

## **AC 2007-2273: THE INSPIRES CURRICULUM: ENGAGING FUTURE ENGINEERS AND SCIENTISTS**

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# **The INSPIRES Curriculum: Stimulating Future Generations of Engineers and Scientists**

## **Abstract**

The INSPIRES Curriculum (INcreasing Student Participation, Interest and Recruitment in Engineering and Science), funded by the National Science Foundation, is being developed in response to the critical national need to recruit more students into STEM-related fields. The curriculum seeks to accomplish this goal by exposing students to a combination of real-world examples, hands-on activities and inquiry-based learning activities that target the ITEA Standards for Technological Literacy as well as national standards in science and mathematics.

Two new modules are being added to the INSPIRES Curriculum in 2006-2007: Engineering in Flight: A Hot Air Balloon Case Study and Engineering Energy Solutions: A Renewable Energy System Case Study. Each introduces students to the engineering design and decision-making process, while also teaching basic engineering concepts. In these curriculum modules, the students progress through a series of hands-on activities and demonstrations, web-based tutorials, and computer simulations during which they learn the principles that govern the system under study. Next, the students are issued a challenge to design, build and evaluate their own systems by utilizing results obtained from computer simulations. At the end of the project, the students return to the computer module to discover about 'real world' applications related to the content they have learned. This part of the curriculum includes career information and video of practicing engineers highlighting their work.

In addition to the curriculum development effort, professional development and in-service training with the curriculum are being provided for teachers prior to module use in the classroom. During the 2006-2007 academic year, several Maryland high schools covering a broad range of demographics will be testing the curriculum and providing data to the study. In this presentation, we will provide an overview of the two new curriculum modules and present results of student learning, interest and attitudes. Finally, we will discuss the results of the related professional development workshops.

## **Rationale**

The recent report "Rising Above the Gathering Storm" written by a pre-eminent committee (National Academy of Sciences, National Academy of Engineering and Institute of Medicine) identified four recommendations that federal policy makers should take to bolster U.S. competitiveness in science and technology. At the top of their list was "to increase America's talent pool by vastly improving K-12 mathematics and science education"<sup>1</sup>. In addition, the National Science Foundation predicts that between 1998 and 2008 employment opportunities for engineering will increase by twenty percent, yet the trend of declining enrollment in engineering disciplines is expected to create a shortage of engineers in the U.S. in the near future<sup>2</sup>. For the U.S. to remain technologically competitive in the 21<sup>st</sup> century, more students must be recruited to science and engineering. While percent of women and minorities in the workforce has grown steadily over the past several years, they still comprise only nine and four percent, respectively, of the engineering workforce<sup>3,4</sup>. The recruitment of more students into STEM-related careers,

particularly women and minorities, begins by stimulating interest and providing a strong foundational skill set to students. It is with this perspective that the INSPIRES Curriculum is being developed.

## **Curriculum Goals**

The **INSPIRES** Curriculum is designed to specifically target three Standards for Technological Literacy put forth by the International Technology Education Association (ITEA):

Standard 8: Students will develop an understanding of the attributes of design

Standard 9: Students will develop an understanding of engineering design

Standard 11: Students will develop abilities to apply the design

The curriculum has been designed to provide materials that are challenging, thorough and effective at promoting learning, but at the same time, interest and engage students. Real-world applications that address current societal needs are prominently featured to help students connect fundamental concepts with application. In order to maximize the potential of school systems to adopt the INSPIRES Curriculum, the cost of implementation has been kept low and significant professional development for teachers is offered.

