A WORTHY Pursuit for Tomorrow's Engineers

Richard Boyer and Taryn Melkus Bayles
Department of Chemical and Biochemical Engineering
University of Maryland Baltimore County

Abstract

There is a growing concern for the lack of college students pursuing degrees in technical disciplines. As a result, six years ago Northrop Grumman launched the WORTHY (Worthwhile to Help High School Youth) program to provide a unique mentoring/educational outreach program with the objective of cultivating and motivating future technical and business talent. Each year, Northrop Grumman selects at least 10 Baltimore inner-city high school students for the program who are entering their sophomore or junior years, based on their interest in pursuing a technical or business degree, academic performance, leadership skills and community involvement. The students work with two Northrop Grumman mentors during the school year on selected projects tailored to their business interests and technical level. Northrop Grumman collaborates with the University of Maryland Baltimore County to provide a six week summer program for the high school students focused on developing technical, business and leadership skills. Upon graduation from high school, qualified students receive multi-year partial scholarships, in addition the students can return to Northrop Grumman or UMBC to work during the summer while they are in college.

This paper will focus on the WORTHY summer program which was delivered summer of 2004 by UMBC's Chemical and Biochemical Engineering Department. UMBC's Shriver Center coordinated the first two weeks of the program, during which the high school students worked on a community service project with elementary school students. This was followed by four weeks of hands-on activities and projects which focused on engineering education. The high school students learned basic engineering concepts, problem solving skills and team work skills. Examples of these activities included toothpick puzzles, aluminum foil boats to float marbles, popsicle bridges, sail cars, paper whirligigs, and magnetic levitation cars. The last two weeks of the program included a final culminating project, which required teams of four students to design, construct, mathematically model and test a hot air balloon. The hot air balloon had to meet specific size, cost, time aloft, and payload criteria. On the final day of the summer program, the Northrop Grumman mentors were invited to UMBC, and the WORTHY students demonstrated their hot air balloon designs and performance, followed by oral presentations of their projects.

Background

In 1998, Robert Iorizzo, President of Northrop Grumman Electronic Systems, started the Worthwhile To Help High School Youth (WORTHY) mentoring program that teams Northrop

Grumman's Electronic Systems sector employees with Baltimore inner-city high school students to help them achieve their dreams of pursuing technical and business careers. "WORTHY is an investment in our future" says Iorizzo, "while the students gain valuable one-on-one experience in a real work environment, our employees are playing a critical role in developing the future of our workforce."[1] Each year, Northrop Grumman selects at least 10 Baltimore inner-city high school students for the program who are entering into their sophomore or junior years, based on criteria such as their interest in pursuing a technical or business degree, ability to maintain at least a 3.0 GPA, their leadership skills and community involvement.

While in high school, each student is given the opportunity to work with two Northrop Grumman mentors during the school year on selected projects tailored to their business interests and technical level. Collaboration with the University of Maryland Baltimore County (UMBC) provides a summer program for the past and present WORTHY students focused on developing technical, business and leadership skills.

Upon graduation from high school, qualified students receive multi-year partial scholarships from Northrop Grumman ($5,000/year for a maximum of $ 20,000 as long as they maintain at least a 3.0 GPA) at an accredited college or university. In addition, Northrop Grumman pays the high school students to participate in the summer program and pays former WORTHY students who are now in college to assist with the summer program.

When the program began, the WORTHY students worked with their mentors at the Northrop Grumman facility during the summer program. However, due to security issues with many of the projects that Northrop works on, it was no longer feasible for the high school students to work at the Northrop site. It was at this time that the partnership with UMBC began. During the first few summers of the partnership, the program consisted of a series of two or three day activities run by different departments on campus. Last summer, Northrop Grumman contacted the authors to develop a four week engineering education summer program, which would have a culminating project, similar to the project-based learning design project that is used in the freshman Introduction to Engineering Design course at UMBC. Unfortunately this request came the day before the summer program began, so the delivery of the program was 'just in time learning' and we were unable to conduct pre and post surveys to assess our summer program.

