AC 2007-2838: ESTABLISHMENT OF AN ENGINEERING EDUCATION PROGRAM AT ROANOKE VALLEY GOVERNOR'S SCHOOL

Dewey Spangler, Virginia Tech

Dewey Spangler is a visiting professor in the department of Mechanical Engineering at Virginia Tech. Mr. Spangler holds an M.S. in Civil Engineering and a P.E. license in the Commonwealth of Virginia. He has served as faculty advisor to over one hundred mechanical engineering sophomores in the area of product design and has taught extensively in the areas of engineering mechanics, programming, GIS, engineering economics, project management, and contract law. His research interests involve aerodynamic flow control, mechanical design, K-12 engineering education, solid mechanics, and non-linear structural mechanics. He has ten years of full-time industry experience in steel manufacturing and has over eight years of part-time consulting experience in the areas of mechanical and civil design. He is currently pursuing a Ph. D. in the department of Mechanical Engineering at Virginia Tech.

Olga Pierrakos, Virginia Tech

Olga Pierrakos is currently a National Academy of Engineering CASEE AGEP Postdoctoral Engineering Education Researcher (PEER) at Virginia Tech in the Department of Engineering Education. Dr. Pierrakos holds an M.S. in Engineering Mechanics and a Ph.D. in Biomedical Engineering from Virginia Tech. Her Ph.D. work pertained to vortex dynamics in left ventricular flows. She has served as faculty advisor to over thirty mechanical engineering seniors involved in biomedical engineering design projects and taught several mechanical engineering fluid mechanics, design, and technical communication courses. Her research interests are outcomes-based assessment methods for a variety of learning experiences in engineering, students' learning mechanisms, using research and design examples to teach engineering concepts, K-12 engineering education, and cardiovascular fluid mechanics research

Establishment of an Engineering Education Program at Roanoke Valley Governor's School

Introduction

To address the growing need for engineering practitioners in the United States and to introduce engineering to secondary school students, Roanoke Valley Governor's School (a.k.a. – RVGS) has initiated an innovative engineering education program. This program is adaptable to other governor school's as well as to conventional, main stream, high school institutions. RVGS, which is similar to other Virginia governor's schools, provides accelerated high school education for gifted learners. RVGS has a service area of twelve high schools and places a strong emphasis on science and mathematics. Thus, the new engineering program adds to the existing strong curriculum of the school. Prior to 2006, RVGS did not have a dedicated course in engineering. Now, a new course called *Governor's School Engineering* (a.k.a. – GSEN*)* exists. This class provides a thorough introduction to the engineering professions and engineering mechanics for high school seniors via an asynchronous-distance learning format. In addition to meeting course requirements, students also participate in a regional robotics competition. Also new to RVGS and its new engineering program is the establishment of on-site computer workstations to assist students with engineering related course work and research. By participating in this education program, talented, hard working students are encouraged to stay in engineering since they learn important fundamental subjects in a well structured yet open minded and supportive environment.

Many high schools offer courses in engineering. Due to a lack of pre-requisite classes, these courses are usually introductory in nature and do not offer opportunities for students to study vector and calculus based engineering mechanics[1]. The course coverage in GESN is the same as that offered in a freshman or sophomore university level statics class, making it unique for a high school curriculum. Exposing high school students to engineering before they apply to a college or university is beneficial since the rigorous course load of a university program makes it difficult to complete an intended major without adding an extra year (or more) to the required time.[2] The first-third of GSEN focuses on the engineering profession and quantitative methods. The last two-thirds of GSEN focuses on the instruction of statics of rigid bodies using vector algebra and calculus. University statics courses have traditionally been used to increase attrition in engineering programs. Often, students who complete such courses do not develop a proper foundation for additional engineering coursework. Many have to repeat this course or take it at a local community college that offers an atmosphere more conducive to learning. Some university students, frustrated with the pace and lack of personal attention, become disillusioned with engineering and pursue other professions. Providing the opportunity of in-depth engineering education at a high school level will encourage talented students to continue in this profession.