Although the INSPIRES Curriculum is designed around specific content areas, a primary focus is on the development of transferable skills that we believe are foundational for success in the study of STEM-related fields. These skills are often neglected in high school curricula yet must be developed for students to succeed in undergraduate science and engineering programs. The key skills targeted by the INSPIRES Curriculum include:

- The ability to work effectively in teams and communicate technical ideas both orally and in writing
- The ability to solve open-ended problems
- The ability to synthesize what is learned in science and mathematics courses and apply the knowledge to real-world problems
- The ability to think creatively with respect to the solution of an open-ended problem
- The ability to describe the natural world using mathematics
- The ability to view and analyze a system as a whole

## **Module Description**

When completed, the INSPIRES Curriculum will consist of five inquiry-based stand-alone modules that highlight a broad range of engineering applications important in society. Two modules are being added to the curriculum in 2006-2007: Engineering in Flight: A Hot Air Balloon Case Study and Engineering Energy Solutions: A Renewable Energy System Case Study. Each introduces students to the engineering design and decision-making process, a theme that is central to all the modules, while also teaching basic engineering concepts. The modules employ a variety of activities including hands-on exercises, demonstrations, web-based tutorials and interactive computer simulations in order to target different learning styles. Many of the

curriculum activities require students to work in groups, thereby promoting teamwork, creativity and leadership skills.

Assessment rubrics are integrated into the curriculum materials to allow evaluation of student learning and module effectiveness. Baseline interests, attitudes and knowledge are established through the use of pre-module assessments taken prior to beginning the curriculum unit. In addition, students are evaluated for their ability to work as part of a team and to apply the engineering design process during a short, 45 minute pre-module design activity related to the module topic. The results of these pre-assessments are compared to similar evaluations given to the students after completion of a given curriculum module.

Each of the five learning modules follows a similar format, which allows them to be taught either as stand-alone units or as part of a larger curriculum. Students are introduced to a module via a professionally produced video segment that features an expert in the field. The video provides societal context for the material presented, essentially bridging the gap between fundamental principles and 'real-world' applications. The students then proceed through a series of hands-on activities that explore fundamental scientific principles related to the module topic. These activities are useful in promoting student participation as well as for stimulating interest in the module content. Next, the students go online where they are issued a challenge to design and build their own system. Before beginning the design project, the students move through an online tutorial to learn background information about science and engineering principles relevant to the assigned challenge. Interactive animations are employed in this part of the curriculum to help students visualize fundamental principles. After completing the tutorial, the students perform an online mathematical simulation. This segment allows the student to adjust relevant parameters to visualize what effect the changes have on the overall design of the system. Students individually determine what they believe to be optimal parameter settings for achieving peak efficiency and low cost. After completing the simulation, the students watch another video that reiterates the design challenge and the goals of the project. Then, using what they have learned from the tutorial and simulation, student teams design, construct and evaluate their own system.

After finishing the design project, students complete post-module assessments that complement those taken prior to module use. The students also participate in another short hands-on design activity to assess how their application of the engineering design process has evolved. Pre/Post data comparison is used to evaluate student learning and to assess the overall effectiveness of the curriculum.

### ***“Engineering and Flight: A Hot Air Balloon Case Study”***

The module, Engineering and Flight: A Hot Air Balloon Case Study, focuses on the challenge to design and build effective, efficient and economical hot air balloons. Balloons are an important tool used by scientists, especially meteorologists, for collecting information at high altitudes. Everything from weather patterns to astronomy and physics can be studied using hot air balloons; NASA even has plans to use balloons on future missions to Mars<sup>5</sup>! This module uses hot air balloons as a ‘real-world’ application to teach students about the engineering design process and basic engineering principles by relating them to successful balloon flight. The tutorial section of the module introduces students to principles such as force balances, buoyant forces, heat transfer, the Ideal Gas Law and material properties through interactive animations that are applied directly to hot air balloon flight. The simulation that follows allows the students to adjust parameters including payload, construction material, temperature, and balloon shape one-by-one to see how each affects the success of the flight.

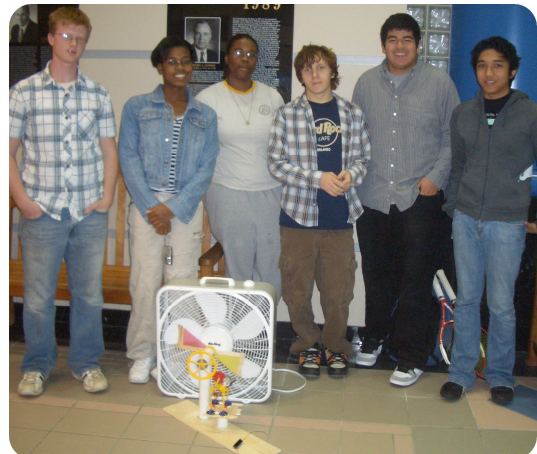


After completing the simulation, the students are challenged to design, construct, test and evaluate their own hot air balloon, powered only by a ground-based, hair-dryer style heat gun. Using what they have learned about the principles involved in balloon flight from the module as their guide, students attempt to construct the most efficient balloon, based on the time that it remains aloft, the payload that it is able to carry, and the overall cost. Once the tests are complete, the students are given the opportunity to evaluate their balloon’s performance from an engineering design standpoint.

