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Crafting a Successful High School Engineering Program

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Marie is an alternate route teacher with an educational background in math, physics, chemical engineering and computer science. As the first girl in her family to go to college, and maybe to prove the point, she earned two bachelor's degrees, one from Montclair State University by day, and 8 years later, one from New Jersey Institute of Technology, by night, while working full time by day at Exxon Research and Engineering. While a traditional female career, like teaching, was the last thing on her mind, she was drawn to educational outreach because she herself had received so little career advice. She eventually ran the educational outreach program at Exxon. After 25 years, 20 at Exxon and 5 in the high tech industry, an unexpected layoff came at a bad time, she was also newly widowed. Job offers that were once plentiful were nowhere to be found. The first, and only, offer to finally appear was to teach physical science at Bayonne High School, for a significant pay cut. A new adventure began. In the ten years since then, she got to start up a research program, an engineering program, a science club, two FIRST Tech Challenge robotics teams, and brought in several new programs such as Technology Students Association, Young Science Achievers, and ACS Project SEED. She's been invited back do pharmaceutical engineering research with Research Experience for Teachers at NJIT every summer for the last 8 years now, with her Project SEED students. In 2008 one of her research students became a Science Talent Search Finalist. He also won best in category awards at the Intel International Science and Engineering Fair two years in a row. In 2010 she was named a Society for Science and the Public Teacher Fellow, and served on the Advisory Council for Intel ISEF since 2012. Marie currently teaches three levels of engineering courses, that she designed, and coaches students doing science research projects for competitions.

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Crafting a Successful High School Engineering Program

Abstract

The Next Generation Science Standards incorporate engineering in many topics because the engineering design method parallels scientific method. Like science, engineering also requires critical thinking and curiosity, with a variety of subjects, or disciplines as they are known, which often overlap. While engineering depends on the principles established by science, it has however, its own identity and thought process, which might explain why pre-college engineering programs are still relatively new. To teach engineering from its point of view requires new content and a new teaching method. The product of the engineering design is technology, so hands on and practical applications are required, along with methods of documentation. Teachers also need a new relationship with students. To teach creative problem solving and productive troubleshooting students must learn not to fear failure, instead they must learn to value what it can reveal and exploit it. To make this happen the teacher must relinquish some control in order to enable to students to own the process.

This paper documents the story of a successful homegrown three year pre-engineering program after six years. The course that began the program, and is still its mainstay, is a fundamentals course titled Intro to Engineering. It is primarily designed for 11th and 12th grade students and can stand alone as preparation for a college engineering program. The course includes: the engineering design method, systems engineering, creative problem solving, reverse engineering, team building exercises, and an overview of the engineering disciplines and applications. Each topic includes introductory notes, a glossary of terms and vocabulary quiz, problem sets, at least one project, and documentation. Since a textbook is not used, students are expected to build a reference binder for notes, handouts, and assignments, and maintain an engineering notebook for their small projects. In the second year engineering class, students select their own projects and build a personal portfolio. Lightly structured, the Engineering class comes with a FIRST Tech Challenge robotics team, a chapter of the Technology Students Association, and access to local programs and competitions. Some students enter the course with a portfolio in hand. The teacher serves as resource and mentor, as the students present weekly plans and progress for a grade. This year a third course is being piloted called Engineering Technology. Designed primarily for 9th grade students, the course focuses on engineering design, project management and hands on technical skills, which allows them to advance to the Intro to Engineering course with a richer preparation. Evaluation will include the effectiveness of the course, the program's impact on the students, and an assessment of the student work.

Introduction

The quest to design a new engineering program, deciding where to start, establishing the running themes for a whole new course, or set of courses, and planning the design and content in a format that can grow, can be a major challenge for classroom teachers, even those with engineering degrees and industrial experience prior to entering the teaching profession. This paper documents the formation of Intro to Engineering, a fundamentals course for students considering a college major in engineering, architecture, or computer science, and how it grew in richness to become the anchor course supporting a larger high school level engineering program.

