AC 2007-2607: FIRST VEX CHALLENGE: A TOOL FOR DEVELOPING AN UNDERSTANDING OF THE ENGINEERING DESIGN PROCESS

Daniel Sullivan, The College of New Jersey

Stephen O'Brien, The College of New Jersey

FIRST Vex Challenge:
A Tool for Developing an Understanding of the Engineering Design Process

Introduction

The FIRST organization has been successful in its efforts to promote interest in math, science and engineering through its various robotics competitions – the FIRST Robotics Competition (FRC) , the FIRST Lego League (FLL) and most recently the FIRST Vex Challenge (FVC).[1] The FIRST Vex Challenge is modeled after the FRC but has greatly reduced the cost and capital investment of the program by reducing the size of the robot and limiting its construction to a specified set of standardized components.

This author has used the Vex design system[2] as a teaching tool within the Technology Education/Pre-engineering teacher education program of The College of New Jersey. Through a series of projects the students are required to apply a consistent methodology with regards to the design process. The Vex system allows for rapid prototyping and testing of ideas as the students work up possible design approaches.

The paper examines the students' perception of the design process as both an abstract concept and as a tool to be utilized to in order to create working systems. This undergraduate work is then contrasted with the design work used by several high school FVC teams to develop their robots for competition in the 2006 FVC game *Hangin' Around.*[3]

The FIRST Robotics Program

During the course of the past eighteen years, the FIRST Robotics program has encouraged young people to challenge themselves and expand their horizons. The vision of the program is simple...

> *"To create a world where science and technology are celebrated... where young people dream of becoming science and technology heroes"*
>
> Dean Kamen, Founder

Programs such as FIRST play an important role in the education of students who wish to pursue careers in science, technology, mathematics and engineering. Whether or not FIRST creates the interest or simply reinforces the students' latent interest, the program is valuable in and of itself for the experience – an experience that involves solving technical problems, working in teams, applying their book knowledge of math and science to real world problems and getting the chance to practice what the FIRST organization calls gracious professionalism.

A team of researchers at the Center for Youth Development at Brandeis University conducted an evaluation of the 2006 FVC pilot season that included observation of the six events and interviews with teams and their coaches/mentors.[4] Both team leaders and team members assessed FVC positively:

- **90%** or more reported that the program had increased participants understanding of basic science principles, how technology could be used to solve real-world problems, and team members' understanding of the engineering design process.
- **93%** of participants reported wanting to learn more about science and technology.
- **80%** or more of participants reported increased interest in science and technology careers and doing well in school.
- **74%** of team leaders participated as a way to get young people involved in science and technology.

Results such as these are typical across all of the FIRST programs – Figure 1 is a graphical representation of some of the major findings of the complete Brandeis University study that examined the impact of the entire FIRST program. It shows that students who participate in the FIRST program are more likely to attend college, major in engineering, and pursue careers in technology.

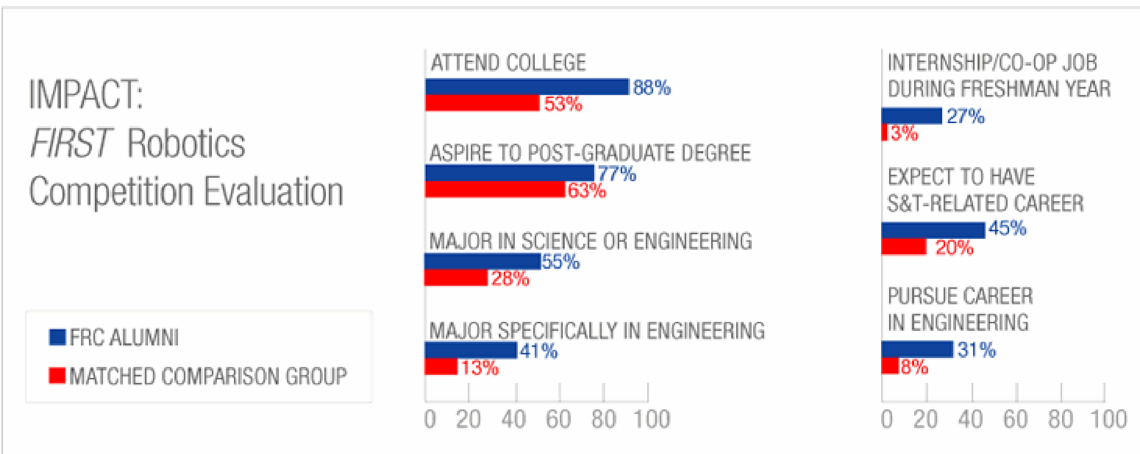


Figure 1: Education in Science & Technology - *FIRST* Students vs. Comparison Group.[5]

