Design of Modules for Pre-Engineering Education

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Abstract

It was our goal in this project to create instructional lab-based modules for the tenth-grade level pre-engineering program at Doherty High School, Worcester, MA. Our sponsor for this project was the Worcester Public School System. We prepared three such modules: flight, robotics, and forces and motion. These modules are designed to be hands-on and focus on creating projects rather than just lectures and tests, and simultaneously to contribute to the satisfaction of the requirements of the Massachusetts Ed Reform Frameworks for Technology. Another of our objectives in the project was to allow for Doherty students to use certain WPI facilities for their projects and thereby to supplement their learning. The broad goal of the pre-engineering program is to highlight the diversity and richness of engineering fields as careers.

Executive Summary

The need for skilled, well-educated engineers has been on a steady rise throughout the past few decades and this need will only continue to grow as we progress into the 21st century. It is this concept that is the driving force behind our project. The WPS (Worcester Public Schools) Engineering Pipeline Collaborative has created a series of educational modules on the subject of engineering to better prepare students for a future in engineering.

The WPS Engineering Pipeline Collaborative is a program sponsored by the Worcester public school system and Worcester Polytechnic Institute aimed towards increasing the amount of education high school students get in the area of engineering and technology. The goal of the collaborative is to give the students a richer technological education by sharing WPI resources with the public school system. We of the project team are working with WPS to complete our IQP (Interactive Qualifying Project), which is a project relating society and technology and is a part of the graduation requirements of WPI. Our team had been commissioned by Doherty High School in Worcester, MA to create three ten week modules. The subjects chosen by the Doherty staff for these modules are forces and motion, flight, and robotics.

There are several different factors we needed to take into account in order to create this program. First off we needed to be sure that our module packet worked in accordinance with the state frameworks. The frameworks are state mandated behavioral objectives that teachers are required to teach in order to properly prepare students for the "real world". Recently a new set of frameworks were devised by the State of Massachusetts that applies to technology and engineering courses and have been approved by the state department of education as acceptable frameworks. Also, the state of Massachusetts administers the MCAS exam as a graduation requirement for high school students. These state guidelines, as well as Doherty's budget restrictions had a strong influence over our design decisions for our modules.

In order to give the students a more rich and diversified experience with engineering we decided to create our modules with the goal of project based learning. The lab activities contained in each module packet require students to work as a team on creative projects that develop skills like the using the design process, prototype testing and revision, graphical data analysis, and hands on work with real engineering projects. We aimed to have the students not just learn the material, but to be able to apply their knowledge to the real world and make their ideas come to life.

One of our greatest challenges was taking complex subject matter and transforming it into something high-school students could benefit from. The level of sophistication had to be greatly toned down for all the subjects. Flight and Forces and Motion were very easy to transform into a useable and easily accessible form for the students. Robotics however is another story. When you think of robotics you think of industrial robots, but robots as a whole are very complex, far too complex and expensive for a ten-week tenth grade level program. Our robotics module therefore focuses on what could better be called the fundamentals of robotics. Subjects like gears, pulleys, levers, and electricity, which are the basis of any robot.

The sponsors are very enthusiastic about the new material we have produced, so much so that they started using an only partially complete flight module as soon as it was produced. From our daily encounters with the students of Doherty we can tell that they are very excited to be the first class to undertake this new program. The students are doing well in the team-driven environment that the modules create and take great pride in their engineering creations.

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Chapter I: Introduction

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Last fall high school students in Worcester received their first opportunity to participate in a class which implemented a new pre-engineering curriculum. The Engineering Pipeline is a pilot program at Doherty High School which will give future engineers preparation for the difficult curriculum that they will face in college. It will also provide potential engineers with the opportunity to explore a field that they may be interested in pursuing. Such programs will contribute to producing trained personnel to meet the labor demands of today's high-tech industries. They will make sure that someone who possesses natural skill in such areas can discover their abilities. Our project was to work with the faculty of Doherty High School to develop coursework and laboratory activities for three of the four curriculum modules that make up their initial program. We also set up the protocol by which the Doherty students would be able to visit WPI and use the facilities, therefore further expanding their lab experience.

The guidelines for this exciting new course have been established by the Massachusetts Department of Education and by The Worcester Public Schools. By the time our project began, the Doherty staff had already designed the first module and all of its content. This module focused on mechanical design and served to teach the students the fundamentals of the design process. This module is the core of the new program because it is here that students will learn how to develop a design, construct a prototype, test the design, evaluate the test results and improve upon their work. A module is a complete unit of coursework that covers one subject and contains the background material, the activities, and evaluation methods.

The full program in which we are participating is entitled the "Engineering Pipeline Collaborative". Our portion consists of three modules specifically for Doherty Memorial High School. Each of these modules will last for one term at Doherty, which is approximately ten weeks in duration. Each module will act like a separate class, not dependent upon the other modules. For each module, students complete a design project over the term to reinforce the lecture material and provide the students with their first hands-on experience in a high-tech field. The four modules will each cover a different area of engineering. Besides the module on mechanical design already in progress at Doherty, the additional three modules are flight, forces and motion, and robotics.

