AC 2007-2671: PROJECT G: MULTIDISCIPLINARY TEAMWORK DESIGN AT ITS BEST

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Project G: Multidisciplinary Teamwork Design at its Best

Abstract

This paper reports on the very impressive outcome of a project designed and built by a group of engineering students. The project was dubbed Project G (short for Godzilla). The students were all undergraduate students, from various graduating classes and mostly from all five of our engineering departments. Their teamwork and their problem-solving skills were very exemplary throughout the project duration. Furthermore, the students accomplished their task from beginning to end without any faculty supervision. An impressive accomplishment which, for us faculty, is interpreted as a testimony that we must, after all, be doing something right in class. Or so we hope at least.

Project G consists basically of a large Lego-built dragon that can move around, and spit fire. The intricacy in its details is a result of the countless hours that the students worked on it and the engineering problem solving skills that they demonstrated. Every step was documented and pictures and videos were recorded, a testimony to the high commitment to teamwork from this group of students who come from a wide variety of disciplines.

We describe project G in an informal manner, and all the steps and solutions along the way of its creation. We demonstrate that with proper preparation, a good selection of courses, a high commitment to teaching and learning, a university can educate its engineering students to solve, without supervision, a very difficult problem that they (and we) can be very proud of. We suggest in conclusion that though project G in its current form would not yet be suitable for a senior design capstone project, it would be a very good example for a multi-disciplinary engineering design project.

Background

In the summer of 2005, nine students served as camp counselors for the Introduction to Engineering Program[1] (IEP) at the University of Notre Dame [2]. IEP is a summer engineering camp for high school students who have just completed their junior year. There are two sessions of three weeks each. IEP's purpose is to provide participants with an overview of all fields in engineering, while giving the students a taste of college life, a look at career opportunities, and a chance to meet professional engineers as well as engineering faculty. Students work on several projects, attend lectures, write reports, code programs, give presentations, and do problem solving and design. The IEP counselors assist the students in their projects during the sessions in the Engineering Learning Center, and help enforce the rules in the residence halls.

Seven of the nine IEP counselors were engineering students at Notre Dame (the other two were a pre-med student and a business student), and eight of them had either previously attended the camp back when they were in high school, or had worked as IEP counselors in previous summers. They ranged from sophomores to seniors and most of them were Engineering majors (Aerospace, Chemical, Computer, Mechanical, Electrical).

Godzilla - The Spark for the Fire

An “engineering spark” hit the counselors around midsummer. As one group of high school seniors traveled back home, a fresh group started to arrive on campus for the second session. Late one night the counselors were reminiscing about their experiences as campers, comparing the small robots they had designed in previous years to those the campers had just created. Despite the fact that the campers' robots would continually become bigger and more complex, the general consensus was that the counselors could out-perform the high school students on every front. For proof, the counselors decided to build a robot to demonstrate just how much could be accomplished by a group of college students surviving on pizza, little sleep, and more Lego’s ® [3] than even a young child could imagine. This top-secret project would be impressive. It would breathe fire. It would be named Project G, or Godzilla.

Figure 1: Project G: Godzilla.

Figure 1 above shows the final version of the robot, along with its controller box. The picture gives an idea of the robot’s size. Figure 2 below shows the robot in action, spitting fire through its mouth.

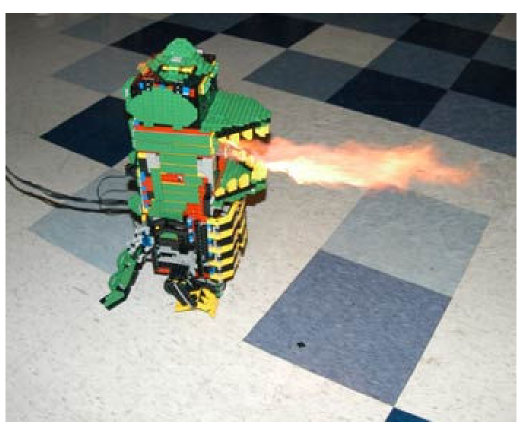

Figure 2: Godzilla breathing fire.

Godzilla - On the Move

After the idea for Godzilla had been conceived, the group began building it from bottom to top. The final goal was to build a walking, fire-breathing dragon. To finish the project on time, the counselors would have to divide the work.

The first group was in charge of the tail, which would swing back and forth to provide stability and support as Godzilla walked. As the robot lifted one leg to take a step, the tail would swing to one side to support the robot's weight and, at the same time, it would prevent the robot from tipping over. In order for the tail to work well, it would have to touch the ground while also being able to slide back and forth easily. To enable this, a smooth round Lego piece was placed on the bottom side of the tail to decrease friction.