Vex Robotic Design System

The Vex robotic design system was conceived of as a means whereby students and hobbyist could explore the field of robotics. This system can be thought of as a logical progression from the products like Lego Mindstorms. By using this system students can focus their efforts on the design and programming aspects of robotics without having to contend with the added complexity that is associated with component selection, sensor design, and material processing.

The starter Vex kit (Figure 2) marketed by Innovation First (www.innovationfirst.com) contains enough parts to allow for the creation of many basic mechanical systems that can be powered by a series of small continuous rotation motors and servo motors with 110 degrees of rotation. The systems built with the starter kit can be controlled via a six channel remote control. The microcontroller can also be programmed to allow for autonomous operation. Programming is done in the C language.

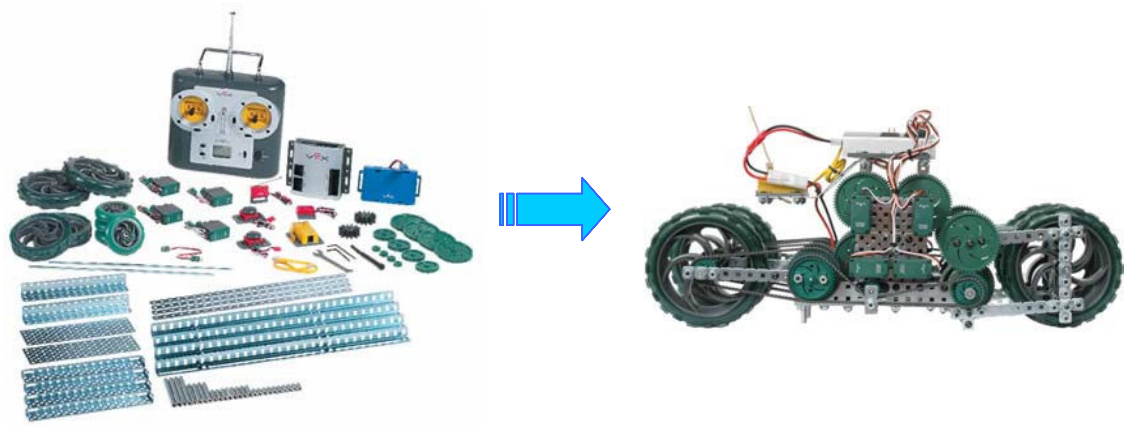


Figure 2: The Vex design system provides a simplified means for students to build mechanical systems that can be controlled either by a six channel remote control or by a programmable microcontroller (figures courtesy of Innovation First).

The Vex system is designed to be usable "right out of the box" and users can follow a step-by-step procedure that explains the main points of the system during the building of a simple robot design termed the *squarebot*.

Pre-engineering Teacher Education Program

Typically, the First Vex Challenge provides the high school student teams about two months to design and build their robot – and most of these teams have already spent some period of time becoming familiar with the system.

During this past academic year the Vex Design System was introduced to a class of junior level students from the Department of Technological Studies of The College of New Jersey who are pursuing degrees in Technology Education/Pre-Engineering. This major has recently begun revising its curriculum to emphasize pre-engineering concepts. As a high level design problem for their Mechanical Systems Design class these students were given a period of just under four weeks to design and build a robot that would be able to compete in the "TCNJ Tic-Tac-Toe Vex Challenge" (description of the challenge is provided on the following page).

The result of the design challenge was encouraging in as much as each student team created a robot design that was able to both successfully pick up a tennis ball and then deposit it into one of the nine boxes. Four of these successful designs are shown in Figure 3.

Challenge Statement
Design and build a remote controlled robot that is capable of navigating the Tic-Tac-Toe playing field (Figure 2). This robot will be required to manipulate tennis balls. The goal is to move the tennis balls from the holding pen and place them in one of nine boxes located in the playing field.