Implementing an engineering program can follow one of two pathways: utilizing an available program, or developing your own program. There are two well-known high school programs available, Project Lead the Way, PLTW [1], and the Infinity Project [2]. However both programs are expensive and neither allows any flexibility to the teachers. Furthermore, there is a lack of program outcomes assessments for Project Infinity, while reports on PLTW have shown existing issues. For instance, a curriculum content analysis concluded that the PLTW curriculum addressed fewer content standards and showed far fewer points of integration of mathematical knowledge than would be expected [3]. Further, other published empirical studies showed mixed results from state achievement test scores [4]. In addition, neither of these two programs are aligned with the current standards. What had been considered alignment was merely a referencing of standards [5]

Reports of "home grown" engineering programs have been reported in the literature (the alternative pathway) [6-10]. Primary reasons for implementation of in-house programs are the desire to meet the perceived needs of the school, teachers, and students, and the cost for the implementation of the available programs. These are also the reasons for the implementation of the program described in this paper.

This paper is divided into five parts that document the formation, execution and expansion of this program around the mainstay course, Intro the Engineering.

- Part 1 describes how the program came into existence, including the research and planning that was required to prepare it for students.
- Part 2 focuses on the students' experience, reflecting on how engineering is included in the Next Generation Science Standards.
- Part 3 discusses forms of assessment required when students do open ended creative work, and the new relationship the teacher must have with the students.
- Part 4 describes the next step, the many possibilities in the Engineering course, for students who successfully finish Intro to Engineering.
- Part 5 describes the next frontier for this program, a preparation for younger students prior to Intro to Engineering.

The story this program tells, like engineering itself, is very dynamic, so elements from all five sections are subject to continuous improvement.

Part 1 The design of a new program

How does a high school science teacher set up an Engineering Academy program from scratch? That was the challenge about eight years ago, for four chemistry and physics teachers with industrial and engineering experience who were gathered in the science office one morning for a brainstorming session. We couldn't just buy a program "off the shelf", the school system did not have the resources at the time, and the timeline for startup was the next school year. At the time, a traditional engineering program may have started with drawing, or maybe CAD if there were computer resources. Our thought that morning however, was of engineering as an applied science, and taught in the format of a traditional science class. It was also felt however, that this was going to be something completely new to our school. In hindsight, the treatment given to engineering in the Next Generation Science Standards [13] validated this decision. The first version of the sample syllabus, included as Attachment 1, was drafted that morning.

Our first goal was to define a concept for a new course, dubbed simply "Intro to Engineering", consisting of fundamentals and small hands-on projects as a "lab" equivalent. It had to include engineering principles as theory, practical problems requiring math skills, mostly algebra, hands-on projects, technical vocabulary, and documentation. The plan suggested that a second year course for longer more sophisticated projects could follow. At the time the school also supported a free form science research class for students who wished to do competitive research projects, so this model could be used for the second year engineering class if the students were properly prepared.

Brainstorming over, a lead teacher was chosen and the work of bringing the program to life in the next school year began. The first step required establishing a high level theme for the program and a definition of engineering. A very comprehensive, and concise definition comes from ABET, the Accreditation Board for Engineering and Technology. Engineering is defined as "The profession in which knowledge of the mathematical and natural sciences, gained by study, experience, and practice, is applied with judgment to develop ways to use, economically, the materials and forces of nature for the benefit of mankind." In one sentence this definition manages to cover theory, practice, practical constraints, ethics, and the impact on society, all high level themes that could be run as a thread through the engineering topics in the new course. The NAEP TEL, an early source of content for the course, divides engineering and technology literacy into three areas "Technology and Society", "Design and Systems", and "Information and Communications Technology". The main engineering design theme for Intro to Engineering comes from the ideas in the "Design and Systems" section and its definition of technology, the product of the engineering design method, as "any modification of the natural world done to fulfill human needs or desires" [14]. The definitions and steps for the engineering design method came from several sources, but in particular the NAEP TEL [14], and the FIRST [18] robotics programs. The main source of material for systems engineering came from the Center of Innovation in Engineering and Science Education, CIESE, program [15] at Stevens Institute, where every object and process could be seen as a system with a specific input, process, output and feedback scheme. It also defines concepts such as system boundaries and lifecycles. Another source, *Technology: Engineering and Design*, [16] defines large processes and industries as systems by defining roles for: people information, tools/machines, materials, energy, time, and capital, through any system. This approach shows students how to think in terms of systems when examining anything from the simplest device to a large industry. Together the concepts of engineering design and systems form the overarching theme for the program of engineering courses.