The flexibility of the module and design challenge allow students to be creative in their designs, yet at the same time they have also learned enough to be able to make scientifically sound decisions and understand from an engineering standpoint how those decisions will impact their balloon’s success.

### ***“Engineering Energy Solutions: A Renewable Energy Systems Case Study”***

Many people are aware that the U.S. will face significant energy challenges in the future. The need to reduce emissions and lessen the nation’s dependence on fossil fuels presents a monumental challenge to scientists and engineers. However, most do not recognize that although it is important to discover and develop alternative sources of energy, it may be even more important to improve upon both current and future technologies to make energy supply systems more efficient. This module, Engineering Energy Solutions: A Renewable Energy Systems Case Study, will address both of these issues



and teach students the engineering principles and design skills required for them to understand this complex topic.

The design challenge for this module is to design and build a system that collects energy from a renewable source (solar, hydro, or wind), converts the energy into a form that can be stored and transported, and then uses the energy to illuminate a light bulb. The goal is to optimize the efficiency of the *system*, simply put, to maximize the ratio of the useful work output to the energy input. The fact that this project forces the students to look at an entire system, as opposed to only a single part, makes it somewhat unique. From the engineering design standpoint, it makes the students think not only about how each parameter and principle affects the end goal, but also about how the different principles and parameters relate to and affect one another.

## Results

The “Engineering in Flight: A Hot Air Balloon Case Study” was completed in the fall of 2006 and is currently being used by over 400 students at one of two Maryland high schools.

The “Engineering Energy Solutions: A Renewable Energy Systems Case Study” is slated to be completed in the spring of 2007. The design project has been tested with 300 students in both high school (YESS Program, <http://www.yesshem.com>) and university environments (ENES101).

One of the requirements of the Introduction to Engineering class (ENES101) at UMBC is to complete a team design project, and during the fall 2006 semester the energy solutions project was used. To help prepare the students for designing and constructing their energy systems a sampling of the topics that will appear in the module were taught in the classroom. These included, but were not strictly limited to, the engineering design process, the laws of thermodynamics and associated material and energy calculations such as kinetic and potential energy, and efficiency. Using this instruction in conjunction with knowledge acquired in other courses, most teams were able to successfully construct energy systems meeting the design specifications.

There was, of course, a range in the complexity of the designs and levels of concept comprehension amongst the students, evidenced specifically by their own evaluations of the projects. During the evaluation, the students were expected to loosely model their system, utilizing applicable mathematical equations to predict their results. Although several teams were able to accomplish this goal with acceptable accuracy, there were a number of instances where students either failed to correctly apply given equations or even identify the equations that applied.

This problem is a perfect example of difficulty with the transferable skills which the module seeks to address. While a majority of students were able to use a given equation and manipulate it to calculate parameters, a very small percentage actually understood its physical meaning. Two of the aforementioned skills are applicable to this situation: the ability to describe the world using mathematics, and the ability to synthesize the knowledge attained in science and math classes and apply such knowledge to solve ‘real-world’, open-ended problems.

In order to attain these skills, it is essential for students to analyze a system based on its physical properties and how they apply to engineering principles rather than the commonly-preferred and much easier approach: simply inserting observable data into a given equation. While either of these methods could lead to the desired answer for one specific problem, students able to utilize the latter approach will be able to apply their knowledge to a broader spectrum of situations. Since mastery of these skills is often difficult to achieve for even upper-level undergraduates, the INSPIRES Curriculum recognizes the importance in beginning their development as early as possible.