The Summer Program

The four week summer program was developed by and taught by the authors and two additional teaching fellows[2] who are MS students in Mechanical Engineering at UMBC. There were 24 students participating in the WORTHY summer 2004 program, along with two former WORTHY students that are in college. As requested by Northrop Grumman, the program consisted of numerous hands-on activities which emphasized basic engineering concepts, problem solving skills, cooperation as teams, and an overall engineering design project. Many of these activities have stemmed from the high school outreach program that is part of our NSF funded **S**cience, Technology, Engineering and Mathematics, **T**alent **E**xpansion **P**rogram (STEP – DUE-0230148)[3]. The engineering concepts were introduced with PowerPoint presentations that were prepared by either the authors or the teaching fellows. The presentations were followed by numerous hands-on activities as outlined below:

Hands-on Activities

Problem Solving Skills

Each student was given a bag of toothpicks, and they were presented with numerous toothpick puzzles[4] to solve. For example, they laid out 24 toothpicks to make one large square containing nine squares (three rows of three squares each). The students were then challenged to remove eight of the toothpicks from the twenty-four so as to leave just two squares, which should not touch one another.

Float Your Marbles

A short discussion of buoyancy was presented (this presentation was emphasized since the concept of buoyancy would be important for their engineering design project that would take place the last two weeks of the program). Each student was given a twelve inch by six inch piece of aluminum foil and then challenged to create a boat that would hold the largest number of glass marbles while staying afloat. Many of the designs were similar, however, the most successful designs resembled flatbed barges and one student was able to hold over 70 marbles.

Bridge to the Future

A presentation with video clips on bridges, bridge disasters, and bridge construction was delivered to the students. The students were divided into teams of 3 to 4; each team was given a limited number of newspaper sheets and a roll of masking tape. Each team was challenged to construct a bridge that had to span a minimum gap and had to hold the greatest amount of weight. The design that worked the best consisted of interlocking rolled coils of paper. As in the ***Float Your Marbles*** activity, the best design was also the one in which the team members thought about how to place the weight before actually placing it on the structure. After this initial bridge challenge, the activity was extended to have the teams build a second bridge; this one was constructed of craft sticks and hot glue. The bridge had to span a gap of four feet; however, the entire structure had to fit into a 4 inch by 3 foot tube. This was done so that the students would realize that actual bridges are made in pieces and then assembled at the site. The most successful team utilized an internal triangular support structure and had their bridge in three pieces rather than two. Many of the other teams had their weakest joint at the middle of the bridge where the two pieces met. Since the weight was being applied in the middle of the bridges, the ones with joints at this point were significantly less stable and thus broke sooner. The winning team had two joints closer to the ends of the bridge and their bridge was able to hold considerably more weight.

Paper Whirligig Design Project

This hands-on activity was based upon a Mechanical Engineering Systems Design (ENME 444) Paper Helicopter Design Project[5] developed by Dr. Bill Wood at UMBC. This activity allowed the students to understand the connection between business and engineering. The whirligig is a device, composed primarily of paper, that spins upon its release and through this spinning action slows its descent. So that the students had the opportunity to interact with new people, the students selected new teams and designed and constructed the 'whirligigs' out of common office supplies: 20# paper, #1 paper clips, and tape. The whirligigs were required to land within a six foot by six foot square from a height of 20 feet. The goal of the project was to make a whirligig that would make the most profit. A score that combines time aloft and price represent the quality of a design:

$$\mathit{Score} = \frac{\text{Time Aloft } \mathit{(seconds)}}{\text{Price } \mathit{(dollars)}}$$

Each whirligig's market share is determined by its score in relation to the scores of the other whirligigs designed and constructed by the other teams:

$$\mathit{Share}_i = \frac{\text{Score}_i^2}{\sum_J \text{Score}_j^2}$$

The best performing whirligig determines the total market size (i.e., one good whirligig will create more demand for all whirligigs):

$$\mathit{Market} = \max\left(10{,}000,\ 10^{\max i(\text{score}i/5)}\right)$$

Profit is the main goal, specifically maximizing profit for the whirligig:

$$\mathit{Profit}_i = \mathit{Sales}_i * (\text{Price} - \text{Incremental Cost} + \text{Incremental Recycling Income}) - \text{Capital Cost}$$

where: $\mathit{Sales}_i = \mathit{Share}_i * \mathit{Market}$

The price is set by each design team, and all of the teams are given Capital Cost values (i.e., development labor, full scale testing), Equipment Costs (scissors, ruler, manila folder pattern stock, etc.), Incremental Costs (manufacturing labor, paper, photocopies, paper clips and tape) and Incremental Recycling Income: (paper clips, white paper scraps). For this activity, the best design was one that minimized the cost of their design while still meeting the required descent specifications.

