as a Solution to Global Warming	Based on GreenFuel's project to use a variety of algae that absorbs greenhouse gases, we intend to research the problems this project faces, give our ideas for solutions to them, and thus sell a presently under-used process. We also intend on applying our research to other fields where it could be applicable.
Small Scale Pneumatic Vane Motor	A gas operated motor designed for use on a scale model gas power generation devices. The motor is solely designed for demonstration of the gas motor system; its efficiency is not optimal.

Bio-Fuel Solution to Global Warming	A small greenhouse to grow algae, a biomass generator and vegetable oil fuel technology is combined into a single unit. This off the grid, carbon neutral source would provide heat, transportation fuel and electricity on a small or large scale.
FlexFuel Car	The FlexFuel Car takes elements of existing technologies and renewable energies, fusing them into a single, seamless vehicle. The engine will be able to run on electricity, hydrogen, biogas, and fossil fuels; this maximizes efficiency of the car according to distance and speed. Most importantly, the design allows consumers to choose the cheapest energy.
Pure Carbon Conversion	The use of Pure Carbon Conversion fuel cells to convert raw fossil fuels efficiently into electricity, while also creating hydrogen to be used as a byproduct.
Livestock and Methane	Bacteria that digest food in the rumen of livestock produce the potent greenhouse gas methane as a byproduct. Using biotechnology, we can eliminate the methane-making gene and introduce an antibody gene, making cows more resistant to disease, eliminating the need for dangerously high dosages of antibiotics.
The Green Machine	Global warming is irreversible, and the best we can do is limit the amount of pollution in the atmosphere. Our goal is to create a catalytic converter that serves purposes both economic and in terms of emission and efficiency. The system works by combining two catalytic converters in a single housing: an oxidizing unit that converts gaseous pollutants, and a particulate reduction unit in which soot particles are trapped and burned off at an exhaust temperature of over 250 degrees Celsius.
Solar Thermal Battery	Solar Thermal Batteries are small-sized rechargeable batteries based on the technology of thermal batteries. Instead of being activated by the electrolytes, they harness the sun's energy to generate electricity. As the substitutes for environmentally damaging batteries, they are commonly applicable in our daily life with portable volumes and adjustable voltages.

To explain the detailed relationship of The Global Challenge learning experience to the primary recommendations of the National Academy of Engineering, we've aligned the attributes of the engineer of 2020 with the program's curriculum content and processes (Table 2).

Table 2. Attributes of the Engineer

<b>Attributes of the Engineer of 2020</b>	<b>Global Challenge Processes</b>
Strong analytic skills	Students must demonstrate their understanding of the science, technology, engineering and mathematics contents that are critical to their solution to global warming and the future of energy. STEM Explorations designed by scientists guide students to develop and use analytic skills to understand the causes and impacts in the complex systems involved in climate change and energy. A scoring tool is used by the students as well as by external judges to rate the demonstration of their analytic skills in their solutions.
Practical ingenuity	The team’s solution must be innovative; it must utilize leading edge science and technology and demonstrate an innovative approach to any outstanding STEM challenges that would need to be solved or addressed in order for their solution to be feasible and globally scalable.
Creativity	Teams go through an initial phase of generating potential solutions as well as rating and justifying their team decisions. Documentation of these decisions is scored as an integral part of their final solution. See “Patent office ideas from the 2006-2007 Global Challenge” (Table 2) for a list of creative ideas by the international teams of high school students.
Communication	<p>Students use telecommunications as they undertake their global teamwork. Students regularly use online chats and “voice-over-Internet” phone and video conference calls. An online electronic portfolio provides each team with a private space for documents, receiving feedback from mentors, and self-scoring using the guiding “Business Plan” rubric.</p> <p>Team advisors and project staff monitor semi-private student communications in the “eFolio” electronic portfolio. Teams are encouraged to submit transcripts of their communications as evidence of global teamwork.</p>
Business and management	The long-term challenge (five to eight months depending on when the team forms) is the production of an innovative and comprehensive “Business Plan” (BP) for a globally significant solution to the challenge of climate change and the future of energy. The format is a modified version of a full scale BP and incorporates innovative several features that address content knowledge and teamwork.