Within the first few days, the tail, shown in Figure 3, became the group's first success. Initially, the team worried that the tail was too big for the robot, but it proved to be just the right size. Extending the tail behind the robot increased the surface area touching the floor, which distributed the weight of the robot more evenly, thereby increasing stability. Unfortunately, as the robot grew, it became clear that the tail could not be used to aid in walking. This meant that the tail would not have a functional use and would be reduced to decoration. The tail would simply wag when a button on the controller was pushed, and therefore, provided a nice touch of animation.

Figure 3: Finished tail.

The second group tackled the design of the legs, one of the trickiest parts of the project. Two sets of legs were quickly built. One set was blocky and solid, designed specifically to carry the heavy weight. The other, more attractive set, had the appearance of claws, but provided little structural integrity.

In the next phase of the project, a way to attach the legs to motors was designed, which enabled them to walk. At this point, the first obstacle was encountered. Structurally, it appeared impossible to attach the legs firmly to the body to prevent them from breaking while also enabling full mobility. It was also feared that, in the end, the Lego motors would not be strong enough to lift the legs. The counselors decided to shift the design from a walking robot to one that drives. Rather than being functional, the legs, like the tail, became decorations. This meant that the decorative legs, shown in Figure 4 with their talons, could be used instead of the blocky set. To drive the robot, a basic, but sturdy set of wheels was built and tested successfully.

Figure 4: Final design of talons.

Several days later, when the full testing began, the team discovered a mistake. The original wheels that drove the empty platform functioned perfectly, but when the full mass of Godzilla's body and head were placed on top of the platform, the Lego motors were not strong enough to move Godzilla. The wheels had to be redesigned or else Godzilla was going nowhere fast. The first change involved using two motors to drive each side. This enabled the robot to slowly move forward; however, this change did not give Godzilla the ability to turn.

To make the robot turn, the NQC [4] program forced one set of motors to rotate forward while holding the other set still. After this failed, the program was modified to instruct one set of motors to rotate forward while the other set rotated in reverse. This solution still did not give the strength needed to turn the robot's enormous mass.

Another attempt to enable turning was to add a wall which touched the ground and wrapped around the wheels. Ideally, the wall would hide the wheels from sight and bear some of the weight of Godzilla, making it easier for the motors to move, and hopefully turn the robot. Once built, however, it was discovered that the Lego's were restricted in height, making it impossible for the skirt and the motors to touch the ground evenly. The skirt was rebuilt, but this time with wheels at each of the four corners. These wheels, resembling wheels on a shopping cart, were free to turn in any direction. It was thought that the wheels might allow the skirt to bear some weight while not encumbering the robot. However, that idea did not work, as Godzilla's weight still proved to be too much for the motors. Additionally, the skirt also had problems because it was extremely difficult to attach the wheels on the corners due to the amount of stress placed on them. Eventually the skirt may have worked, but fortunately another group solved the problem.

While some worked on the skirt, others were trying different sets of wheels to see which combination might work best. Each set turned out to be as problematic as the previous one. Then, the team had an epiphany: When the wheels were originally designed, the counselors had been thinking in terms of speed. In building with Lego motors, a common practice is to put a large gear on the motor output, attached to a small gear on the axle, enabling the robot to reach higher speeds. For every rotation of the motor, the wheels would rotate several times. This process worked well for small robots because the load on the motor was smaller. Godzilla was no small robot though. Essentially, the motors were forced to work extra hard to start turning the wheels. The solution was to reverse the gears, as shown in Figure 5. Every rotation of the motor would now move the wheels only a fraction of a rotation. The result of this strategy removed most of the strain placed on motors and allowed Godzilla to drive and turn.

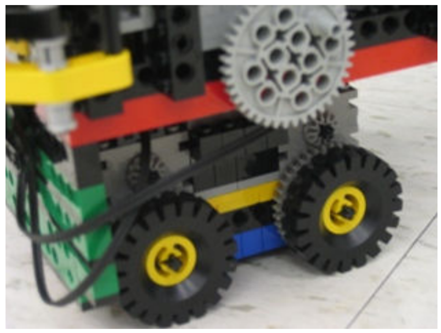

Figure 5: Motors used to drive and turn the robot.