K 'NEX™ Sail Vehicles

After a presentation on aerodynamics, the students were challenged to construct a fan powered sail vehicle to maximize distance traveled while minimizing cost. Each team was given a bag of

K ‘Nex™ parts and miscellaneous items which included tires, rings, small, medium & large plastic bags, tape, scissors, etc. and a cost sheet for each of the parts, as well as fan testing time. Several excellent designs emerged, with a maximum distance traveled of 45 feet; however, the winning team was within five feet of the maximum distance but the team was able to build their sail vehicle for almost half the cost as the other designs.

Magnetic Levitation Car

The students were put in teams of two in order to build their magnetic levitation cars. Each team was given two blocks of high density Styrofoam, a small motor with fan blades and four magnets. A pre-constructed racetrack was available (UMBC had hosted Project Lead the Way teacher training the two weeks prior to the WORTHY summer bridge program) for testing. This project took considerable patience to get the weight of their cars balanced. The magnets on each side of the car had to be reversed because of the polarity of the track, however, the biggest challenged was to have the magnets close enough to the walls of the track since this is what supplied the power to the fans, yet, there had to be enough clearance for the car to move easily down the track. Many of the teams had their patience rewarded as their cars zipped down the track very quickly, as shown below in Figure 1.

Figure 1: Some of the WORTHY student team’s Magnetic Levitation Cars

The Engineering Design Project

Over the last four years, the Introduction to Engineering Design course at UMBC has been revised from a traditional lecture and design-on-paper course, to an active learning lecture and project based learning engineering design course[6]. The design teams are required not only to research, design, construct, test and present their product, but also to evaluate their product's performance based on a mathematical model they create. 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. Northrop Grumman is familiar with the design projects that have been used at UMBC and requested that one of the projects would be used for the WORTHY program. 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.

To introduce the design project, an overview of the Introduction to Engineering Design course at UMBC was presented, along with videos that have been made of each of the product testing of previous design projects (except for the hot air balloon design project – we didn't want to influence the WORTHY students' designs). The design teams were assigned, to ensure that each team would have at least one person that was familiar with Excel for the development of the mathematical model.

The value of teamwork was emphasized by having the teams go through a group problem solving simulation[7]. Each of the students read through the details of a hypothetical subarctic survival situation, in which a plane has crashed in northern Canada and 15 items were salvaged prior to the plane drifting away and sinking. The students had to rank the items according to their importance to their survival. After everyone had finished the individual ranking, the teams met and discussed the situation, and then ranked each of the items as a team. After comparing their answers with the Canadian Para Rescue Specialists, the students found that they performed better as a team, than individually.

The teams were also given a planning exercise before they began the design project. Each team was given a bag of Tinker Toys™ and they were told they could not put together any of the pieces. Instead, they had to plan how they would use the pieces (as shown in Figure 2) to build the tallest tower (the actual construction time would be limited to two minutes; therefore the planning time was crucial). Once their planning time (twenty minutes) was up, all of the pieces went back into the bags and the teams had two minutes of build time. Many of the teams had impressive structures, but not all of the teams were able to finish because of the time limit. This was a valuable lesson that would carry through to their design project.

Figure 2: The planning stage of the Tinker Toy™ Construction Challenge

Hot Air Balloon[8]

The WORTHY summer program design project was to design, construct, model, predict the performance, test and evaluate a hot air balloon. 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, and followed by the actual launch. The preheat time using the hair dryer was not required, but optional. Each team was also required to create a mathematical model implementing Excel 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 x payload x model accuracy x cost index

Where model accuracy was 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 was calculated using:

$$\frac{\text{WORTHY Program Minimum TOTAL Design Cost that met the design requirements}}{\text{Your Team TOTAL Design Cost}}$$

The authors and Teaching Fellows went over heat transfer concepts, buoyancy, ideal gas behavior, etc., and helped the teams develop their mathematical models which predicted how long their hot air balloons would stay aloft. Once each group had decided on the design and materials of construction of their balloons, one of the team members went shopping for supplies while the other teammates completed the mathematical model. The mathematical models helped the teams realize that their design were not going to work as they had originally thought since their payload calculations came out negative. This meant that many of the teams had to rework their initial designs and go shopping for additional materials. On the final day of the summer program, the Northrop Grumman mentors were invited to UMBC for a reception, and the WORTHY students demonstrated their hot air balloon design and performance (as shown in Figure 3), followed by oral presentation of their projects and activities that they were involved in over the course of the summer program. The substantiation of the WORTHY program was readily seen in the working projects that the students designed in the engineering challenges.