With the basic principles of good engineering (design, testing, and evaluation) in mind, we set up projects that allowed Doherty students to create solutions to the problems presented to them in a scientific manner. The program we created does not consist mainly of lectures on technique. It was designed in a way such that each student will have designed and built at least three tangible products during the school year, at least one for each module we set up. We evaluated our own design by the effectiveness of our work in sparking students' interest in the field of engineering. We will be pleased if we can also demonstrate to students that they have talents they didn't know they possessed.

Our sponsor for this project was the Worcester Public School System, specifically Doherty High School. This project, the Interactive Qualifying Project (IQP), was completed as part of our graduation requirement for Worcester Polytechnic Institute.

Chapter I: Introduction

According to Worcester Polytechnic Institute the IQP can be best described as follows. "The IQP challenges students to identify, investigate, and report on a topic examining how science or technology interacts with societal structures and values. The objective of the IQP is to enable WPI graduates to understand, as citizens and as professionals, how their careers will affect the larger society of which they are a part. This project is usually undertaken in a student's junior year." (Worcester Polytechnic Institute, 1999, http://www.wpi.edu/Academics/Projects)

Chapter II: Background

This chapter reviews case studies of programs similar to the pre-engineering experiment at Doherty High to analyze what they contain, how they have been used, and how well they accomplished their goals. We examine the requirements established by the State of Massachusetts for pre-engineering programs and the resources necessary to implement them. We also identify potential stumbling blocks as we see them arise in the literature. Finally we review the steps and principles required for designing effective pre-engineering project modules for high school students.

The Values of Pre-Engineering Programs

The American Association for the Advancement of Science (AAAS) claims that current high school curricula do not adequately teach students mathematics, science and technology. Even satisfactory grades on exams do not mean that the information is retained in the long term, according to their extensive research. The obstacles to better learning they cite include textbooks that are inadequate and also the structure of the curriculum itself (American Association for the Advancement of Science, www.aaas.org).

The Raytheon/UMASS Engineering Collaboration (EC) is a program that is developing guidelines and curriculum for pre-engineering education. The mission statement of this organization is that they hope to be involved in increasing the quality and quantity of students who pursue a career in engineering. Their program chiefly targets minorities and women. Their particular program is still being developed and once teachers are prepared to instruct the students and a curriculum is in place, students will be able to gain a better understanding and hopefully a greater interest in the field of engineering.

The Raytheon/UMASS EC feels strongly that if a student becomes interested in engineering in high school, attends courses like these and continues on to college, chances are that the student will have a more enjoyable, more educational college experience. Also students who have completed this program are more likely to stick to their choice of study in college. This therefore reduces the large number of students who drop out after a short time in a college engineering program. They also feel that this work ethic will carry on to working in the professional field as well. By learning about engineering from the 10th grade, they hope the students will become quite familiar with the field. (Engineering in Mass Collaborative, 2000, http://www.eimc.org/raytheon.htm)

Among students entering an engineering school and/or program, a student with knowledge about and interest in engineering will have an advantage over others who have not participated in a pre-engineering program. As third year engineering students, we feel that the first year at an engineering school can be very difficult, especially if the student is not familiar with the material.

Another similar program is called Project Lead the Way. Project Lead The Way, Inc. (PLTW) is a non-profit organization that has partnered with some schools in New

York State. They have developed a four-year program for high school students. The program combines the traditional math and science courses with various engineering courses. Some of these include *Engineering Design*, *Digital Electronics*, *Computer Integrated Manufacturing*, and *Principles of Engineering* (Charitable Venture Foundation, 1998). This program is designed to attract more students to engineering at an earlier stage in their lives and provide them with the opportunity to decide if it is a genuine interest to them (Ibid.).

PLTW also has an intensive training course for teachers who will be participating in the program. It is essential that the teachers be well prepared if these programs are to be a success. Teachers first attend pre-core training to prepare them for the intense core training. Both of these training sessions take place at a summer training institute, which is run by PLTW.

The benefits of a program such as Project Lead The Way are numerous. It is expected that it will increase the number of high school graduates who continue at an engineering institute and become successful engineers in the professional world. The program should also provide opportunities for everyone, regardless of race or gender. Since the students are prepared ahead of time, the drop out rate at engineering colleges hopefully will be reduced significantly (Ibid.)

Content of Programs

The small number of other schools that have traveled this road before and set up pre-engineering or similar programs in their local area are the inspiration for the Engineering Pipeline Collaborative. Project Lead the Way of Troy, New York has a more generalized curriculum. It covers many aspects of science and technology, not only specific engineering disciplines. Like our own project, its course structure involves four units; design and modeling, the magic of electrons, the science of technology, and automation and robotics. The first module of their program applies the same educational principle we have used, which is to teach technique first, then work on various engineering disciplines. The next unit of their plan is about electrical and computer engineering. Module three is about physics and covers the areas of kinematics, energy, and light and sound. Their final unit is a module on robotics, which is comparable to our robotics module, but also adds enough computer science to cover the programming of robots (Charitable Venture Foundation, 1998).

The State of Massachusetts has a program which encompasses pre-engineering in schools. It is called PALMS (Partnerships Advancing the Learning of Mathematics, Science and Technology) and is a section of the Massachusetts Department of Education. Pre-engineering is only part of PALMS' focus, as they are concerned with K-12, not just high school. PALMS has created a new framework for the *Science and Technology/ Engineering Curriculum*. It involves physical, life and earth sciences and also special sections on technology and design. The technology and design section teaches how technology and society interact. (Massachusetts DOE, http://www.doe.mass.edu/frameworks/archive/sci96/science8.html)

We used the lessons in Project Lead the Way's course outline as a template for our own modules. We covered most of the same concepts, mechanics and energy transfer, industrial processing, and programming. Our own program, however, is more project-oriented.