The strength of the INSPIRES learning modules is that they stress the application of concepts and not just the concepts themselves. The tutorial and simulation sections of the energy module focuses on effective methods of analyzing the system and understanding how the variable parameters affect its operation. The importance of focusing on these aspects of the problem-solving method is supported by the issues that students in both the YESS program and the ENES101 course have experienced. Many of the students in these environments are familiar with the concepts covered by the energy design project, but despite their knowledge, they still struggle to apply it because that is not a skill on which their previous courses have focused. In fact, one section of the ENES 101 class, who had the opportunity to view and critique the flight and health care curriculum modules, expressed the opinion that a similar energy solutions module would have significantly enhanced their success with the design project. Five of the sixteen students that were asked to give suggestions for the energy design project explicitly stated that they think the complete learning module would have improved the results of their project.

“The creation of a program like this for the energy design project that we completed in ENES 101 would be incredible. It would heighten student’s awareness of the energy crisis as well as teach flow rates, voltage, current, power, work, and energy.”

All but three students explicitly expressed their agreement that the learning modules were effective teaching tools.

“Projects like the ‘Engineering and Flight’ module are great learning tools, because they motivate the pupil by engaging him or her directly and by providing immediate feedback on the success or failure of each step.”

## **Professional Development**

Professional development activities and in-service training of teachers are important aspects of the INSPIRES project. Prior to implementation of the curriculum, all teachers are required to attend a two-day workshop. Because Maryland technology education teachers herald from widely disparate backgrounds, we have found such training to be critical to successful implementation of the INSPIRES Curriculum.

During the summers of 2005 and 2006, professional development workshops were held for high school teachers interested in



implementing the INSPIRES Curriculum into their classrooms during the following academic year. Twenty-three teachers representing public schools from seven different Maryland counties, including Baltimore city, have attended the training. The majority of those teachers came from technology education disciplines, however, specific areas of concentration such as biology and computer programming were also represented. During the workshops, the teachers are “taught” the curriculum in the order and format that it is to be implemented in the classroom. This methodology allows us to provide an example to the teachers of how we believe the curriculum should be presented. The teachers perform each of the hands-on activities, take all student assessments and work through the online tutorial and simulation. While there is insufficient time to allow for completion of the overall design challenge, the activity is presented to the teachers and examples of student design solutions are provided and discussed.

At the end of the professional development workshop, participating teachers were asked to complete questionnaires concerning their impressions of the workshop. In addition, data were gathered on the teachers’ attitudes, backgrounds and previous professional development activities in technology education. Teacher evaluations of the two-day workshop are presented in Table 1 below.

**Table 1: Teacher Impressions of the 2005-2006 Professional Development Workshops**

Scale: 1 = Strongly agree to 4 = Strongly disagree

	Mean Response ± standard error
<b>Rate the usefulness of the following curriculum topics</b>	
Opening video	1.33 ± 0.16
Content tests	1.43 ± 0.17
Hands-on exercises	1.00 ± 0.00
Short engineering challenges	1.11 ± 0.11
Design challenge video	1.28 ± 0.15
Engineering design challenge	1.05 ± 0.05
Computer module	1.26 ± 0.15
Tests of design knowledge	1.33 ± 0.16
Ending Video	1.34 ± 0.20
Providing individual feedback	1.23 ± 0.08
<b>Please indicate your feelings about the following statements</b>	
I feel the design specifications given are appropriate considering the education level of my students	1.40 ± 0.17
The module fosters an understanding of the connectivity between engineering, science, and math	1.17 ± 0.13
The use of the module will facilitate active learning among students	1.23 ± 0.14
I am enthusiastic about using the education materials in my classroom	1.07 ± 0.07
Using this material in the classroom would be a waste of time	3.71 ± 0.18
The workshop was interesting	1.09 ± 0.06
The instructors were knowledgeable about the material	1.05 ± 0.05
The workshop was well organized	1.28 ± 0.08
Questions and comments were well received	1.09 ± 0.06
I feel reasonably prepared to use the material in my class	1.36 ± 0.14
This workshop was worth my time	1.09 ± 0.06
This workshop was the appropriate length of time	1.18 ± 0.08



To date, teacher responses have been highly favorable both to the curriculum and to the workshop format. Of the 23 teachers trained, 22 have indicated a desire to adopt the INSPIRES Curriculum. To date the INSPIRES Curriculum has been tested in 5 counties in Maryland and a summer engineering camp at the University of Virginia Polytechnic Institute and State University. At this time, the first two tests of the “Engineering in Flight” module are ongoing in Maryland counties with significant student diversity as shown below in Figure 1. Testing of “Engineering Energy Solutions” will begin in late 2007.