Game Statement
Two robots will be placed within the playing field at specified locations. Tennis balls, differentiated by color will be placed in each robot's ball corral. The game begins and each robot endeavors to move its color tennis balls from the corral to the field boxes. Whichever robot has the greatest number of their tennis balls in a box owns that box. Games play stops when either:

1. A robot owns three boxes in a row or a diagonal (a Tic-Tac-Toe).
2. Two minutes elapses.

Winning the Game
The game can be won in one of two ways:

1. If a robot manages to complete a Tic-Tac-Toe in under twominutes, that robot is declared the winner.
2. At the end of two minutes, the robot with the greatest number of "owned" boxes is declared the winner. In the event that there is a tie in the number of owned boxes – the robot with the most individual tennis balls within the nine boxes in the playing field is declared the winner. If a tie still exists, the entire game will be repeated.

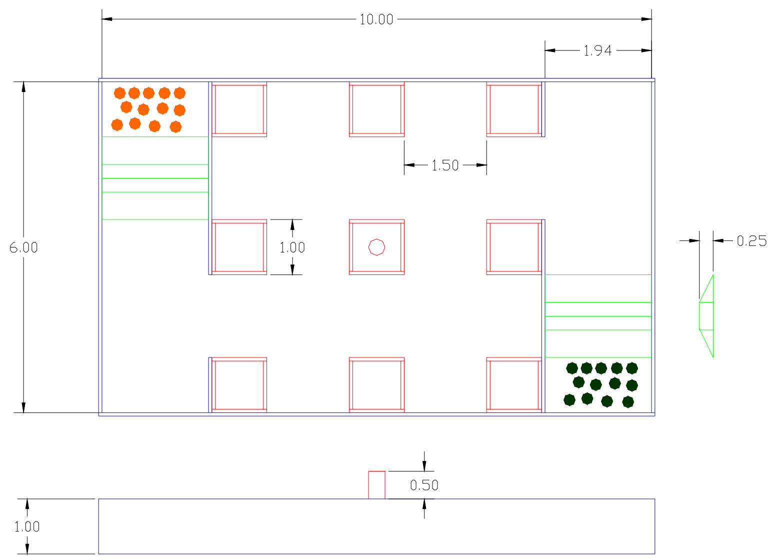
Game Elements

1. The balls used will be standard tennis balls (2.5" – 2.625" diameter)
2. The playing field will be constructed from ¾" MDF
3. The playing field walls will be 12 in. tall.
4. Each box within the playing field will be 12"x12"x12".
5. The tops of eight of the boxes will be open; the center box will have a plexiglass cover that is fitted with a 3" ID x 6" tube.
6. Each ball corral is isolated from the playing field by means of a ramp platform. The ramps will be constructed of sheet metal and they will mate to a 6"x 18"x 3" platform. The ramp platform will have overall dimensions of 18"x 18"x 3".

Robot Construction
Each robot will be constructed using Vex robotics component parts. The robot will be constructed using a Vex Starter kit plus additional components that will be supplied to each team. Bartering between teams is permissible. Only Vex parts may be used!!

Team Makeup
There will be five teams – four teams of two students and one team of three students. Teams will be randomly assigned by lot.

Documentation
The goal of this documentation is for your team to capture all the details of the design process that you used to create your robot. Your documentation report should contain the following sections:
1. Problem Identification
2. Framing the design brief
3. Investigation and Research
4. Generating alternative solutions
5. Choosing a solution
6. Developmental work
7. Modeling and Prototyping
8. Testing and Evaluation
9. Redesign and improvement



Game field for the Tic-Tac-Toe Vex Challenge. All dimensions are in ft.

Through observation of each of the student teams it was apparent that each team latched onto an idea early in their discussions and then worked to complete that goal. There was very little experimentation with different configurations or prototyping of individual systems. It was also clear that much of the design documentation was completed post-challenge and was not complied from existing notes. There was also very little direct application of any analytical work with regards to anticipating if a design would work prior to building it.

Figure 3: Design solutions to the Tic-Tac-Toe Vex challenge posed to junior level TCNJ technology education/pre-engineering majors in a course on mechanical systems design.

These observations clearly point to a need to increase our instruction concerning the design process. Without clear direction students without much practice in open-ended design tend to default into the mentality that the first idea is the only idea. This was evident in feedback received from some of the teams. Some of these comments went as far as to say that the teams were unwilling to abandon an idea because even though it was proving troublesome they were unwilling to modify their approach and chose rather to spend additional time and effort making a poor idea work.

