# YESS -- Young Engineers Seminar Series

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## Abstract

The Young Engineers and Scientists Seminars (YESS) program targets gifted high school students from the Baltimore/Washington areas who have a strong aptitude in the engineering and science fields. Science, Technology, Engineering and Mathematics High School teachers are asked to nominate students for participation in the program. This program was founded in 2002 and is funded by the Historical Electronics Museum with a grant from the Northrop Grumman Corporation. Speakers in the YESS have presented on topics as diverse as plasma physics, stealth radar, biomedical imagery, super computers/micro technology, aeronautical engineering, astrophysics and satellite reconnaissance.

This year, the program has been revised from a strictly seminar series, to a hands-on program designed to help students understand the engineering method. In seven sessions, students learn how to go from theory to modeling, designing, building, and testing. The hands-on project is the modeling and design of a hot air balloon, which students built and tested. The hot air balloon had to meet specific size, cost, time aloft and payload criteria. The program is a scaled-down version of the Introduction to Engineering course that the authors teach at the University of Maryland Baltimore County. At each seminar, the high school students learn engineering fundamentals that relate to their design project and participate in hands-on activities and competitions. The students compete for prizes provided by Northrop Grumman. In most of the sessions, a technical expert presents material on topics related to their design project; examples include: the Engineering Method, Buoyancy, Materials Testing and Properties, and Computer Modeling Techniques. Monetary awards were made as part of the final hot air balloon competition. Pre and post surveys for assessing the effectiveness of the YESS program were compiled and will be presented at the ASEE Annual Conference in June 2005.

## Background

The Mission of the Historical Electronics Museum is to educate industry, government, students and the general public on the evolution and the importance of defense and commercial electronics of the past through the exhibition and interpretation of historical significant artifacts and documents related to electronics technology[1]. The education goal of the museum is to provide visitors with an understanding of the basic concept of electronics and an appreciation of evolutionary milestones of sophisticated electronics systems. In support of these objectives, the museum's priority is to provide a motivational environment for students of all ages to gain an understanding of basic engineering and the career opportunities available through higher education. With this priority in mind, the Historical Electronic Museum started the Young Engineers and Scientist Seminars (**YESS**) program in the fall of 2002, for highly gifted high school students from the Baltimore/Washington areas who have a strong aptitude in engineering or science. The first two years of the program consisted of a series of dynamic seminars on topics as diverse as plasma physics, stealth astrophysics and satellite reconnaissance. In the fall 2003, the authors presented one of the seminars on "Careers in Engineering and Introduction to Engineering Design". This seminar involved a variety of hands-on activities that the students rated favorably at the end of the seminar series. Despite having excellent speakers last year, the student attendance was erratic, and varied from 23 to 55, with only one student attending all of the seminars. The Board of Directors of the Historical Electronics Museum met over the summer 2004, to strategize as how to improve the attendance of the YESS program.

Members of the Board of Directors of the museum were familiar with the Introduction to Engineering Design course at the University of Maryland Baltimore County (UMBC) (which the authors teach). Over the last four years, this course has been revised from a traditional lecture and design-on-paper course, to an active learning lecture and project based learning engineering design course[2]. The design teams are required not only to research, design, construct, evaluate, test and present their product, but also to develop a mathematical model of their product's performance. It is important that the students have a fun yet inexpensive project to design and build, but they must also develop a mathematical understanding of the fundamental engineering principles that make their design work. Successful engineering design projects have included human powered pumps, water balloon launching devices, hot air balloons, wooden block transport devices, hemodialysis systems, and chemically powered vehicles. Therefore, the Board of Directors asked the authors to lead the seminar series for the fall 2004, by offering a scaled-down version of UMBC's Introduction to Engineering Design course to help the high students understand the engineering method.

In August, letters were sent to Science, Technology, Engineering, and Mathematics High School coordinators inviting them to nominate students for the program (teachers and parents were also invited to attend the program) from Anne Arundel, Howard, Baltimore, and Carroll counties, as well as Baltimore City. The new hands-on approach to the program was described in the letter and a new website[3] was created to feature the YESS program. The website was updated throughout the fall with information that the students needed to create their design projects, as well as pictures of the hands-on activities. Student photo/survey release forms signed by the parent/guardian were collected from each of the students.

In an effort to assess the effectiveness of the YESS seminar, survey instruments were created to capture self-reported data including demographic information, parent's occupations, interest in science and engineering, level of understanding of key content areas, as well as measures of confidence in math and science and general attitudes and expectations for the seminar series. Students completed pretest surveys on the first night of the series and posttest surveys on the last night. Twenty-two students completed both sets of surveys, 39 completed pretest surveys only and 15 completed posttest surveys only. Shown below, Table 1 is a break down of the YESS survey respondents by sex. Since pretest and posttest instruments were matched, demographic questions were omitted from the posttest form. Based on pretest data (n = 61), 75% of the participants were men, 68% were White, 15% were Asian, 2% African American, 3% Native American, and 12% chose the category Other. Over half of the respondents were seniors in high school (53%), 35% were juniors, 10% sophomores, and 3% were freshmen. Most respondents were from Howard County (53%) followed by Anne Arundel County (28%), Baltimore County (17%) and Prince Georges County (2%), all in Maryland.