Godzilla – The Bowels of the Beast

After building the platform and wheels for Godzilla, ideas for the body began flowing. At this point in the design process, it was known that one RCX (see the Appendix for an explanation of a RCX) was needed solely to move the wheels and tail, and another RCX was needed to control the mechanism that would blow fire. The method of generating fire or fitting the fire mechanism inside the head was not known. The group was once again divided to have some people work on the head and fire while others built the body. Those assigned to the body knew that the design needed to be bulky enough to fit the two RCX units, while also giving the group designing the head a substantial platform to build on.

Solving the problems, the body was made to stand alone. Essentially, the robot had three parts: the wheels, the body, and the head, allowing for easy changes to any of the parts after completion. Two large platforms were used to create this separation. Both the body and the head would be built on these platforms to allow for easy removal.

The placement of the RCX's was designed around the tail mechanism. It was known that the tail would be on the back of this platform, which limited available space. From previous work with Lego robots, it was known that these RCX's usually needed to be easily removed due to frequent program changes. In our case however, it would be useful if updated programs could be loaded into the RCX units without having to remove them. Based on these factors, it was decided to have one RCX mounted vertically on the front of the robot while the other sat on top of the tail structure with its transfer port facing out of the back of the robot, as shown in Figure 6.

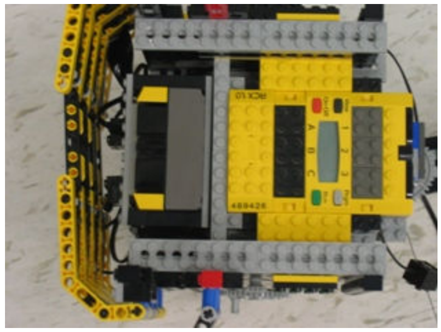

Figure 6: Both RCX units in place in the robot.

The vertical RCX was slightly difficult to attach because the Lego's made it tough to mount pieces in this manner. In the end a structure was built around the RCX, shown in Figure 7, which then slid into the front of the robot and could be easily attached by inserting a few rods into Godzilla's sides.

Figure 7: Structure built around the RCX.

Having the RCX in front of the robot did not appear aesthetically pleasing; thus, a rib cage was designed to cover the RCX, as shown in Figure 8. The rib cage was placed on hinges so that it could be easily opened to provide quick access to the RCX.

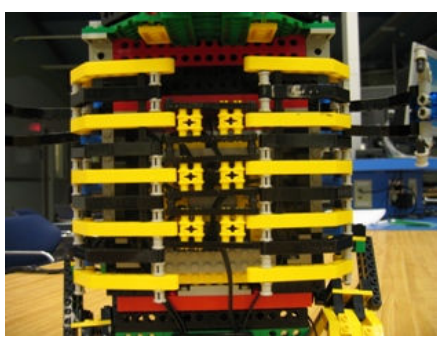

Figure 8: Rib cage used to cover the RCX.

The second RCX sat on top of the tail. A small pocket was built for it to sit in. It was once again designed so that rods could be inserted in the sides to hold it in place. By positioning the RCX carefully, new programs could be loaded into it without ever having to remove it from Godzilla's body.

After both RCXs were mounted, the body was leveled off, enabling the head to be placed on top.

Godzilla – Fire in the Hole

The third group was in charge of making Godzilla "breathe" fire. Producing fire was perhaps the most daunting task in creating the robot. Most of the counselors had experience building and programming Lego robots, but there was no precedent for making fire.

Many plans were evaluated. One idea was to drive a lever with a motor which would apply torque to the button of a lighter. It was decided that a butane lighter would be the most suitable since it required only one button to be pushed to light. Any kind of aerosol substance could be used to propel the flame from the head. Due to size constraints, a travel size bottle of aerosol was needed. Axe Body Spray ® was chosen as it was the smallest bottle readily available (and it had a pleasing scent!).

The first attempt at creating fire failed. A motor was built and thought to have enough power to depress the lighter and the Axe Body Spray, but the torque required was far too high for the motor. The focus of the group turned toward the lighter since it was much harder to activate than the spray. It was thought that the current motor was the strongest motor that could possibly be built; therefore, the only recourse was to modify the lighter to be easier to light. Some of the group members disassembled a lighter to try to reduce the strength of the spring, but it did not work. As Figure 9 shows, many lighters were tested and ruined.

Figure 9: Broken lighters.

Another approach was tried. After a few days, an idea arose of using a nichrome wire. This type of high resistance wire would heat up in only a fraction of a second, well over the ignition temperature for butane, which was a primary ingredient in Axe Body Spray. The wire was ordered and tried in the robot, but ended up melting under its own heat.