With the overarching themes in place, each content topic was built using the same format with a focus on three elements: engineering thought, math and technology, and literacy with writing. Each topic format included a set of notes, a glossary of terms, problem sets requiring math, hands on projects, and documentation in the form of reports and an engineering notebook.

Sources for topics and "topic flow" included the *Engineering Your Future: A Project-based Introduction to Engineering* [11] developed by several partners including the Boston Museum of Science, Project Lead the Way, PLTW [1] for their ideas on engineering design, and easily adaptable lessons came from *Try Engineering* [17] and *DiscoverE* [21]. The CIESE [15] program also supplied lessons on reverse engineering and engineering entrepreneurship. Historical notes and special topics came from the PBS NOVA series. Lastly the "big picture of Engineering in society" can be completed with the National Academy of Engineering's "Grand Challenges" of Engineering, [22] and the many professional, outreach, and awards programs found on the "Dedicated Engineers" portal [20]. Another problem at the start of the program was the lack of an adequate textbook, aside from the fact that the resources to buy it were lacking if it did exist. In 2012 a good pre-engineering text was published, *Pre-engineering* [12], but by then a system had already been developed where students built their own reference binder. The book did serve as a reference to confirm practices that were already being done. In the end the lack of one textbook freed the program to use many textbooks. While these are the major sources used for content in the formation of this course, it is almost impossible to cite every source that has been used over the years to enrich the courses in this program within the context of this article. New sources are added every year, for example, a short lesson on the patent process that was included early on using material from the USPTO website [24], was updated this year with content from their new outreach program for young inventors, USPTO Kids. One program, the Research Experience for Teachers, RET, at New Jersey Institute of Technology, NJIT, added not just content, in the form of new lessons, but enrichment in the form of relationships with engineering, architecture, computer science and technology at the university level.

Part 2: Execution: How to get inside students' heads, teach critical thinking for engineering, form a new relationship, and create an "engineering thread" in the spirit of Next Generation Science

Textbooks and curricula for traditional science courses, biology, chemistry, and physics, all start with the same fundamentals, habits of the mind, scientific thought and scientific method. The lessons that follow are usually basic skills such as units and measurement, and perhaps some basic lab skills, and use of a lab notebook. After this a typical science course would start with basic ideas for that area, for example, chemistry would start with properties of matter, and scaffold new topics on this foundation. Attachment 1 gives the syllabus of topics for Intro to Engineering, and follows a plan not unlike a typical science course. Although the format is similar, this is where engineering establishes its own identity. The natural equivalent for scientific method is engineering design method, which can be used in its entirety in every project. While science tends use the SI unit system exclusively, students of engineering must learn to be "multilingual" in units systems, with an even stronger focus on the meaning of units and conversion between systems. Students in this course are often taught to find answers based on the expected units.

When taught as a science, engineering is special because the focus is on critical thinking, not just in the evaluation of scientific ideas, but especially in the practical reality of application. One exercise, used in the first days of school, is a game called "What's wrong with this picture". It's a set of simple word problems, the speed of a student running around a football field, the volume of a piece of wood, the mass of bird landing on birdfeeder, and the final temperature of a bag of vegetables put in a freezer. The math is simple enough for students to do in their heads. Sharper students are doing it while the problem is read. Each problem however, has something not quite right. The speed of the running student, in meters per second, is impossibly fast, the piece of wood is the size of a redwood, the bird on the feeder is the size of a turkey, and the final temperature of the bag of vegetables is below absolute zero. Students usually don't notice the problem with the answers until they are told to think twice. While science teachers must focus on getting the concepts right and have to be careful not to throw students a curve till they have achieved a certain mastery of the material, engineering has the luxury of pushing them out of the comfort zone right away. Students are told from the start to think twice, what they do now in engineering must be real.