Another observation was that the student's design process focused on a single problem – picking up the ball – before considering all aspects of the challenge. Consequently , almost every team found that they were unable to negotiate the ramp when it was placed in the game area a day and a half before the competition.

These are all areas that need to be addressed in future design activities and the lessons learned from this project are being reviewed as the technology education curriculum is revised to reflect a more analytically based pre-engineering focus.

High School FVC Teams

The 2006 FIRST Vex Challenge was called "Hangin' Around" and it required the student teams to devise a robot that could accomplish a number of tasks to be able to earn full points for their team. These tasks included:

- the ability to deliver softballs into a low corner goal of the playing field
- the ability to pick up softballs and deposit them into a 2 ft high opening called the high goal
- the ability to control and maneuver a 30 in diameter inflatable ball
- the ability to get up onto a freely rotating 1 in high 2' x 2' platform
- the ability to grasp a 1 in diameter pipe and raise itself off of the rotating platform.

Thirty-eight teams of high school aged students competed at an FVC regional event that was held at The College of New Jersey on Sunday Dec. 3, 2006. The teams varied in experience from veteran teams who had participated in the pilot program the previous year to teams that obtained their Vex kits only weeks before the event. Some teams had experienced mentors who were familiar with the FIRST philosophy and other teams were start-ups with practically no mentoring. Some teams had ten members some teams had 4 members. But all teams were successfully able to compete in the competition.

The teams were required to keep an engineering notebook in which they were required to document the teams meetings and design work. The following section has been complied from feedback received from a number of the teams that competed. The section ends with two articles that provide additional background on two very different teams.

Team Overdrive

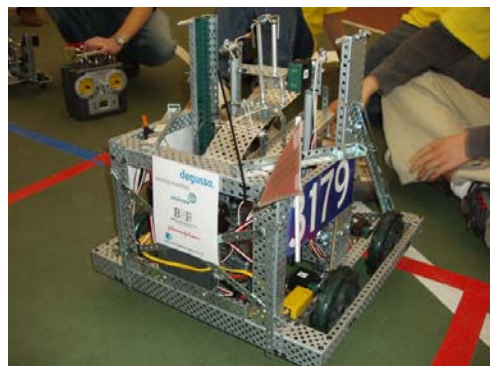
Student comments on their FVC experience.

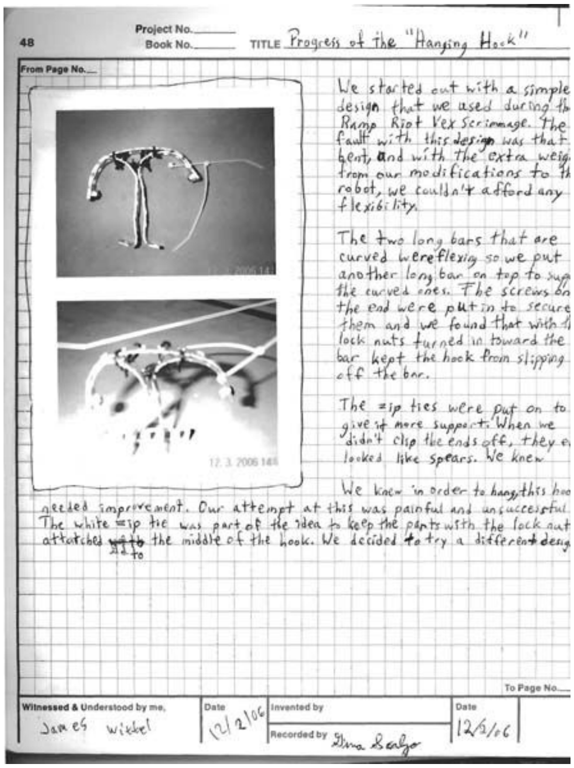
My Experience in a FVC Team   By Marissa Scalzo

I have learned many things from being in a FVC team. I have learned specifically about robots: how they work, how to build them, and how to drive them. I have learned team-building skills, how to organize brainstorming using House of Quality and Fishbone diagrams, how to keep a laboratory notebook, and how to work within a team. But my favorite thing that I learned is Project Management. I used Microsoft Projects to keep up a Gantt chart for my team's schedule. A couple of my team's mentors helped me use Microsoft Projects, and gave me some pointers as I went along. I had so much fun! I also learned things while at competitions. I learned even more things about robots after looking at other team's robots while scouting. I learned to get over my public-speaking fear while presenting to the judges at a competition and presenting to companies while fundraising for my team. I'm so glad that I had the opportunity to be in a FVC team and learn all these things.