Teaching Strategies in Other Programs

Engineering Outreach Program at Washington State U.

For the past two years, Professor Michael D. Symans of Washington State University and his civil engineering students have visited local eighth grade science classrooms during National Engineers Week. The eighth graders work on building bridges with the engineers. This program's goals are similar to those of our project. Pupils learn about the design process, computer drafting, prototype construction, and testing. Programs like these help students to focus on a task and turn their ideas into real world solutions. The goals of the Engineering Outreach Program are:

1) "To enhance student interest in science and mathematics by demonstrating real world applications of these subjects."
2) "To provide the students with an understanding of the type of work that structural engineers do."
3) "To plant the seeds to consider future careers in engineering."

(Introducing Middle School Students to Engineering, http://www.wsu.edu/~symans/Educ/educ.htm)

Engineering outreach programs like this one introduce engineering to K-12 students. The need for massive personal commitments of time and effort keep these programs minimal. Thus most programs, like this one, are one-day events. Seeing the results that this program had in stimulating young minds to engineering, we feel that incorporating project-oriented engineering content throughout the school year will be even more effective.

The outline of Project Lead the Way focuses on a more traditional method of education with daily lessons and daily assignments based on small concepts. We believe that engineering cannot be taught in this way. If we are expected to effectively prepare students to be engineers then we must teach them to work like engineers.

Role of the Massachusetts Department of Education

What is needed to make the process of creating a pre-engineering curriculum more effective is the harmonious involvement of people statewide. That task cannot be accomplished without financial, human, space and time resources at the local level. Our state laws, as well as most other states, do not regulate the curricula which need to be taught in public schools. The State of Massachusetts does however have a framework which each local school district needs to adhere to when designing their separate curricula (Schachterle: Lecture on Educational Reform in Worcester, Sept. 27, 2000).

The Education Reform Law of 1993 requires that all public school students in grade ten be tested using The Massachusetts Comprehensive Assessment System (MCAS). The purpose of the law is to ensure that all students in Massachusetts' schools are provided with an opportunity to learn the material covered by the academic learning standards of the Massachusetts Curriculum Frameworks. (Source: Massachusetts Department of Education, www.doe.mass.edu)

Most public schools in Massachusetts need educational funds from some financial sources to create their special programs of study. The foundation reserve program was established by the Legislature as part of the State of Massachusetts' budget. This program was established to provide special financial assistance to municipalities for meeting their goals under Education Reform Law of 1993. It was recognized that the shift to competency objectives established by MCAS required both new financial assistance and new effective educational frameworks for public schools. Today, for example, Lighthouse Technology Grants are funded by the Department of Education to identify, enhance and disseminate existing classroom projects that incorporate new technology with the learning standards in the state curriculum frameworks to motivate students to learn. Those projects that have already proven their effectiveness in the classroom will serve as models, and their classroom teachers will serve as mentors to other schools. The Lighthouse Technology Grants recipients will be offering technology development opportunities throughout the school year and summer. (Source: Massachusetts Department of Education, www.doe.mass.edu)

The Massachusetts Department of Education also works to enhance teacher professionalism. The Teacher Quality Enhancement Office at the Massachusetts Department of Education is committed to strengthening teaching ability in Massachusetts. It also develops alternative paths for new teachers to create incentive teaching more professionally (Source: Massachusetts Department of Education, www.doe.mass.edu).

The Cost of Pre-Engineering Programs

According to the AAAS there is possibly no more guaranteed way to minimize the effectiveness and usefulness of a reform than to underfund it. The AAAS draws these three basic conclusions:

1. A substantial investment in public education has been taking place.
2. The level of this investment has been rising in real terms.
3. The rate of increase is diminishing and is likely to continue to do so in the near term.

(AAAS Project 2061: Finance, http://www.aaas.org/education)

The AAAS argues that it is practical to have cost estimates of proposed educational reforms before making decisions about putting them into action. Some examples, which the AAAS uses to elaborate on the topic of cost estimates, include the work of Borg and Gall (1989) who estimate the cost of development of a minicourse that would contain 15 hours of instruction. In the 1970's this minicourse would have cost around $100,000. These authors' estimate that today a "similar major curriculum project" would cost somewhere in the millions. They use the ratio 1:10:100 used in industry to estimate the funds required for research and development. In their example, if one million is spent to do the essential base inquiry into the subject, then ten million more would be required to develop the program to its most useful form, and another hundred million to build and publish the final product of the science education reform (AAAS Project 2061: Finance, http://www.aaas.org/education).

We believe that research and development costs in industry are not the same as those in education. Research and development in industry employs some of the highest paid skilled corporate employees. It is an elaborate process involving costly testing and quality control. Its time frame is at once lengthier and more stringent than what is required for educational reform.