Due to the special environment provided by governor's schools, there is a high level of confidence in student success in GSEN. Early on students are exposed to subjects that are usually reserved for instruction in the freshman college year of engineering. GSEN itself is comprised of two parts. Part One (approximately one-third of the course) emphasizes the engineering professions, problem solving techniques, and engineering design. Part Two addresses the study of statics of rigid bodies in two and three dimensions. This course is available to students at

RVGS and to other governor's school students via an online computer course management system (CMS). GSEN has a pre-requisite of introductory calculus and extends over the entire school year. RVGS is one of the first high schools in the United States that allows students to take an online calculus based engineering mechanics course for college credit. Most other high school engineering programs investigate the profession in general terms and then focus on "hands-on" project oriented activities. Many of the programs reviewed by the authors involve summer "boot camp" type curriculums usually not requiring a mathematics background beyond algebra or trigonometry. While important, these programs do not allow students to be exposed to concepts in engineering mechanics[3]. The RVGS program allows students to apply concepts learned in other math and science courses to the solution of involved engineering problems. There is no better way to initiate students to the high expectations that await them than to provide an opportunity to actually solve involved engineering problems, such as exists in a statics course .

RVGS not only offers innovative courses for students, but also exceptional research and mentoring opportunities. At RVGS, most students begin study in the 9^{th} or 10^{th} grade and continue in the program until graduation. Students are exposed to concentrated study in algebra, statistics, trigonometry, and calculus throughout their tenor. During one entire month of the academic year students participate in an intercession period and do not attend classes. During intercession they conduct research using experimental facilities available at RVGS and interact with engineering researchers and practitioners via mentorship opportunities. Intercession ends with an event called Project Forum where projects and presentations are judged by various professionals in the field. All incoming students take an introductory lab course in physics. Students spend one-half of the academic day at RVGS and the other half at their home high school.

The engineering education department at RVGS incorporates coursework, a robotics competition, mentoring, and research opportunities via collaborations with research university faculty and with new state of the art computer workstations. GSEN represents an innovative approach to learning, not only because it is the first class of its kind, but because of its integration with on-site infrastructure and local colleges and universities. GSEN is available to students who have taken an introductory calculus course covering differentiation and integration. Students take GSEN in addition to a full time academic load and meet with the instructor during their lunch hour or after class, as needed. The instructor for GSEN has a professional engineering license and is endorsed in secondary mathematics education. Those who successfully complete GSEN receive three (3) dual enrollment credits from a local community college in EGR 295: *Topics in Engineering*. Pending approval with Virginia Tech, transfer credit will also be granted. Until university transfer credit is established students are strongly encouraged to maintain a portfolio of all course work in GSEN and to petition the engineering department to which attendance is contemplated for credit in an introductory engineering course and in an engineering mechanics course in statics.

Ethnic and gender demographics are shown for RVGS and GSEN, respectively, for the 2006-2007 academic year. Students attending RVGS represent the top two percent of academic performance within the surrounding service area, which has a general population of over 150,000. Diversity issues are a continuous concern in the engineering professions and it is

encouraging to have the representation of minorities and females in GSEN as demonstrated in Table 2.

Table 1 - RVGS Demographics

Total Number of Students	270
Female	130
Male	140
African Americans	8
Asian American	18
Caucasian	243
Hispanic	1

Table 2 - GSEN Demographics

Total Number of Students	8
Female	2
Male	6
African Americans	1
Asian American	1
Caucasian	6
Hispanic	0

GSEN is delivered via an asynchronous, distance-learning format to students at RVGS and will eventually be available to other participating governor's schools. A Blackboard CMS provides an interface between students and the instructor. Students access the CMS through a password protected website link. Students download lecture material in PDF or scanned format along with a corresponding video file of the instructor explaining the material. All testing takes place at the governor school and is proctored by a certified employee. Homework assignments are posted on the website and are submitted to the instructor at RVGS electronically or by US mail. Graded homework is returned to the student electronically or by US mail as well.

Conventional high school curriculums can readily adopt a program similar to that offered at RVGS. Perspective students should be exposed, preferable before entering their senior year, to introductory calculus (specifically: differentiation and integration of algebraic and simple transcendental functions), vector algebra (specifically: addition, cross product multiplication, and use of **i**, **j**, **k** unit vectors), unit conversions, and dimensional analysis. If they lack calculus or vector algebra, an introductory course in these subjects could be taken during the first semester of their senior year while taking GSEN. Topics such as vector algebra and dimensional analysis can easily be integrated into existing algebra and pre-calculus courses. In many cases these topics are already being taught and only lack an engineering applications emphasis. In some cases special primer courses can be developed to address deficiencies in pre-requisite subjects. The instructor(s) for a GSEN type course does not need to possess an engineering background (although preferred). Only a background in instructional applied mathematics (through calculus) is necessary, along with a willingness to learn about engineering through self-instruction or additional coursework.