The hands-on projects for engineering are a necessity, but more than the typical science lab with partners, students must learn to work as a team, learning to brainstorm, critique ideas together, divide tasks and coordinate projects. The first projects must teach the process as well as the engineering concepts. In one project students are given lists of open-ended challenges and asked to brainstorm and prioritize a list of things they need to know about each problem scenario *before* they propose a solution. The Next Generation Science Standard *MS-ETS-1,*[13] *Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions,* places this at middle school level, however if high school students have not had this experience this is the place to start. They must learn to frame the problem, understand the meaning of constraints, and get the "trial and error" process right before they jump to the answer. Some students however, just need to have something in their hands before they can visualize a solution to a problem, and can only design and document after the fact. In the experience of teaching this class, each new group can be starting in a different place. In this process, the teacher needs to build a new relationship with students, which also involves some trial and error, where he/she can assess the students' starting point and begin to turn over more ownership of the work to students. This enables students and makes up for missing experiences of critical thinking in their past. Students also must learn that the "engineering view" of their projects must cover all the details of a real project.

In their next engineering design project student teams play the role of engineering contractors submitting bids for a design for a new public park. They are told that an old building was removed leaving an empty city block that had recently been approved for a public park after a "brownfields" clean up operation. Its location lends itself to be a gathering public place for employees on lunch and family groups on weekends. They are given the dimensions and condition of the park and told that the city will place a perimeter sidewalk, lighting and a public restroom, which they must incorporate in the design. They are provided a list of items, such as concrete, playground equipment, sod, benches and tables, flowers and trees, with prices and time requirements for the installation of each. Students must prepare a scaled drawing of their design, a timeline for construction in the form of a Gantt Chart, and a cost estimate with both a total cost and cost per square meter. Students learn to put the plan in a logical order, for example, giving time for concrete to dry, and installing fragile flowerbeds last. Students also understand that their price per square meter must come in somewhere between the cheapest option, covering the whole space with grass, and the most expensive, covering it with concrete, but they are not told this upfront. If this fact does not occur to them naturally the teacher can guide them to it during their discovery process. This project raises students to the high school level, aligning with Next Generation Science Standard [13] HS-ETS1-3 *Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.* To keep students on task the teacher must circulate constantly from group to group encouraging and enabling to keep students from becoming overwhelmed or losing focus. When finished, students are often very proud of their designs and remember them years later. One student even wrote about his design for the park project in a college essay.

Continuing in the spirit of teaching engineering as applied science, the balance of Intro to Engineering gets its content from special topics that science teachers may not have time to cover, but can still be aligned with Next Generation Science Standards [13], in particular PS2 Motion and stability, PS3 Energy, and PS4 Waves. In mechanical/structural engineering students examine types of structures, machines and gears, and robotics. In chemical engineering, students explore industries such as food science, oil refineries, and pharmaceuticals, and do elementary mass and energy balances that are more application based than what they do in chemistry. In electrical engineering they learn about the history of electrification as one of the National Academy of Engineering's great accomplishments of the 20th century [22], get the basics on ohm's law, circuits and motor designs that they might not get in physics. The special topics include solar energy, and hydrogen cells used in hybrid automobiles. The last special topic is acoustics. Its project is a big favorite, students must design and build a playable musical instrument and write a user guide to play it. In the final exam project students must prepare a ten minute PowerPoint presentation based on an episode of the Science Channel's "How It's Made". They must describe the process in terms of engineering design and systems, highlight a patented or trade secret item in the process, point out "best practice" such as recycling and employee safety, describe the economics of the process, and give an entrepreneurial evaluation as if they owned the factory. This last exercise gives them a chance to weave the whole learning experience of the year into one project.

Students who successfully finish this course and are not graduating are eligible to take the next level class, Engineering. In this class students are given the freedom to build their own portfolio of projects, at least one of which, should be competitive. Many of them have already been prepared for this by being recruited by members of the current Engineering class for projects such as Technology Student Association [19] TEAMS and state conference, and extracurricular robotics. The more motivated ones create their plans for Engineering as they finish Intro to Engineering.

Part 3 Taking Stock: A plan for evaluation and continuous improvement

When students do open ended creative projects, small or large, designing a fair grading guide can be a challenge. Do you give more credit the "keep it simple stupid" design that's done quickly and always works, or the "all the bells and whistles" model that took a little longer and may be a little less reliable? Students have exercised engineering thought with both outcomes, and which path they take usually comes from their learning style. When giving the assignment the teacher must make the required outcomes very specific, even telling students what will get them an A, B or a C, but without giving away too much of the discovery process.