A real cost item in curriculum development is "continuing teacher professional development" (AAAS Project 2061: Finance, http://www.aaas.org/education), something that is pivotal in any education reform, but especially in science programs. Continuing teacher development is needed because the fields of science and technology are growing and changing very quickly. The AAAS cites the estimates of Miller, Lord, and Dorney (1994) who say, "that between 1.8 and 2.8% of the operating budgets in the districts they studied were devoted to professional development." This small percentage amounts to approximately $1,755 to $3,529 for each classroom teacher. According to Darling-Hammond, it is atypical for a school to spend more than one percent on teacher's professional development. A total of $1.2 billion dollars would be required if all American states took the 1% out of the $117 billion they gathered for public education for grades K-12 in 1993-1994 (Ibid.).

The AAAS agrees that it would be enviable to be able to estimate the amount of money that would be necessary to execute a change in a science and technology curriculum by adding pre-engineering courses, however the Association states three reasons why it is challenging to attain such estimates. First, major reforms such as these require crucial departures from current routines. It is significantly easier to do cost estimates of current forms of education, simply because there are large amounts of data from which information can be derived. In new areas of curriculum no similar track records exist. Preliminary efforts can be examined, but most estimates would be based on assumptions.

Secondly, there is a problem which the AAAS refers to as "supplement versus supplant." The fact that reform is even being considered must mean that there are some spots in the current curriculum which have shortcomings. The cost of reform must be accounted for, even if the new program will need no extra resources once it has been properly set up and running. The money, which needs to be spent on the cost of the reform, shouldn't be looked upon as a simple addition to what already exists. The analyst also cannot simply subtract the resources that are intended for the program which is being reformed. The execution of reform is frequently very difficult, because the "reluctance to change fundamental practice" also needs to be accounted for when approximating the new costs (Ibid.).

Their third reason for the difficulty in making good cost estimates is that in the case of science education reform there are hidden benefits which cannot be included in purely fiscal analysis. For example, we could conclude that "enhanced scientific literacy significantly improves the quality of public discourse over land use" (AAAS Project 2061: Finance, http://www.aaas.org/education). So an informed public can make better decisions about environmental issues. This better educated society can steer clear of the cost incurred in land use. The money they would save by not making these mistakes could more than make up for the cost of the science education reform. The problem with this argument is that it is another assumption. All that can be done is to point out and identify those hidden savings and/or benefits could be considerable.

These three limitations need to be understood by those responsible for putting a price tag on science education reform (Ibid.). The issues which the AAAS addresses may appear intimidating to someone trying to implement a pre-engineering program, but it is very important to have some idea of what kind of resources the new curriculum would require in order to succeed and be useful. Similar cost estimates have been done, but the nature of science education reform "is unique in terms of the breadth of its goals" (Ibid.).

The Pedagogical Issues associated with Pre-engineering

Investigations in science and engineering involve a range of learned skills, habits of mind and subject matter. These elements are not taught or used separately. They work together to help students understand concepts and put them into practice. The purpose of engineering education in Doherty High School is for students to understand how to use these disciplines so that the students will value and participate in the intellectual program before entering a college.

The Massachusetts Department of Education describes science as human attempts to give good explanations of phenomena in nature. The result of scientific investigation is an understanding of natural processes. Scientific explanations are always subject to change as a result of the new evidence. Ideas with reasonable explanations have been established as theories or modified as laws of nature. Overall, the major criterion of science is clear, rational thought that is succinct about patterns of nature (DOE: http://www.doe.mass.edu)

However, according to the Department, engineering is much different from science. Engineering strives to design and manufacture useful devices or material, defined as technology. The microwave, microchip, and engine are examples of technology. Each of these emerges from scientific knowledge, imagination, diligence, talent, and luck of its practitioners. In spite of their different ends, science and engineering have become closely related in many fields. The instruments that scientists use, such as the microscope, balance, and chronometer, all result from engineering. In contrast, scientific ideas, such as laws of motion, the relationship between electricity and magnetism, and the atomic model have contributed to improvement of the internal combustion engine and nuclear power (Ibid.).

The Massachusetts Association of School Committees points out that high quality pre-engineering curricula simultaneously serve the goals of equity and excellence. *At the level of the pre-engineering curriculum, teachers should act on the belief that young students from every background can learn to solve rigorous science and engineering problems*. Teachers and administrators should advise students and parents about why it is important to take rigorous and advanced courses in engineering fields. (Massachusetts Association of School Committees, www.masc.mec.edu)

Assessment in the pre-engineering curriculum informs teachers about how to improve classroom practice, and report student progress. It provides students with information about how their knowledge and skills are developing and what can be done to improve them. It lets parents know how well their children are doing and what needs to be done to help them to do better. Multiple information gathering strategies can be used to provide a full picture of student progress. These include paper testing, performance testing, interviews and evidence of class participation to measure student observation to instruction. Diagnostic information gained from multiple assessments allows teachers to adjust their teaching skills to ensure maximum student achievement in the pre-engineering curriculum (Massachusetts Department of Education, www.doe.mass.edu).

Examples of Existing Pre-engineering Modules

Doherty Bridge Building Module

One module that we had access to was the bridge building module that Doherty used during the first term of the 2000-2001 school year and will also be used in the future. This module was an introductory mechanical engineering program on bridges. Contained within it are material lists, bridge history, explanations of types of bridges, day-by-day lesson plans, and project explanations for both teacher and student. The goal of this module is to improve students' math and social skills. It will also give them the opportunity to learn and apply abstract concepts like stress, fulcrums, the law of gravity, and the strength given by different geometric shapes. The key is that these concepts are not presented in an abstract form. Instead the students are allowed to experiment and get hands on experience with them. Another key to success in this project is the students' ability to actually apply the math they have been doing all their lives, as well as current math instruction, to a problem.