Figure 3: One of the WORTHY team's Hot Air Balloon Design

Future Programs

Many of the early WORTHY students have gone on to become highly successful college students. Due to the last minute request by Northrop Grumman for us to develop this summer program, it was not within our scope to assess the future of the WORTHY program. However, in follow up conversations Northrop Grumman has indicated that the WORTHY students and mentors enjoyed our summer program and preferred it over previous summer programs; they have asked us to deliver the program again in summer 2005. We have made recommendations to Northrop Grumman to attain a better outcome in future programs.

By working more closely with Northrop Grumman and having sufficient time to plan the summer program, this program can reach out to more students. The program currently has two Northrop Grumman employees mentoring each student, but there is little interaction between them. If each student were given one mentor and a chance to work with their mentor on a regular basis, the program could double the impact on Baltimore area students. In addition, if Northrop Grumman did not pay the high school students to participate in the summer program (or simply offer to pay transportation/food expenses versus the $12 per hour that was paid to each of the high school students summer 2004), they would be able to offer more scholarships to more students. The program would also attract the caliber of student who is truly interested in the ultimate goal of the program. It was our experience last year that many of the students attended the summer program for monetary reasons and were not interested in pursuing engineering or business careers. It has been our experience in developing other outreach programs, the lure of the scholarship money, mentoring opportunities and the summer program is sufficient to attract the caliber of student that the program deserves. Also, having sufficient time to plan the summer program would allow us to tailor the activities and project to the interest of the WORTHY students and Northrop Grumman. This would allow the experience to have a more lasting impact on the students.

Bibliographic Information

1. "Northrop Grumman Celebrates Sixth Year Supporting High School Mentoring Program", http://www.irconnect.com/noc/press/pages/news_releases.mhtml?d=59699, accessed October 3, 2004.
2. deGrazia, J.L., J.F. Sullivan, L.E. Carlson and D.W. Carlson, "A K-12/University Partnership: Creating Tomorrow's Engineers," *Journal of Engineering Education*, vol. 90, no. 4, 2001, pp. 557-563.
3. Bayles, T.M., Spence, A.M. and C. Morrell, "Science, Technology, Engineering and Mathematics Talent Expansion Program: A Focus on Diversity", *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition*. Presented during the Recruitment & Outreach in CHE Session #2213 at the ASEE Annual Conference, Nashville, TN, June 24, 2003.
4. PUZZLEGRAMS, A colorful, challenging collection of 178 classic puzzles compiled by Pentagram, Simon & Schuster, Inc., New York, 1989.
5. Wood, W.H., III, ENME 444 Paper Helicopter Design Project, Spring 2004, Department of Mechanical Engineering, University of Maryland Baltimore County, and personal communication, July 2004.

6. Bayles, T.M. "Improving the Freshman Engineering Experience", *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition*, paper 2004-1602. Presented in the Freshman Programs Division Session #2253 at the ASEE Annual Conference, Salt Lake City, UT, June 22, 2004.
7. Lafferty, J.C, Subarctic Survival Situation™, Human Synergistics, Inc., 1987.
8. Burrows, V., personal communication August 2, 2002 and http://129.219.116.31/Featured_Lessons/con_lessons.html, accessed August 19, 2002.

RICHARD BOYER is a senior majoring in Chemical Engineering (Bioengineering track) at the University of Maryland Baltimore County. In addition to developing and teaching the WORTHY summer bridge program, he has been a Teaching Fellow for the Introduction to Engineering Design ENES 101 course at UMBC. He is a Meyerhoff scholar at UMBC and has conducted fermentation research with Dr. Mark Marten for the last three years.

TARYN MELKUS BAYLES is a Professor of the Practice in the Chemical and Biochemical Engineering Department at UMBC. She has taught Introduction to Engineering Design at UMBC over the last 5 years. Within the last two years she has received over $3M of National Science Foundation funding in Engineering Education and Outreach. She has been recognized by her students and peers with several teaching and mentoring awards.