	<p>A detailed scoring guide allows the teams to work iteratively on their solution and receive feedback from people outside the team on the major elements of the BP:</p> <p>Table of Contents</p> <ol style="list-style-type: none"> <li>1. Executive Summary</li> <li>2. Industry Analysis</li> <li>3. Product Description &amp; Technical Analysis</li> <li>4. Market Analysis</li> <li>5. Manufacturing and Operations</li> <li>6. Financial &amp; Political Feasibility</li> <li>7. Key Personnel</li> <li>8. Bibliography</li> <li>9. Appendix</li> </ol>
Leadership	<p>One of the barriers of global teamwork in an all-volunteer team is the various levels of team member commitment, access to communications, and persistence on a long-term project. Successful teams all develop internal leadership solutions to these issues.</p>
High ethical standards	<p>In the final solution, teams are scored high for honest team-appraisal sections that reflect on the problems and adjustments the team made along the way. Good documentation of references is essential for a high scoring solution. Innovative ideas can come from a synthesis of pre-existing technologies put together in a new way, so teams are encouraged to use acceptable practices for acknowledging prior work. Students also each make a personal statement about their role in the teamwork process, which is included in the final solution as documentation of global teamwork.</p>
Professionalism	<p>A resident scientist and group of undergraduate engineering students provide additional contact points, subject area expertise and team support to the international teams.</p>
Dynamism, agility, resilience, and flexibility	<p>Several rapidly changing conditions test the students' adaptability. School schedules around the world are not coordinated, so sometimes students are on vacation or between school years in the middle of the long-term project of their team. Time differences make synchronous communications difficult. Students do not use asynchronous communication tools in their normal "school life," so communications are halting, passive, and sparse unless strongly encouraged. Decision-making in a dispersed team with such barriers takes much longer than students are used to in "school project teams." These sorts</p>

	of challenges require a dynamic change in practices. For example, students need support in learning to propose an idea to the group, when feedback might be sparse and cultural communication difficulties impede progress. In worst case scenarios, teams might need to reconfigure around one or two highly invested members. The project encourages every student with an interest to be resilient and persist through all the changes while staying focused on their interest, their core idea, and the prospects of completing “the toughest assignment you’ll ever give yourself in high school.”
Lifelong learners	Since the entire project depends on student initiative and self-directed learning, life-long learning capacities are provided as scaffolds for learning (e.g., self-scoring, seeking objective observer and expert advice, self and team monitoring in relationship to a suggested schedule, self-paced and self-leveled online learning modules). Structuring the production of evidence for scoring also rewards students for using lifelong learning practices.

Evaluation research on The Global Challenge in 2007 has started to identify the characteristics of the students who are attracted to and successful in learning via an all-online, complex, problem-driven international team challenge. The students are comfortable with using new technologies. They have used the Internet an average of eight years. They are eager to make international connections, both through formal and informal methods, and to work closely with other students but not necessarily through their local schools or teachers. They are comfortable taking on a rigorous extra-curricular project. Many say they care deeply about global warming—the topic may have played a significant role in those students’ choice to participate.

Based on a comparison of new pre- and post-surveys that form a baseline for future data collection, as a group the students 1) were expecting the challenge to be difficult and felt good about their work on the GC even if they didn't complete the competition, 2) got out

of it more than they expected (be it knowledge about STEM, or becoming change agents, or team and community building, recognition both locally and internationally for their work, an opportunity to travel, etc.) and 3) now feel a sense of ownership for the problem that was posed about global warming. They feel empowered to help find a solution.

These observations indicate that the program is meeting its mission to “give students the tools and confidence to solve global problems together.”

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