The project was developed to integrate skills learned in their other math and science classes. Social skills are improved by organizing the students work in teams of five which form a "construction company." This company must create task schedules and design and build the bridge together. The students were assessed on this project in two main areas: 1) The neatness of the finished bridge, cost of the bridge, and how the final bridge matches the original plans; 2) the amount of weight their bridge could hold for a thirty second period without breaking.

We feel that this project worked well with the goals we set up for the creation of our own modules. It made students apply their math and science skills, and added one more crucial factor….fun. It should kindle the thought of becoming an engineer in the minds of the students.

Yale-New Haven Flight Module

This module, created by Yale University contains an extensive report on the history of flight and the key events that led up to the Wright Brother's flight at Kitty Hawk as well as the mechanics of balloons and airfoils (Paul V. Cochrane, Yale-New Haven Teachers Institute, 1998, Flight (http://www.cis.yale.edu/ynhti/curriculum/units/1990/7/90.07.05.x.html)). Several third party project materials are mentioned and suggested, but their actual detail is not discussed. The main principles of flight and the mathematics, science, and physics behind it are touched upon, but not nearly in enough depth for what we want to create in our own modules. No explicit projects are proposed other than a vague guide for a helicopter model. At the end of the module there is a large bibliography and compilation of other readings, which helped us with the creation of our own module. These also aided us when we created our more in-depth modules. Overall this module is lacking for what we need to produce in each module. This module was designed well, but it was made for a different audience than ours. Even though it lacked in many of the areas we wanted to cover, except history, it still provided us with a guideline, which we used to build upon.

Yale-New Haven Paper Airplanes Module

Another sample module from Yale University focuses on the same method of teaching flight through the use of paper airplanes. This module is more relevant to what we are doing as it focuses much more on projects and the creative design process. Students are invited to build their own airplane models. Working with paper airplanes allows a student the opportunity to explore, design, redesign and even do independent study on flight.

Paper airplanes are a useful activity because they offer students the opportunity to step back from daily routines and pressure to enter the world of freedom of design. They could enjoy taking a piece of paper, folding it into whatever shape they desire, and flying their particular creation across the room. Paper is a cheap and easily attainable resource that the students can use to make their projects. Because of the availability of the material the module can stress the design process without having to waste a lot of school money on scrapped designs. This way the students can experiment freely and test their designs for multiple prototypes. (John P. Croty, Yale-New Haven Teachers Institute, 1998, Paper Airplanes (http://www.cis.yale.edu/ynhti/curriculum/units/1988/6/188.06.02.x.html))

Conclusions

The three existing modules don't go into nearly as much depth as our own project modules did; however they were quite valuable as a guide. These cases provided us with an outline structure that we adopted for our module template. Also the two sample modules on flight gave us some ideas for projects to give the students as well as a useful historical background on flight, which we adapted for use in our module on aerodynamics.

As a final guideline we received a syllabus template, from a Clark University graduate program, that will direct us in the creation of our modules. Unlike the sample modules stated above in the case studies, this document is an outline that highlights the main areas of a course syllabus and how to structure a class. What we learned from the outline was that it places strong emphasis on clearly stating the course goals and the materials that are covered. We took this into account when writing our own modules so that we clearly outline to the students what is expected of them to successfully complete this program. This outline helped us organize our work so that we could better state what is expected from the students, the faculty, and from us in the production and implementation of this module.

We see that while the cost of a new pre-engineering program may be considerable, so will be the benefits. The students will not only be better prepared for an engineering major when they attend college, but they will also be better citizens as a result of it. The program should help meet MCAS requirements for the school. There are various examples of similar programs which can guide us, but most important are the frameworks set by the state which we must follow. Using what we learned in this review, together with our own experiences as high school students and students in a university engineering program, we hope to have created relevant, effective and interesting project modules for Doherty High's students.

Chapter III: Methodology

Project Goal

Our goal for this project was to create three out of four modules that will be used in a pre-engineering project at Doherty High School to prepare students for college and a career in the field of engineering. These modules, (flight, robotics, and forces and motion) include projects, lab sessions, history, and background information designed to reinforce the material being taught in a lecture format. They provide students with hands on experience in their respective fields of engineering and make these high tech disciplines interesting to the students.

An important component of each module is the completion of several small projects over the course of a ten-week term. Concepts will be taught in sections. After a topic has been covered in lecture there will be a lab session where the students will have an activity to complete using the new knowledge they have acquired. This could be a project, lab activity, computer simulation, or a set of questions to answer. Let’s take an example from the flight module, wherein the students will learn about airfoils. After the lectures on airfoils, the students will work with a computer simulation of airfoils so that they can see how certain factors really affect the airfoil. Then they will physically construct their own airfoil out of balsa wood and paper and test it in a wind tunnel.