RVGS offers advanced courses, usually reserved for instruction in the first year of college, that integrate mathematics and sciences. For example, in Integrated Mathematics (IM), students are taught proper unit conversion and dimensional analysis techniques. IM is taken by all entering freshmen and sophomores at RVGS. Also, students are introduced to concepts in dynamics such as position, velocity, and acceleration and statics and dynamic equilibrium via interactive laboratories in IM and in Laboratory Physics. Table 3 shows courses taught at RVGS that are directly relevant to material taught in GSEN with the corresponding year students typically take each class.

Table 3 - RVGS Courses Relevant to Engineering Education

Course	Academic Level
Governor's School Engineering*	***Senior***
Integrated Mathematics	Freshman
Laboratory Physics	Freshman
Fundamentals of Research	Freshman
Contemporary Pre-calculus	Sophomore
Laboratory Calculus	Junior
Advanced Calculus*	Senior
Advanced Governor's School Physics**	Senior
Product Design Engineering	varies
Aerodynamics	varies
Professional Mentorship	varies
Modeling and Simulations	varies

*Course carries advanced placement credit.

** Course carries three college dual enrollment credits

GSEN, being one of the newest courses in the program, allows students to explore applications in mathematics and science during their high school stay. Concepts taught in physics, trigonometry, and calculus are reinforced in GSEN. Students graduate high school with a real sense of how science and mathematics join together to help develop and maintain a civil society. In order to preserve the rigor and expectations of an engineering course in rigid body mechanics, RVGS utilizes the same syllabus, textbooks, and exams that are used in courses offered by a community college or university. The curriculum for GSEN, shown in Table 4, indicates that intercession and project forum occurs during the last month of the first semester. This curriculum (minus intercession) is the same as that offered at a community college or university. The RVGS instructor requires all students to have a calculus and vector based textbook on statics. Each online lecture is comprised of reading material and an accompanying video lecture in AVI format to aid the student in understanding the material. All lecture material is available for download at the GSEN course website.

Table 4 - Topics in GSEN

Topic	Week(s)	Semester
The Engineering Profession	1,2	1
Engineering Design – A Process	3,4	1
Engineering Solutions	5,6	1
Representation of Technical Data	7,8	1
Engineering Estimations and Approximations	9,10	1
Dimensions, Units, and Conversions	11	1
Intercession and Project Forum	**12,13,14,15**	**1**
Introduction to Engineering Mechanics: Statics	1	2
Statics of Particles	2,3	2
Rigid Bodies: Equivalent Systems of Forces	4,5	2
Equilibrium of Rigid Bodies	6,7	2
Distributed Forces: Centroids and Centers of Gravity	8,9	2
Analysis of Structures	10	2
Forces in Beams and Cables	11,12	2
Friction	13	2
Distributed Forces: Moments of Inertia	14	2
Method of Virtual Work	15	2

Robotics Competition

In accompaniment to the coursework, students in GSEN are also required to participate in a competition with area high schools involving the design of an autonomously controlled robot. Robot components such as servos and programmable circuit boards (a.k.a. - bread boards) are provided by Parallax, Inc. Students meet in teams of four to six to construct the chassis and ping-pong ball delivery device that is later attached to the components provided by Parallax. Instructions are sent to the robot via a USB interface between a PC and the programmable circuit board. Instructions are written by the students using a procedural basic programming code (P-BASIC). From these instructions the robot must deliver ping-pong balls at each corner of an eight-by-eight foot track autonomously, meaning that no human intervention can occur to assist the robot in its task. Infrared sensors (line followers) located at the front of the robot allow it to trace a black strip attached to the surface of the track. Students are required to work on the robot during their lunch period and after school and receive mentoring from the GSEN instructor. Figure 1 shows the robot adjacent to one of the ping-pong ball delivery pockets.