A sample rubric for grading these projects would be

- A: The students achieved the goal of the assignment, on time, used engineering design properly, and documented results as required.

- B: The project goals are "almost" there, or achieved perhaps more by accident than skill, and the documentation is good, but could be a little more complete, or just neater and more organized.
- C: The project is not quite complete or functional, but at least one part is viable, and with a little more time or work students could have achieved the goal.
- Failure: The project work plan is not viable, or the students gave up.

When creating this grading rubric, the easiest level to define is the "A". Defining the level of work for the "B", "C", and failure, is much harder. The teacher must examine where the students came up short. Did they run out of time? Did they lose focus or motivation? Did they not understand the constraints? Are they lacking some related skills, maybe in math or use of tools? If they failed to achieve the goal, why did the miss the point, or just give up? This is where the teacher must have a new relationship with the students. While playing the desired role of "Guide on the Side" the teacher must find a way to tune into each group's thought process, encouraging good ideas, discouraging plans that miss the point, and especially, showing students how to analyze a failure, all without judgment.

Using the Next Generation Science Standard [13] HS-ETS-2 and its middle school equivalent, students can be taught break the challenge down into smaller achievable goals, and be encouraged by each piece that they get to work. It minimizes failure on the low end and helps the high-end students as well. Those students who get to a working solution as quickly as they can are encouraged to build on their success and add a level of complexity. The students who must have an elaborate solution to every challenge will learn to get each part working as they go, to achieve a more robust solution and to improve their skills in analysis when troubleshooting the parts that don't work as planned. The teacher can even build a "reflection" at the end of a project where students can give feedback. In the second year class this is done regularly. Some students will always complain when confronted with something that pushed them into an uncomfortable place. They will beg for more guidance when they are not told exactly what to do in each step. Success, however, comes when they start to enjoy the challenge.

To keep the curriculum dynamic, a few new projects are added to Intro to Engineering each year, and existing ones are examined for effectiveness. Instructions are tweaked and updated, based on student results and student feedback. When the teacher strives to form the new relationship with students, the students themselves often give good feedback on what would make their learning experience better, and even offer suggestions to make it more challenging. The park project, which has become a favorite, has gone through some changes over the years based on student feedback, for example a previous year's version only allowed students to include playground equipment, but not a basketball court, or a fountain. Students asked for more of a palette of options. Students also asked for a grade on each part, so now they get three grades, one for their design, one for their Gantt chart schedule, and one for their cost estimate. Over the years some projects have been dropped for various reasons, for example, sometimes a better version replaces them, or a replacement is found for a kit that may fail easily. It took a few tries before a reliable electric motor kit was found. The current lesson on reverse engineering requires students to disassemble one-use cameras and compare the internal workings of different brands. This lesson will likely be replaced in a future class because the technology is getting old and may not be available. Also, with cell phone cameras, students are not as familiar with film cameras as in past years.

Problem sets are also examined. All good engineering problems are word problems, which can be the bane of any student who is weak in math. Each set must teach a particular concept, so that students can use them as references for projects. Each topic is examined for balance and completeness. For example, are there enough gear ratio problems so that students can understand how to build a gearbox for maximum torque with Lego gears? When the first set of material balance problems in chemical engineering were introduced they seemed impossibly hard. Though they were taken from college level textbooks, they required only algebra. Even good students, however, were throwing up their hands in frustration. When a simpler set was added first, based on kitchen recipes and mixing paints for colors, students got the thought process and came through the harder set with much greater ease.

Lastly, the engineering notebook is graded. Students are asked to keep a bound notebook, not spiral, to be authentic. Real engineering notebooks are a bit costly, but plain bound composition books can be found in the dollar store. Students can learn to set up these blank notebooks like a real notebook, with a table of contents, dates and page numbers. Initially, more attention is paid to format, and as the year goes by, content is considered. Since school policy counts lab work as only 20-30% of the students' grade, and the notebook is meant as a journal, they are graded by simple inspection for format and completeness.