Table 1: YESS Survey Respondents by Sex

| Group | Men | Women | Missing | Total |
|---|---|---|---|---|
| Pretest and Posttest | 16 | 5 | 1 | 22 |
| Pretest Only | 29 | 10 | 0 | 39 |
| Posttest Only | | | 15 | 15 |

The program was designed to have the high school students learn how to go from theory to modeling, designing, building, and testing. The hands-on design project was to model and design a hot air balloon, which the students had to build and test. During each seminar, presentations on topics related to the design project were provided, along with a short hands-on challenge where the students competed for prizes. The program met every other week from September 22 through December 15, from 6:30-9 PM. There was no charge for the program and complementary food (usually subs or pizza) was provided at 6 PM. Prizes were awarded each evening for various hands-on activities (which will be described below), and cash awards were made for the final hot air balloon design competition. The prizes were provided by Northrop Grumman and consisted of Northrop Grumman logo ball caps, visors, bags, playing cards, key chains, etc. The Young Engineers and Scientists Seminars program was funded by the Historical Electronics Museum in conjunction with a grant from the Northrop Grumman Litton Foundation. The following are descriptions of each of the seminars:

### Introduction to Engineering

At the first evening of the YESS program, an overview of the Engineering profession was presented (greatest engineering achievements of the $20^{th}$ century, what is engineering, salaries, work environment, opportunities, types of engineers, etc.). This was followed by a ***So You Want to be an Engineer*** game, where the students had to match job descriptions with types of engineers. This was followed by an overview of the Introduction to Engineering Design course at UMBC. Videos of the various design projects (except for the hot air balloon project, since we didn't want to influence their upcoming design) were also featured to give the students a better understanding of what will be expected of them when studying engineering. UMBC's Office of Information Technology has filmed the design process over the course of the semester and has produced a video ("Video: Teamwork, Design, and Making Things Work! Undergraduate Design Class" produced by Bob Kuhlmann and Damion Wilson of UMBC's New Media Studio http://www.umbc.edu/engineering/cbe/ ). The hands-on activity for this first evening is described below and was adapted from the ASME website[4]:

***Introduction to Engineering Challenge Objective:***

Design and construct a structure of maximum height capable of supporting a volume of water with the materials provided and within the allowed time period. After having constructed the structure, each team was required to carry the structure, with water in the cup(s), through an obstacle course in the shortest possible time. Each structure must be constructed ONLY with the provided materials. In order to qualify, each structure must have the volume of water at least 10 inches in height from the bottom of the structure. The structure must be carried (by only one team member) over the specified course while holding the structure from the bottom.

- The materials provided were:
  - 30 straws
  - 20 pipe cleaners
  - 10 rubber bands
  - 10 toothpicks
  - 11 paper clips
  - 2 cups
  - 1 paper bag

The contest winner (bragging rights) was determined using the following formula:

$$\frac{H^3 \bullet V^2 \bullet \left(V_{final} / V_{initial}\right)}{T}$$

where: H – structure height in inches
V – final water volume in ml
$V_{initial}$ – initial volume of water in ml
$V_{final}$ – final volume of water in ml
T – time in seconds

The goal of this activity was for the students to begin to think about the connection between mathematics and engineering. Figure 1 illustrates one of the students running the obstacle course with her team's design.

Figure 1: The 'Running' of the Introduction to Engineering Challenge Obstacle Course.

## The Engineering Method

On October 6, Dr. Roland Anders, Chief Scientist, from Northrop Grumman delivered an excellent presentation on the engineering method, innovative engineering feats, and the importance of planning in the engineering process. The hot air balloon project was also introduced at this seminar (and will be described below). A tinker toy design challenge concluded the evening:

### *Tinker Toy Team Building Project*

The goal of this project was to develop an appreciation for working in teams, under a time constraint. The objective was to build the tallest possible, self-supporting structure; using only the Tinker Toys® provided. Each team had 20 minutes to design and plan, during which ***none*** of the pieces could be assembled and all of the pieces had to go back into the bag at the end of the design phase. This was followed by **90 seconds** of construction time.