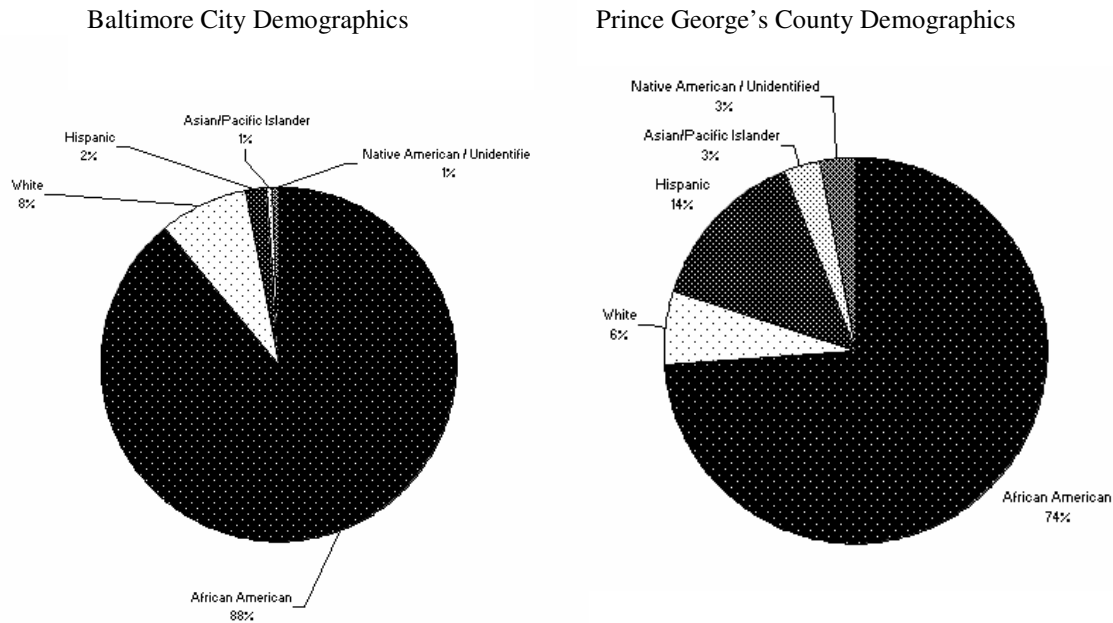


Figure 1. School System Demographics for counties currently field testing “Engineering in Flight”.

## Conclusion

Analysis and evaluation of the work completed by students on the design projects for the Engineering in Flight and Engineering Energy Solutions modules give strong indications that there is a need for the engineering exposure and skills provided by the INSPIRES Curriculum. Previously reported results of preliminary trials using the “Engineering in Healthcare” module indicate that the curriculum is effective at teaching these skills, and is successful at targeting the ITEA Standards<sup>6</sup>.

Teacher response to the curriculum has been very encouraging, supporting the proposition that there is a strong need and desire for the materials being developed. The teachers currently using the “Engineering in Flight” module in their classrooms will be asked to evaluate the module and its effectiveness once their students have completed it. These evaluations will be presented in the final manuscript along with the student learning data. We anticipate that these results will continue to support the preliminary results obtained thus far with other modules. In particular, we expect that the online animations and hands-on activities will continue to be well-received by

the students and a large percent will indicate that these activities aid the understanding of the material presented.

The INSPIRES Curriculum will ultimately include five stand-alone modules. In addition to the two modules highlighted herein, the Engineering in Healthcare module has been completed and two new modules, Engineering in Communications and Information Technology and Engineering and the Environment, will be added to the curriculum in the near future.

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