The overall school grading policy for a science class calls for 70% of the grade to come from tests and quizzes, and 30% from classwork, labs and homework. Because of the unique mixture of assignments the only traditional quiz is for technical vocabulary, and is of course closed book. Key problem sets and large projects that require multiple days are counted as tests because even if students are absent for illness or field trips the work can be made up. Short one-day challenges and the engineering notebook count as lab and classwork. If a student is absent for a longer time, short challenges can be discounted from their grade, and in some cases substitute assignments for projects can be given. This is the case for the occasional student placed on home instruction due to a long illness.

The school district requires a test at the end of each quarter. To test the material properly the exams for engineering are open book, because the focus must be on understanding not memorization. In the first quarter students do a short design proposal in essay form to test their comprehension of engineering design and systems. The next two quarter tests are problem sets with some open ended questions, and the last one is their presentation. Students in Engineering follow the same format, and it is being tried in the new Engineering Technology class this year. Very few students fail Intro to Engineering. Students are told at the beginning of the year that two things are difficult, failing and getting an A. Every assignment must be done well for an A, but few students fail because the format of the class allows for a lot of teacher intervention when a student is having trouble. The few that do fail do so by simply not doing the work.

The ultimate measure of success for Intro to Engineering is that most of the students who finish it are well prepared for technical programs, in either engineering, architecture or computer science in colleges. The majority of students go on to engineering and technical programs. Intro to Engineering has benefited students across the academic spectrum too, including students preparing for technical trade schools, and a few special needs students.

The one challenge it still must overcome is the gender ratio. Even though the engineering teacher is female, only one in ten students in each class is female. Addressing this issue would require another paper, however, the new Engineering Technology class, addressed in the last section of this paper, which is meant to prepare 9th graders for Intro to Engineering, is over 40% female. While it is too soon to say, one of the goals of this this early course will to see if can narrow the gender gap for this program.

Another option for students who finish Intro to Engineering, and can manage their own work, but are not graduating, is the second year Engineering class discussed in the next section.

Part 4 The next step – a second year student driven Engineering class

The second year Engineering class was envisioned from the very start, but had a quiet beginning almost as an experiment. Four students from the first Intro to Engineering class launched the first Engineering class by forming FIRST [18] Tech Challenge, FTC, team 3774. We received a corporate grant that funded not only the fees to register the team and buy their tools and supplies, but also four new laptops because there was nothing at the school capable of running the required software. The team was led by a girl, one of two in the first offering of Intro to Engineering. She was encouraged to apply to the NJ Governors School for Engineering, though she was considered a long shot she was accepted and thrived. Her experience gave her the confidence to lead the group, which did not even have their own class period, but were contained inside one of the Intro to Engineering classes. The team also began the tradition of recruiting help from members of Intro to Engineering. Their existence inspired students in Intro to Engineering to begin planning projects for their own turn in Engineering. At the time a study was being done to raise the roadbed of the Bayonne Bridge, a landmark that is a city heritage. Two students approached me about doing "mock bids" for the raising of the bridge roadbed as one of their projects in the coming year. This was the beginning of the special dynamic that would characterize the Engineering class. The projects would be competitive and award winning, and the students would run the class, with the teacher acting as mentor and guide. Attachment 2 shows the student requirements and pacing guide for the Engineering Class.

In its second year the Engineering class established its identity with 18 students doing a very rich diversity of projects. The FTC robotics team finished their season by founding a second extracurricular "feeder" team, FTC 4890, where they could mentor younger students in robotics and create a "farm team" for Engineering. Students in Engineering submitted projects to the Hudson County Science Fair, an Intel ISEF affiliated fair, the Northern NJ Junior Science and Humanities Symposium, the Young Science Achievers Program, the Panasonic Creative Design Challenge and the Technology Student Association Conference, TSA, bringing home an impressive collection of trophies and awards. The two students who prepared the mock bids for the Bayonne Bridge project were honored by the Port Authority of New York and New Jersey. One student won a bronze medal at the Hudson County Science Fair for his design. They began the tradition of leaving a legacy project for future engineering classes, and doing presentations and demonstrations of their projects for faculty and students at the end of the year. The mix of projects is different each year. While mainstays have been the FIRST Tech Challenge team and TSA [19] student chapter projects, which run the gamut from fashion to Vex robotics, students have also added a number of independently designed projects, from a working skateboard "hover board" to a working remote control drone that could take movies. One girl figured out how much piezoelectric energy she could generate from the school's drum line team, and designed a device to harness it. Another student prepared a lesson and demo of amateur rocketry that included all the physics and calculus classes in the school. Some students manage to get summer internships for engineering and continued their projects from the summer. Two students had internships with NASA doing robotics and continued that work as a class project. While their numbers have been few, almost every one of the girls in Engineering has distinguished themselves by winning awards.