Procedures for Module Creation

1. Background and Material Research for Modules

The goal of most of the research we did was to identify the basic ideas and concepts that students need to learn for flight, forces and motion, and robotics since these are the areas of study that the three modules focus on. We also did further research into teaching methods and how to effectively plan an academic program for high school students. Our sources include examples of modules which other schools have used (specifically the ones used to teach the subjects of our modules), textbooks on flight, robotics, and force and motion, internet sources, reference texts, and materials on teaching methods and program design.

2. Preparing outlines for each module

We prepared an outline of the module syllabus (Appendix C) and project/lab instructions (Appendix D) from the example modules that we have. Each individual module and component was written to follow theses general outlines.

3. Costs and feasibility

At this point we had to meet with the Doherty advisors regarding the budget so that we could design the modules accordingly. We had to find the best projects for the students to do which fit within the financial constraints we were given. Also we needed to determine the protocol by which the Doherty students will be able to visit WPI and use certain facilities.

4. Designing coursework

We became familiar with the classes our students were taking in courses such as math, science, language and history in order to gauge the level of sophistication appropriate for our modules, and in order to make a connection between engineering and other studies. The modules are project based; most of their work will be done in the labs. The majority of the homework is lab report write-ups and so on. The homework is geared towards the creation of lab reports so the students will learn to properly express their findings in an organized scientific manner.

5. Organizing coursework

Once we obtained all the material, we needed to organize the way in which we presented the module so that it would be useful for the students but also so that it would be easy for any teacher to pick up, understand, and use in their own classroom.

6. Conforming to State Frameworks

One of the most important things we had to do as we designed these modules was to make sure that we were conforming to the state frameworks as well as making sure we were helping the students to pass the MCAS exams. As we went step by step through creating our modules we compared them to what we needed to have to follow the state requirements and adjusted our work as necessary.

7. Student assessment

In terms of student assessment we considered two items concerning meeting state requirements; first is how the modules are designed so that the state framework requirements are met and second how the module helps the students to pass the MCAS exam.

8. Writing the final project report

The majority of the report was done after completing the previous steps for each module. Each module consists of supply lists, timelines, purposes, objectives, a teacher package, and a resource package.

Chapter IV: Discussion

What worked and didn't work

Our original plan for the project was followed basically word for word. We ran into no major stumbling blocks. One small problem was finding projects and materials associated with the robotics module which were on a tenth grade high school level and did not involve using the Lego Mindstorm® kits. In each module there was a gigantic amount of material to plow through in order to single out concepts, more than we had suspected there would be. This wasn't really a stumbling block but did increase the amount of work greatly.

What would we recommend be done differently

We don't feel that there is much more we could have done in our situation. Without having written any sort of education material before this, we were limited in experience.

What future projects could we recommend

Future projects could easily stem from this one. Worcester Public Schools, and specifically Doherty High School, would like to extend the curriculum from the middle school all the way up to twelfth grade. Students could come just as we have to develop these modules for each grade.

Cost issues

Cost was one of the things that we expected would seriously control how the modules would be created. It turned out that we could be given no real budget to work within. We were allowed to use materials from the educational catalogs Doherty High had been using. Though Doherty purchased some useless equipment, that served no purpose and would most likely never be used, we were told that the Lego Mindstorm® kits we wanted to use would be too expensive. This put a great hindrance on the robotics module since there is very little material which can otherwise be used for projects for a tenth grade class.

Assessing the effectiveness of pre-engineering programs in creating a larger pool of engineers

Without setting up a large scale controlled experiment it is very difficult to tell the exact impact that a pre-engineering program has on increasing the number of engineers. We can guess from seeing the excitement a program like this generates in the students in individual classrooms that it does influence them to pursue a career in engineering. While no one can guarantee that the actual number of engineers will increase, we can guarantee that many more students will be exposed to the field than were before. This implies that there would minimally be a small increase.

State Frameworks Compliance

Shown below is a table from the 1999-2000 Massachusetts state frameworks for a technology/engineering course. The first two columns are directly quoted from the mass Department of Education website (www.doe.mass.edu). The third column lists which activities from our modules complete these objectives and how they accomplish this. It should be noted that the state of Massachusetts Department of Education groups their frameworks in terms of grade level. Shown below are the framework standards for grades 9 – 10.

Topic	Curriculum Framework Learning Standard	Module and Projects that emphasize these concepts
Nature of engineering and systems of technology	1. Develop an understanding of technology in terms of goals, inputs, process, output, feedback, and how it uses resources such as people, materials, tools, energy, information, finances, and time (the universal system model). Technology involves decisions related to advantages and disadvantages of process and products	The projects require the students to make design goals and requisition materials, then re-engineer their original design to test results and material availability.
	2. Observe, explore, and analyze the processes and systems used in construction as foundations are placed, superstructures are erected, and utilities are installed	Non-applicable to the course materials
	3. Use electronic and graphic media to explore and analyze telecommunication processes and systems, including source, encoder, transmitter, signal, channel, receiver, decoder, and destination.	Non-applicable to the course material
	4. Analyze a product to determine the need it was designed to meet and the customer(s) it was meant to attract.	Non-applicable to the course material
Engineering: invent, design, produce, use, manage, and assess	5. Invent a product to meet a need, or redesign a product to optimize its operation.	Airfoil construction, glider construction and air car activities all have a competitive element that requires students to optimize some quality of their project, like lift generated or max sped attained