My experience with FIRST VEX Robotics   by Gina Scalzo

I was exposed to FIRST when I was at my dad's work place (Ethicon) during Take Your Daughters & Sons to Work day. They have a team with Bound Brook HS called Robbe Extreme. They gave us a brief presentation and allowed us to drive the robots that day. I was immediately interested and liked the way they were learning new things every time they came into the work place. But my chances of being on a team were slim, after all, who would think of having a homeschooled robotics team? Enter FVC and Team Overdrive. My sister and I were amazed when we learned about them and the Challenge for this year: Hangin' Around. The only difference between FVC and FRC was that the robots were smaller and cost less, not a bad thing. They still give the learning experience in science and technology. I am a freshman and haven't decided on my career choice as of yet, but I have been exposed to a lot more ideas since I have been in this team. Team Overdrive has given me the environment to practice things that we would face if we were an engineer. Some of those things are problem solving, engineering notebooks, Gantt charts, and fishbone diagrams. FIRST is giving new hope and opportunities to our children, our schools, our country, and our World.




48 Project No.___ Book No.___ TITLE Progress of the "Hanging Hook"

From Page No.___

We started out with a simple design that we used during the Ramp Riot Vex Scrimmage. The fault with this design was that [it] bent, and with the extra weight from our modifications to the robot, we couldn't afford any flexibility.

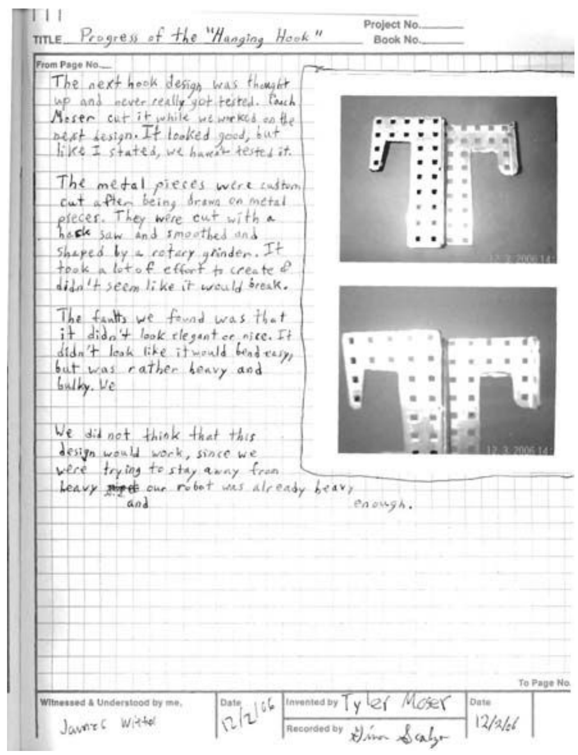
The two long bars that are curved were flexing so we put another long bar on top to support the curved ones. The screws on the end were put in to secure them and we found that with the lock nuts turned in toward the bar kept the hook from slipping off the bar.

The zip ties were put on to give it more support. When we didn't clip the ends off, they e[ven] looked like spears. We knew

We knew in order to hang this hook needed improvement. Our attempt at this was painful and unsuccessful. The white zip tie was part of the idea to keep the parts with the lock nut attatched ~~with~~ to the middle of the hook. We decided to try a different design.

To Page No.___

Witnessed & Understood by me, James Wittel Date 12/2/06 | Invented by | Recorded by Gina Scalzo | Date 12/2/06


TITLE Progress of the "Hanging Hook" Project No.___ Book No.___

From Page No.___

The next hook design was thought up and never really got tested. Coach Moser cut it while we worked on the next design. It looked good, but like I stated, we haven't tested it.