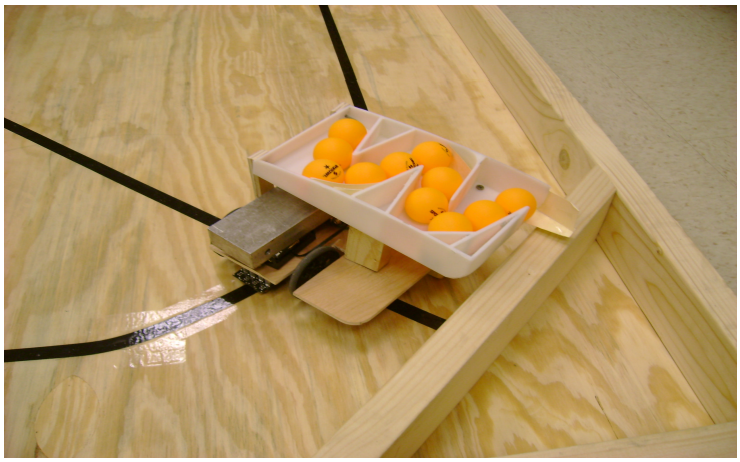

Figure 1 - GSEN Robot submitted for VWCC Competition

Results from the 2006 Virginia Western Community College (VWCC) Robotics Competition are shown in Tables 5 and 6. RVGS placed sixth out of nine in combined categories and second out of five in the high school category. This is impressive considering that RVGS participated in this competition for the first time in 2006 and that the students were receiving no academic credit towards high school graduation for being on the team. Also, each college team and several of the high school teams had members who had extensive experience with CAD software, specifically AutoCAD's Inventor. No members of the RVGS team had any prior knowledge of CAD. Competition rules required that at least one complex component of the robot had to be designed using solid modeling software. The part(s) were then produced on a rapid prototype (RP) device and were attached to the robot. Several of the RVGS team members learned Inventor over a two day period and were successful in producing a device for holding the ping-pong balls using RP technology (shown in white in Figure 1).

Table 5 - Competition Results for All Teams

Team	Report	Presentation	Competition	Total	Rank
Community College 1	12.2	24.0	90.9	127.1	1
Community College 2	10.2	23.2	90.0	123.4	2
Community College 3	13.0	23.2	45.0	81.2	3
High School Team 1	13.2	26.2	36.0	75.4	4
Community College 4	8.6	23.8	31.0	63.4	5
RVGS	***12.4***	***25.0***	***21.0***	***58.4***	***6***
High School Team 2	12.8	24.5	2.0	39.3	7
High School Team 3	8.8	21.2	1.0	31.0	8
High School Team 4	4.2	18.8	1.0	24.0	9
Average Score	10.6	23.3	35.3	69.2	

Table 6 - Competition Results for High School Teams

Team	Report	Presentation	Competition	Total	Rank
High School Team 2	13.2	26.2	36.0	75.4	1
RVGS	***12.4***	***25.0***	***21.0***	***58.4***	***2***
High School Team 1	12.8	24.5	2.0	39.3	3
High School Team 4	8.8	21.2	1.0	31.0	4
High School Team 3	4.2	18.8	1.0	24.0	5
Average Score	10.3	23.1	12.2	45.6	

JETS Team-S Competition

GSEN students also participate in the JETS (Junior Engineering and Technology Society) Team-S competition which involves solving real world engineering problems in a team setting. Students travel to a local university or four year college to compete with other high schools from across the state by solving problems in areas of engineering ranging from environmental design to computer programming. Problems are submitted by practicing licensed engineers. Teams are broken into varsity and junior varsity categories and solutions are judged by engineering faculty at the host institute. This exercise provides excellent preparation for taking the Fundamentals of Engineering (FE) and Profession of Engineering (PE) exams.

A New Educational Paradigm

The students are not only exposed to design but are also introduced to engineering research via presentations and demonstrations by faculty from Virginia Tech. Research based learning at the secondary school level offers a new educational paradigm that demands a commitment to the intellectual growth of individual students, redefines the role of engineering in society, and stimulates students to pursue careers in engineering and research. Integrating research into secondary engineering education serves to increase recruitment and retention and enables future engineers to become societal leaders. One speaker recently addressed the inter-connections and diversity of fluid mechanics as a field pertinent to all engineering disciplines. Students were exposed to fluid mechanics research examples relating bridge and aircraft design to blood flow characterization in the heart. Upon completion of this type of "research transfer" presentation and demonstration, our objectives were for the students to be able to:

- articulate and recognize the role and importance of engineering in society,
- explore the diversity of fluid mechanics and biomedical engineering fields by using tangible and intuitive real life examples,
- understand how seemingly diverse areas of research are connected through fundamental engineering principles and how these principles occur in everyday physical or technological processes,
- appreciate the interdisciplinary and multidisciplinary character of modern engineering,

- develop awareness of emerging engineering fields and of future research trends and challenges.