## The Hot Air Balloon Project

The YESS program design project was to design, construct, model, predict the performance, test and evaluate a hot air balloon. The hot air balloon project was selected since the materials for a successful design project are inexpensive and the underlying concepts of the mathematical model lend itself to a wide variety of designs. The hot air balloon was powered by a ground-based heat gun (provided by the Chemical and Biochemical Engineering Department at UMBC), it was required to stay aloft a minimum of 12 seconds, carry a minimum payload of 10 grams, and was restricted in size to fit into a volume of 2 meters by 2 meters by 2 meters. In addition, the cost of the materials used in the design could not exceed $30.00. Each team was allotted 15 minutes to setup the balloon at the launch site, 5 minutes of preheat time (using an ordinary hair dryer), up to five minutes of thermal heating using the heat gun, followed by the actual launch. The preheat time using the hair dryer was optional. Each team was also required to use Excel to create a mathematical model that predicted how long their balloon would stay aloft. Inputs to the model had to include the payload, balloon surface area and volume, balloon material and properties, temperature of air inside the balloon at lift off, etc. The "bragging rights" for product performance were assessed using the performance metric:

***Time aloft (in seconds) x payload (in grams) x model accuracy x cost index***

Where **model accuracy** is calculated using the SMALLER of:

$$\left| \frac{\textit{Predicted Time Aloft}}{\textit{Actual Time Aloft}} \right| \quad \text{or} \quad \left| \frac{\textit{Actual Time Aloft}}{\textit{Predicted Time Aloft}} \right|$$

The **cost index** is calculated using:

$$\frac{\textbf{YESS}\text{ Program Minimum TOTAL Design Cost}}{\text{Your Team TOTAL Design Cost}}$$

In addition, each team was expected to complete a design notebook[5] as a log of the evolution of their designs and as a record of their expenses.

## Buoyancy

The October 21 seminar discussed the concept of buoyancy and the relationship between volume and surface area that would influence their hot air balloon design. The hands-on challenge follows:

### *What Floats Your Boat?*

The goal of the project was to develop an understanding of buoyancy. The objective was to construct a boat that floats the maximum number of marbles from the 12 inch by 6 inch piece of aluminum foil that each team was given. Each team was given 20 minutes for the construction. One of the successful designs is shown below in Figure 2.

Figure 2: A successful boat that held 213 marbles.

## Heat Transfer and the Properties of Materials

Dr. Tim Topoleski, Professor of Mechanical Engineering provided an excellent overview of material properties related to his Biomechanical Engineering research. Students learned that in biomechanical applications, the heat transfer characteristics of materials and fluids are quite important. The heat transfer hands-on challenge was:

### *Keep It Kool!*

> The goal of this activity was to develop an understanding of heat transfer. The objective was to keep ½ cup of ice-cold water as cool as possible using only the materials provided. Students were to minimize the rate of heat transfer while minimizing the weight of the

insulating device. Some of the designs are shown in Figure 3. The "bragging rights" for this activity was:

$$\frac{1}{\left[\left(T_{final} - T_{initial}\right)/\left(t_{final} - t_{initial}\right)\right]^2 \bullet Mass}$$

where T - Temperature
t - time
Mass in grams

| **Materials:** | **Mass: (grams)** |
|---|---|
| Paper Bag | 7.5 |
| Plastic Cup | 5.0 |
| Dixie Cup | 4.5 |
| Plastic Baggie (each) | 2.5 |
| Rubber Band (each) | 0.7 |
| Cotton Ball (each) | 0.4 |
| Tissue Paper (each square) | 0.2 |
| Foil Square (each sq.) | 0.4 |
| Plastic Square (each sq.) | 0.1 |

Figure 3: Keeping it Kool!

## Mathematical Modeling

Dean Sheridan, an engineering teacher and mathematical modeling consultant from Glenelg High School provided an excellent overview of the usefulness of mathematical modeling in engineering. An overview of the necessary equations for the hot air balloon mathematical model was also discussed. An Excel spreadsheet with the necessary inputs, balloon properties, etc., which provided the predicted time aloft was also reviewed (and a PDF file of the spreadsheet and important equations were also posted to the YESS website). The design challenge is given below, and it was especially rewarding to see the innovative teams that were willing to 'think outside of the box' for this challenge, as shown in Figure 4.

### *A Bridge to the Future*

The challenge was to construct a free standing device that supports a load across an open distance defined by to 2x4 blocks. The teams were given two-2x4 blocks, four sheets of 8 ½ x 11 sheets of paper, and 12 inches of ¾ inch masking tape. The following rules had to be adhered to:

- The device has to sit on the blocks so that it could be lifted and set back down at will. The teams could only tape to the paper and not the blocks.
- No part of the load could be in the same vertical plane as the blocks.
- The load must be supported for a minimum of 30 seconds.
- Failure occurs when any part of the paper or load touch the ground.