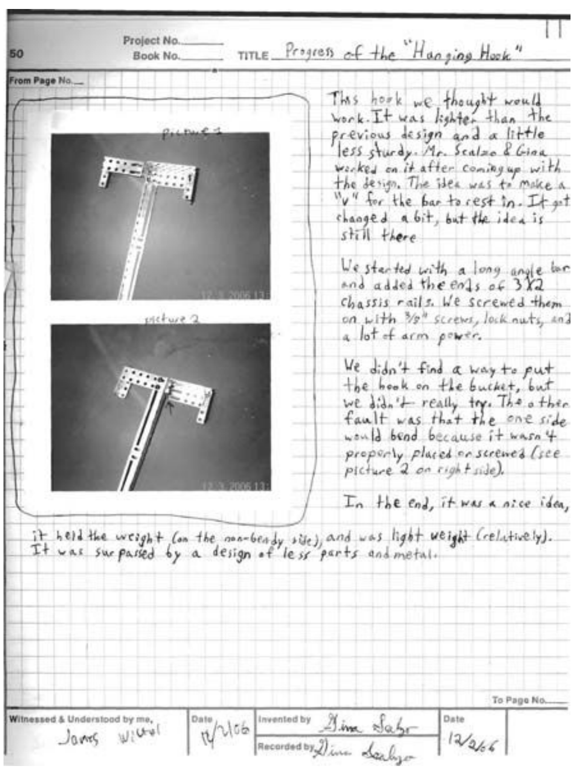
The metal pieces were custom cut after being drawn on metal pieces. They were cut with a hack saw and smoothed and shaped by a rotary grinder. It took a lot of effort to create & didn't seem like it would break.

The faults we found was that it didn't look elegant or nice. It didn't look like it would bend easy, but was rather heavy and bulky. We

We did not think that this design would work, since we were trying to stay away from heavy ~~and~~ and our robot was already heavy enough.

To Page No.

Witnessed & Understood by me, James Wittel Date 12/2/06 | Invented by Tyler Moser | Recorded by Gina Scalzo | Date 12/2/06


50 Project No.___ Book No.___ TITLE Progress of the "Hanging Hook"

From Page No.___

picture 1

picture 2

This hook we thought would work. It was lighter than the previous design and a little less sturdy. Mr. Scalzo & Gina worked on it after coming up with the design. The idea was to make a "v" for the bar to rest in. It got changed a bit, but the idea is still there

We started with a long angle bar and added the ends of 3X2 chassis rails. We screwed them on with 3/8" screws, lock nuts, and a lot of arm power.

We didn't find a way to put the hook on the bucket, but we didn't really try. The other fault was that the one side would bend because it wasn't properly placed or screwed (see picture 2 on right side).

In the end, it was a nice idea, it held the weight (on the non-bendy side), and was light weight (relatively). It was surpassed by a design of less parts and metal.

To Page No.___

Witnessed & Understood by me, James Wittel Date 12/2/06 | Invented by Gina Scalzo | Recorded by Gina Scalzo | Date 12/2/06


TITLE Progress of the "Hanging Hook" Project No.___ Book No.___

From Page No.___

Our smallest design yet was a lot different than the others and created by Mr. Shotyk. The main objective of it was to have a sturdy, small hook with a lot of ability.

The main structure was a square bar, curved to make two hooks, a bearing block, 2 collars, & 2 3" partially threaded beams with 3/4" screws. The square bar is strong and light weight so it was perfect for a hook.

Our only problem seemed to be the bearing block. Would it hold? Mr. Shotyk picked it up by the hook and we held our breaths. It stayed intact, but we were skeptical. When we tried the other side, it still stayed and even after we shook it a little, it didnot ~~give~~ bend or break.

In the aftermath of working on the bucket, the hook was placed on the robot and we finally tested the hook on the real bar. The hook was really good and stood the pressure well. We reinforced the bearing block with a metal piece and it showed very good strength and little movement.

To Page No.

Witnessed & Understood by me, James Wittel Date 12/2/06 | Invented by Doug Shotyk | Recorded by Gina Scalzo | Date 12/2/06

Four pages from Team Overdrive's engineering notebook that details the evolution of the design of their hanging hook.

Occam’s Engineers

Comments from team member Joshua Kaplan.

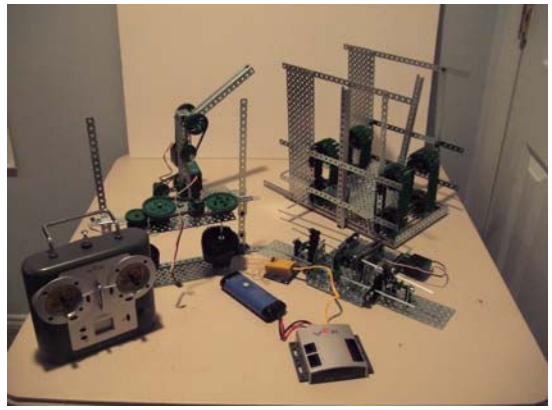
I formed our high school's robotics team together with my friend (Michael Medford). So I can share insight from two perspectives: logistics and actually building the robots.