Clearly, this course is not meant for the timid. Students must have the ability to run their own projects. A student might be capable of getting an A in Intro to Engineering, but lack the creativity or motivation for Engineering. At the same time there are some B level students in Intro to Engineering who excel in projects, and come into their own zone in Engineering. Students in Engineering are graded on the quality and quantity of work in their chosen portfolio of projects, and how well they meet their own goals. They must regularly report to the teacher, as a mentor, in whatever form is suitable for their projects. This can be an engineering notebook, a team progress report or weekly schedule, or a work binder. The teacher can then shop for the students' supplies, help them troubleshoot problems, set them up in competitions, and find any number of outside resources. At least one project must be competitive, and they must own their work. While they can certainly help each other, and must if they are on a team, they can't just be helping another project as their main goal. The grading policy for this class is slanted to doing more. If a student meets all his or her goals with a good competitive project the grade is 85. If a student is ahead of schedule, a team leader or key contributor, helps other projects or has multiple projects and/or wins awards, the grade rises. If a student is behind schedule, not keeping up with a team, or not fully responsible for his or her work, the grade starts to drop. If students can't work without being told what to do by a team member or the teacher, on a regular basis, they can barely pass. Care is taken to advise students not to take this class if they can't live up to this responsibility. For those who can it is a wonderful experience.

Part 5 Future plans: A class for younger students and beyond

Up to now the Engineering Academy program has been exclusively for 11th and 12th grade students. In the last two years however, a few accelerated 10th graders have been admitted to Intro to Engineering. While the impact of their presence in the long term remains to be seen, they have been successful in opening up Intro to Engineering to qualified 10th graders, and two juniors are now in the Engineering class, which up to now has commonly been called "senior engineering". Their case will be discussed later in this section.

This year a new 9th grade class was introduced called Engineering Technology. It came about for several reasons. First a new academic STEM track program was introduced for incoming students, and next year a Physics First track will be introduced. Both programs call for an engineering seminar class. It also answers a need seen in the Intro to Engineering class for students to have a little prior exposure to technology skills, engineering design, and project planning. As mentioned in the second section of this paper some students must start learning engineering design skills that are at the middle school level according the Next Generation Science Standards [13], simply because they have never been exposed to them. Students in Engineering Technology learn technical project skills and engineering design through a number of small projects and challenges from many sources including *DiscoverE* [21], *Design Squad* [23] and teacher designed challenges. In the process they will learn tool skills, such as the use of a soldering iron, power tools, a multimeter, probeware and possibly, 3D printing. They can also be recruited by Engineering for TSA[19] projects, and are invited to join the extracurricular FTC robotics team 4890.

The class is designed to give students an experience of engineering design with an emphasis on hands on projects. The grading scheme is even reversed. Instead of 70% on tests, and 30% classwork and homework as it is with a typical science class, classwork and homework is counted as 80% and tests 20%. At the end of this year this class will be examined for its successes and shortcomings to prepare it for another group of students next year. Attachment 3 shows the proposed content plan for this course that was prepared at the beginning of the year. It has already evolved based on the students' experiences this year. This is expected because this is a pilot program. So far, the first class has a lively dynamic, almost to where it resembles the Engineering class, but simpler. The students understand that we are piloting this class and so we have a dialogue established to include learning experiences for them that will make it work.

If this class succeeds there will come a day when 10^{th} graders entering the Intro to Engineering class are not an exception. This would also allow a student to finish the Engineering class as a junior. What's next? The plan for this is already in the works, and one student has been selected to pilot an independent study for his senior year, perhaps with college credit.

This program has been very popular at our school and continues to grow. There are several possible next steps that can be added in time. Recently a grant allowed us to buy a bank of 30 laptops loaded with engineering software including 3D modeling. This is the first new computer hardware purchase for engineering since the four laptops were bought for the start up of the FIRST Tech Challenge robotics team. The roll out is still work in progress, but will make a big impact as more students get to use them. Last year a 3D printer was purchased. Its use has been limited to the Engineering class due to the lack of laptops with the required software, but this too is about to change with no shortage of students looking forward to it. To paraphrase an old billboard under construction, for future developments "watch this space".