	6. Use science, math, and engineering principles to design and optimize the product.	Scientific principals and mathematical calculations are required to create working prototypes in all of the many design/construction based projects (gliders, air cars, etc.)
	7. Produce (using tools and machines), use, and evaluate a prototype of the design solution.	Multiple projects require physical construction of the student's designs. These activities include flight sections airfoil and balloon creation activities, and the forces in motion air pressure car construction activity.
	8. Document the solution using scale orthographic drawing (with computer aided design, when available).	The use of CAD drawing systems is heavily recommended for many of the activities. Airfoil, glider, and air car activities all recommend using CAD to design the prototypes.
	9. Describe the economic, personal, and environmental impact of the designed product.	The background sections describe the social and environmental impacts of each project
	10. Prepare an engineering presentation and report on the finished product.	The fight modules glider construction activity, and the air powered car activity both require oral presentations to explain and defend their design choices.

This Table contains a set of frameworks for scientific inquiry that a module or curriculum should encourage in the students.

Topic	Curriculum Framework Learning Standard	
Inquiry	Pose questions and state hypotheses based on prior scientific experiences.	See Below for the description of how our modules conform to each of these standards.
	Use mathematics to analyze and to support findings and to model conclusions.	
	Question interpretations or conclusions for which there is insufficient supporting evidence, and recognize that any conclusion can be challenged by further evidence.	
	Model physical data using multiple representations.	
	Communicate and defend a scientific argument.	
	Formulate and revise scientific models.	

Scientific inquiry of the state frameworks compliance

Our modules work strongly with the concept of experimentation and hands on data collection. Several computer simulations are used throughout the program to assist in this; Range, EngineSim, FoilSim, and The Animated Blackboard all work to allow for a large amount of students to be working in an experimental setting for minimal cost. The computer simulations allow students to manipulate their "virtual lab" gathering data about the situation without the need for expensive lab equipment. The value of this is not only having cost effective labs but also works to provide the students with a tool for prototyping. The airfoil construction lab is where we used this most. First as a tool teaching and illustrating the concept of flight and then as a guide to maximize the lift generated by the students airfoils.

Laboratory exercises have been included into the course materials to encourage curiosity among the students. A practical in class demonstration/ mini-lab packet has been included in the flight module to illustrate the existence of invisible forces like air pressure and buoyancy with a visual display. The point of these demonstrations is to take a subject like lift and make it seem more "real" and less like a sequence of calculations.

Structured lab reports and oral presentations are required for multiple activities to encourage the students to be prepared to document and explain their design choices and back them up with hard evidence. These presentations also help to build the students public speaking abilities and also require them to organize their thoughts and effectively express their ideas to others. The importance of writing good quality lab reports is stressed so much to get the students ready to communicate their ideas on a professional scientific level. This also is to establish an educational link between English classes and their relevance to technology and engineering.

Our curriculums backbone is a strong foundation in math. More specifically the exercises in these modules targets skills like graphing data, graph analysis, unit conversion, algebraic formula manipulation, and vector mathematics. The intent of all this math is to ensure that students get enough practice with these skills to score well on the math portion of the MCAS as well as to provide a practical use for the math.

Chapter V: Conclusions

Our objective in this project was to create three modules, one for flight, one for robotics, and one for forces and motion. Through research and our own experience we designed the most appropriate modules we could. The level of sophistication had to be greatly toned down.

Flight and Forces and Motion were very easy to transform into a useable and easily accessible form for the students, robotics however is another story. When you think of robotics you think of robots, but robots as a whole are very complex, too complex for a small group of normal high school students to manage. Our robotics module therefore focuses on what could better be called the fundamentals of robotics. Subjects like gears, pulleys, levers, and electricity, which are the basis of any robot.

We do not necessarily feel that the order in which Doherty High is approaching the modules is the best. We feel that the forces and motion module should come first, the mechanical design second, flight third, and robotics fourth. Using Doherty High's current arrangement mechanical design, flight, robotics, then forces and motion, doesn't make sense. The forces and motion (basic Newtonian physics) module is the background material for the other modules, yet it comes last. This creates some redundancies in the material. If it was ordered in the way we suggest it would make much more sense to the students, and remove those redundancies. Nevertheless, not knowing whether the order will change or not, each module we created is completely independent of the others. This is done in such a way that any of the modules can be picked up by any teacher anywhere and be used without needing the others.

Reactions of the sponsors and students

The sponsors are very enthusiastic about the material we have produced, so much so that they started using an only partially complete flight module. From what we have seen from our interactions with the students they seem to love it. The ones we have talked to like the project-based class, instead of having lectures everyday. We can see the excitement which the project have created within the class.