As far as logistics go, it's a lot of work. We, the students, run the team entirely ourselves. Robotics is quite expensive, I can't imagine how hard it would be to fundraise for FRC. That said we've raised plenty of money and so with that we have bought all the robotics parts we need and we bought all the components to assemble a practice field. The most difficult part is trying to get companies to give you money when you are a first year team and you have no track record. Local businesses are the best yield rate, although they typically donate less than large companies; it's a trade off.

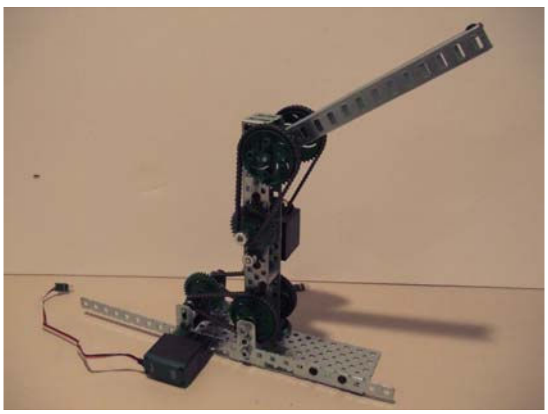
Robot building, well that's amazing. However, the Vex kit has some serious limitations. Plastic gears were a poor choice, and the chain and sprocket kits are disastrous. So transferring power throughout the robot becomes a game of how to do so without anything breakign or any chain snapping. The kit makes up for this added complexity by being well designed in other regards. The care taken to make everything work on 1/2" increments works out wonderfully when mounting and fastening pieces together. When designs get complicated and things must be mounted at an angle, it can get tricky. The metal can be easily bent, which is both a good and bad thing. Typically it is bad as it adds too much potential flexibility to the robot. Rigidity seems to almost always be preferable.

The sensors are quite useful; however, having only 20 seconds of autonomous mode limits their use. The ultrasonic sensor is very good at measuring distances, but trying to use it for type of navigation system is very complicated. As the sound waves do not travel perfectly straight, but instead disperse, it is often very difficult to determine what distance is actually being measured. With lines placed all over the field, using the infrared line trackers is of course a possibility. The line tracker sensors work well, but it trying to navigate with them takes far more time than dead reckoning. Our team has decided dead reckoning aided by optical shaft encoders and bump switches is the best method. At first we concluded the optical shaft encoders were essentially worthless because of their lack of precision. However, we discovered we that a combination of rigidly securing them to the chassis and having them run at a faster speed than the wheels through gearing allows them to work effectively. Bump switches are a fool proof method of limiting motion. With their curved switch on top we are able to have items hit into the bump switch and then continue to rotate. The limit switches work in exactly the same way; however, they lack the durability our robot design demands. Our limited experience with the light sensors have left us convinced they work well, but that the data they provide is not particularly useful in this competition.

The judges talked to us about our design, motivations, aspirations, team structure, and planning process. Our judging went fairly well, earning us the achievement of the Amaze Award, an award meant to signify our team's unique excellence.



Here is a various assortment of prototype models that we created to test designs that we hoped to eventually incorporate into our competitive robot.



This is another of our prototypes, a double jointed arm that, with programming, could achieve independent horizontal and vertical motion.

This is the practice field that we build, which is almost an exact replica of the actual competition arena with the exception of the wooden perimeter. All the rest of the materials and dimensions are exactly out of the field construction manual.

---

[1] http://www.usfirst.org/

[2] http://www.vexlabs.com/

[3] http://www.usfirst.org/community/fvc/

[4] FIRST Vex Challenge Evaluation Summary, Center for Youth Development, Heller School for Social Policy and Management, April 21, 2006. (http://www.usfirst.org/uploadedFiles/Who/Impact/Brandeis_Studies/FIRST%20Vex%20Challenge%2006%20Survey%20Final.pdf)

[5] http://www.usfirst.org/who/content.aspx?id=46