Students also participate in tours of state-of-the-art research facilities such as Virginia Tech's senior project lab, *Ware Lab*. At this facility, university engineering students participate in teams to construct entries for a variety of national competitions such as Mini Baja, Formula One, and autonomous vehicle groups. Also, during the school year, students tour a virtual reality facility in the computer engineering department and a dedicated robotics research lab, know as the *RoMeLa* facility, in mechanical engineering; both located on the main campus of Virginia Tech.

Establishment of an Engineering Workstation at RVGS

Due to the increase in the use of personal lap tops and tablet PC's in many university engineering programs, high schools need to address the availability of similar technology when teaching students. One way of achieving this is to provide students with workstations having the necessary engineering software and hardware. RVGS plans to provide on-site engineering workstations which include the following items:

- Plotting devices capable of printing A through E size drawings.
- One or more universal material testing machine(s).
- Networked lap top computers (one per student) with necessary computer software, including:
    - three dimensional parametric CAD software (e.g. *Inventor*),
    - control systems software (e.g. *Lab View*) ,
    - mathematical numeric and symbolic software (e.g. *Matlab*),
    - statics and strength of materials instructional software (e.g. *MDSolids*), and
    - structural analysis software (e.g. *RISA*).

A dedicated area within the RVGS facility is required for storage of testing equipment, plotters, and lab tops. Students will access workstations, as needed, during the school day to assist them with homework, projects, and exams in GSEN. During intercession students will use workstations to conduct engineering related research.

Assessment

An informal qualitative assessment of the students currently taking GSEN revealed that they are highly valuing the exposure to engineering and are optimistic about their future career goals. Participants felt that this course represented a unique experience that they will benefit from it when they go to university. Most of the students taking GSEN plan to go into engineering as a profession and stated that their decision to do so was based on the experience they gained by enrolling in the engineering education program at RVGS. More quantitative assessments of the program will be made by engineering education researchers by way of surveys and focus studies in the near future.

Also in the near future, RVGS engineering students will have the opportunity to interact with university engineering seniors and graduate students engaged in design and research projects.

This goal will be facilitated by the current instructor who teaches, in addition to GSEN, courses in a mechanical engineering program at a local research university. Assessments of this endeavor will be made over the course of the next few years. Other questions that this initiative plans to address over the next few years include:

- Feasibility of increasing the interaction and collaboration between high schools that offer this program with neighboring community college and university engineering programs.
- Quantitative assessment of the success of students who complete the engineering education program at RVGS after they articulate to a college or university, focusing on:
    - number of students successfully graduating from four-year engineering programs,
    - number of students entering graduate school after receiving an undergraduate degree in engineering,
    - number of students receiving professional licensure in engineering.
- Student assessment of instructor(s) and the RVGS engineering program during and after courses have been completed.
- Increase in the use of distance learning technologies (compressed video, real-time synchronous instruction, etc.) in order to network with other high schools wanting to participate in an engineering education program but who lack proper resources.
- Assess the effectiveness of providing a well equipped engineering computer and CAD work station to enhancing student's educational experiences.

Conclusion

In order to introduce engineering to a younger population, RVGS has initiated an engineering education program for high school seniors. This program provides students with an opportunity to receive three dual enrollment credits in engineering along with a chance to work with state-of-the art computer software and testing equipment. Students are exposed to engineering analysis and design concepts through course material and via participation in a regional robotics competition. Students are also introduced to engineering research via guest speakers, participation in tours of state-of-the-art university research facilities, and interaction with engineering practitioners during intersession periods. The success of this program is indicative of the capabilities of highly motivated students when exposed to engineering in an environment conducive to academic learning. As the success of this program continues additional engineering classes, equipment, and research opportunities will be made available to students at RVGS and other governor schools nationwide via distance learning. This program serves as a model for other high schools to bridge the gap between local colleges and universities and allows engineering be something that can be learned during high school, not after one enters the university environment. Once students, at an earlier age, start learning about the vast and exciting world of engineering, the more likely they will continue with this rewarding profession.

Bibliography

1. URL: http://www.args.k12.va.us/; Appomattox regional Governor's School for the Arts and Technology, Programs of Study.
2. URL: http://www.imagine101.com/; Instructional website for the engineering education program for Madison West High School.

3. URL: http://www.prenhall.com/orsak/toc.htm; The Infinity Project website, Engineering Our Digital Future Curriculum.