The "bragging rights" were determined by:

$$\textbf{Distance}^3 \;\; \textbf{x} \;\; \textbf{Mass}^2$$

where: Distance is measured between the blocks in centimeters
Mass of the load in ounces

Figure 4: A Bridge to the Future!

## The Hot Air Balloon Project

During the next seminar, the teams worked on finalizing their designs and worked on their mathematical models. The design testing took place on December 15, with many innovative designs, one of which is shown in Figure 5. A DVD of the hot air balloon project testing was created by a parent of a participant, and will be shown during the presentation.

Figure 5: Up, Up and Away in a Hot Air Balloon!

## Results and Conclusions

Last summer the Board of Directors of the Historical Electronics Museum met to strategize as how to improve the erratic attendance of the Young Engineers and Scientists Seminars program. The attendance in the 2003 program ranged from 23 to 55 students per seminar, with only one student attending all of the seminars. The attendance in the 2004 program has ranged from 50 to 72 students (with an average of 63 students at each session). Eleven students attended all of the seminars, and fifty students have attended at least two-thirds of the seminars during the 2004 YESS program. In addition, there were 10-15 visitors (high school teachers and parents) at each seminar. The Board of Directors has expressed their delight with the improved attendance of the YESS program. At the design project testing, each of the eleven students with perfect attendance received a $50 gift card to Best Buy™. Monetary awards were also made to the top three design teams (based on the hot air balloon project bragging rights), in the amount of $800, $600 and $400 per team respectively. Comments from many of the students and parents during the YESS program indicated that the hands-on activities and the design project were enjoyable additions to the seminars.

As a pilot effort to assess the effectiveness of the YESS program, student participants completed surveys at the beginning and end of the seminar series. The instruments were designed to capture changes in student interest in science and engineering as well as a host of related attitudes and confidence levels related to math, science, and engineering of interest to the seminar designers. Most of the students expressed strong or very strong interest in YESS (63%) at the beginning of the experience. Since some of the participants attended the 2003 seminar series (that followed a different format), this modest enthusiasm for YESS may have been influenced by their mediocre experiences the year before. By the end of the series, 84% of the students rated their enthusiasm for YESS as strong or very strong. In response to, "Overall, I learned a lot in this seminar series," 62% agreed or strongly agreed. As another sign of satisfaction, students were asked if they would recommend this program to a friend. Seventy-six percent agreed or agreed strongly with this statement.

The seminar is reaching students from a wide range of families as reflected in parental occupations. Of particular interest to the seminar designers was whether students coming from families with a parent or parents who work in an engineering or technical field held different expectations or claimed different knowledge compared to students whose parents work in non-technical fields. Of the respondents to the pretest, 13 (27%) indicated that their mothers were in a technical field and 19 (35%) of the fathers. Seven students are in both counts because both mother and father are in technical careers. There was no difference between groups of students based on parental occupation on their interest in an engineering career, their knowledge of science and engineering fields, their plans to major in science or engineering in college, or whether their interest in science is related to becoming a doctor or other health professional. A few more students with parents who are *not* in engineering or a technical field feel pushed into science or engineering field rather than being motivated by their interest. These students also claim greater knowledge of science and engineering careers than their peers.

On the posttest instrument, students indicated whether their skills or interest increased, stayed the same, or decreased on a number of items based on their participation in the seminar series. Over half of the students reported *increased* capacity on the following items: interest in pursing a career in science or engineering (54%), interest in teamwork (60%), ability to work in teams (57%), confidence in successfully studying science or engineering in college (51%), understanding how math helps solve problems in science and engineering (57%), and knowledge of science and engineering fields (78%).

The responses of the 22 students who completed the pretest and the posttest surveys were analyzed using a paired sample t-test. On only two survey items was there a statistically significant difference between the two administrations of the survey. Students reported a statistically significant increase in their level of understanding of **buoyancy** ($t = -3.906$, $p < .05$) and a statistically significant increase in the level of agreement with the statement: Other people in my life are pushing me into science or engineering rather than my interest ($t = -2.748$, $p < .05$). In general, the differences in means from the pretest to the posttest were in the expected direction or remained stable, but no other changes were statistically significant.

One methodological concern in measuring changes in confidence and knowledge with a group of students selected for their talents in math and science is the risk of a ceiling effect. If interest and knowledge are high prior to an intervention, it is difficult for the intervention to demonstrate any statistically significant positive effect. In some cases, students' self-rated levels of confidence or knowledge decreased from the pretest to the posttest. The authors speculate that these trends may reflect a renewed appreciation for the complexity of science and engineering fields and a healthy reassessment of their expertise after the seminar series. They *thought* they knew a great deal at the start of the program, but the seminar series expanded their understanding such that they now know that their knowledge is more tentative and incomplete. If the seminar series continues, a survey question can be designed to determine if this interpretation has merit.

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