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Attachment 1

Intro to Engineering - Sample Syllabus

Each topic has a set of notes, vocabulary, a problem set and/or project and a writing assignment

First quarter: Fundamentals of Engineering
Orientation and review – Physical Science, vocabulary and writing

How to think like an Engineer - Engineering Design Process

- Creative Problem Solving / mathematical modeling
- Project management / cost engineering
- Systems Engineering
- Reverse engineering
- Entrepreneurship and patent law
- Engineering societies and careers
- Engineering “games”
  District Assessment: open book essay – Engineering design proposal

Second Quarter: Engineering Disciplines

- Chemical Engineering and thermodynamics
- Heat transfer and fluids
- Mechanical and Structural engineering
- TEAMS competition preparation
- Engineering “games”
  District Assessment: open book - Problem set

Third Quarter: Engineering Disciplines

- Computer Engineering and simulation
- Electrical Engineering, DC circuits, radio, electric motors
- TEAMS competition preparation – 2015 theme: The Power of Engineering - Energy
- Engineering “games”
  District Assessment: open book problem set

Fourth Quarter: Engineering Disciplines

- Special Topics: Solar Energy/Technology Student Association
- Acoustical Engineering
- Final projects
  District Assessment: Final project presentations

Attachment 2

Engineering – Pacing and Project Guide 2014-15

Students in Engineering will apply skills learned in Intro Engineering to longer term engineering projects. They will select at least 2-3 major projects for the year. At least one project must be competitive. Each student must leave a "legacy" project.

The projects and competitive events available to Engineering are:

- FIRST Tech Challenge team 3774
- Panasonic Creative Design Challenge
- Technology Student Association, TSA
- TEAMS (TSA)
- Young Science Achievers – team and solo projects
- Other competitions such as Commander of the Hill, Toshiba Exploravision, West Point Bridge Project, Women in Technology, etc.
- Student initiatives and continuation of summer projects

Marking Period 1 – plan and requirements – 45 days – 9 weeks

Week 1 and 2 – select projects, plan schedules and reporting process
Weeks 3-9 – Students meet goals for projects, for example:
-TSA chapter formation, projects selected and timelines planned
-FTC team selection and plan for robot build, documentation and competition
-Panasonic Team and other small projects form schedules and reporting plans
-Solo projects plan for competitions with schedules and documentation

District Assessment: Report on project progress - 1 day

Marking period 2 – competitions and project reviews – 45 days

District Assessment: Report on project progress – 1 day

Marking period 3 – competitions and project reviews – 45 days

District Assessment: Engineering knowledge test – 1 day

Marking period 4 – competitions, “legacy” projects, final presentations - 45 days

District Assessment: Project presentation – 1 day

Attachment 3 - Proposed Curriculum Plan for Engineering Technology

This is the pilot offering of a course designed for students to build skills for technical projects. It includes a series of large and small projects, in teams and as individuals. Each student will select one long-term project suitable for competition. (Science Fairs etc.)

Requirement: a bound Engineering Notebook for projects that stays in the classroom.

First quarter: Fundamentals of Engineering Design and Technology
Honor code and Safety contracts, Grading policy and expectations, Course requirements

- Engineering design and problem solving
- Measurement and documentation
- Creative Problem Solving
- Working with constraints
- Reverse engineering
- Entrepreneurship and patent law
- Engineering careers
- Engineering "games"
  District Assessment: open book essay - problem solving challenge

Second Quarter: Engineering Technology Skills (Electrical and Mechanical)

- Small Circuits and motors
- Using Mechanical energy
- Machines
- Maglev devices
- Engineering "games"
  District Assessment: open book - Problem set

Third Quarter: Robotics

- Design Projects - robotic arms/hands
- Programming and use of sensors
- Engineering "games"
  District Assessment: open book Problem set

Fourth Quarter: Special topics

- Computer modeling - 3D design/3D printing
- Use of probes/science tech equipment
- Engineering "games"
  District Assessment: Final project presentations