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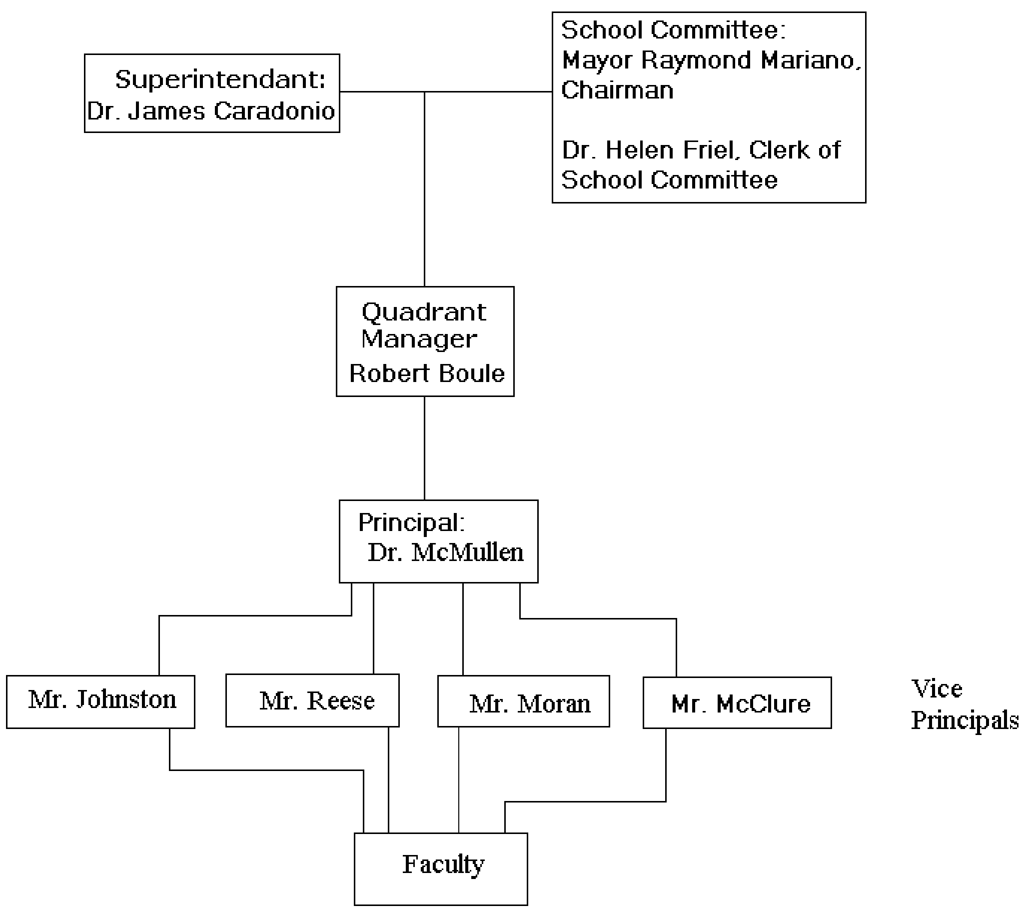
Appendix A: Worcester Public Schools

Appendix A: Worcester Public Schools

Our sponsor for this project is Worcester Public Schools, specifically Doherty High School.

The Worcester Public School System hierarchy:



Worcester Public Schools' mission statement:

"The Worcester Public Schools provides learners with a quality education in a safe and healthy environment. We believe that all students can achieve at high levels as they prepare to become productive citizens in our changing technological world. We are committed to supporting students, parents, educators, and citizens in their pursuit of learning."

Appendix B: Module Syllabus Template

Note: This template was created for our own personal use. Each module syllabus we designed followed this template to insure that they are all consistent.

Module Template

I. Course Description/Introduction

This module will concentrate on the area of robotics. Specifically, and most importantly, the areas of ________. Projects and labs will be the main methods by which the students will gain knowledge of concepts in robotics. Also to supplement the lectures there will be computer-related and other activities.

II. Course Goals

This module is designed to help each student gain knowledge of the basic concepts of robotics. Also to make this module relevant to the students' language, history, math, and science classes. Through the completion of projects, labs, computer aided and other activities, and lectures this goal will be reached.

III. Course Objectives/Learning Objectives

-
-
-
-
-
-

IV. Methods of Evaluation

- Attendance and class participation
- Projects/Labs
- Assignments
- Exams

V. Required Supplies

VI. Course Schedule

Week 1 –

Concepts:

1.

Assignments:

1.

Week 2 -

Concepts:

1.

Assignments:

1.

Week 3 -

Concepts:

1.

Assignments:

1.

Week 4 -

Concepts:

1.

Assignments:

1.

Appendix B: Module Syllabus Template

Week 5 -

Concepts:

1.

Assignments:

1.

Week 6 –

Concepts:

1.

Assignments:

1.

Week 7 –

Concepts:

1.

Assignments:

1.

Week 8 –

Concepts:

1.

Assignments:

1.

Week 9 –

Concepts:

1.

Assignments:

1.

Week 10 –

Concepts:

1.

Assignments:

1.

Appendix C: Project/Lab Instructions Template

Appendix C: Project/Lab Instructions Template

Note: This template was created for our own personal use. Each project/lab we designed followed this template to insure that they are all consistent.

Project Lab Title

Purpose:

Explains the main concepts to be learned from the project/lab.

Materials:

Lists the materials need to complete the lab

Safety:

Lists any safety precautions needed for the project/lab.

Procedures:

Explains in detail the steps necessary to complete the lab.

Notes: any extra things the teacher should be aware of.

Appendix D: Compact Disc

Appendix D: Compact Disc

This Compact Disc contains our report, the flight module, the forces and motion module, the robotics module, and all the software which is used in the modules. This includes FoilSim, EngineSim, Range, and Animated Chalkboard 2000. All this software is public domain, and therefore can be used freely.

Appendix D: Compact Disc