After being perplexed for a few more days, some worm gears were discovered in the parts available to the group. One of them was used in an attempt to make a motor with a higher torque. The worm gear came much closer to lighting the lighter, but kept slipping and popping off. After examining the mechanism, it was concluded that the one motor driving the worm gear was cantilevered, causing the worm gear to slip. To solve the problem, two motors would successfully be used to drive the same worm gear, as shown in Figure 10. After this change, the lighter lit and the Axe Body Spray sprayed. Godzilla breathed fire! When this was realized, housing for the motors, the Axe Body Spray, and the lighter was built and would eventually become the inside of the head.

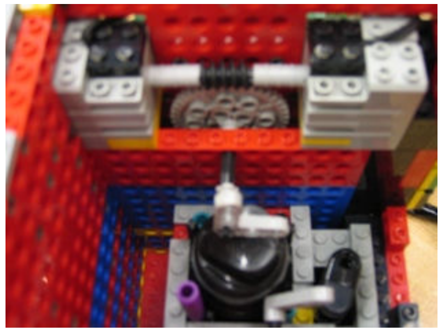

Figure 10: Design of motors to push Axe Body Spray ® and lighter down.

Godzilla – Controlling the Uncontrollable

Deciding how to control Godzilla caused a number of problems. All previous robots ran independently, and were designed to be turned on and to interact with their environment based on their programs. In our situation, however, allowing a computer program to determine when to shoot fire sounded hazardous. A decision was therefore made that the fire needed to be triggered manually, which would be easy to do with a touch sensor. A controller would be built to allow a single user to control all of the robot's functions.

The ideal design for the controller was to have some sort of a joystick or control pad to control directions, and buttons to trigger the fire and to move the tail. After looking at the available pieces, it was concluded that a joystick would be difficult to implement. The only other option was to use some type of game pad with buttons similar to a Nintendo ® controller. Supports were designed to hold the touch sensors to enable them to be pressed from above, as shown in Figure 11. For the game pad, a cross piece was built that would pivot on a stand in the middle so that one direction could be pressed at a time.

Buttons were attached to rods so that when the button was pushed down, the rod would press the touch sensor. A structure was built around the buttons to make it look like an actual Nintendo controller.

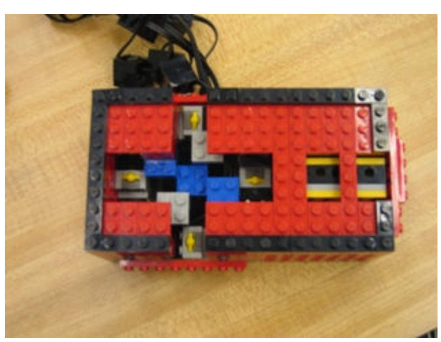

Figure 11: Touch sensors used in the controller.

The final code that controlled Godzilla (refer to the Appendix for a full listing) was written in the NQC (Not Quite C) language [4]. Functions in Godzilla were primarily hardware driven. The code for one RCX allowed for motion in all four directions by driving the right and left motors appropriately with the touch of a sensor, which was housed in the controller.

The other RCX in Godzilla controlled fire breathing mechanisms as well as the tail wagging. The tail wag, controlled by one touch sensor housed in the controller, simply fired a motor that was routed through a rotation sensor. Code for the fire involved running four motors, two for the lighter and two for the Axe Body Spray. All of these motors had to run first in the forward direction and then in the reverse direction. The motors fired for a shorter amount of time in the reverse direction to return the levers to their original positions. These timings were attained by trial and error, and trials were done to make Godzilla's fire breathing capabilities repeatable.

Since the group wanted to incorporate as many different tasks as possible, it was decided that Project G would play music. The song quickly decided upon was "We didn't Start the Fire" by Billy Joel. One group member found the score to the song and programmed it into the robot, which enabled Godzilla to play music. The music was a simple, but nice, addition. Godzilla played the song once at the start up and never played it again. The rest of the code was used to control the buttons shown in Figure 12. The up button on the cross piece was used to move the robot forward and to also stop it. It was pushed once to start the robot moving forward and then pushed again to stop it. Turning Godzilla to the right was controlled by the right button on the cross piece while turning to the left was controlled by the left button on the cross piece. The down button was actually not used for any function. Time ran out before figuring out how to make Project G move in reverse.

Button "b" (the left gray button) started the fire, while button "a" (the right gray button) started the tail wagging.

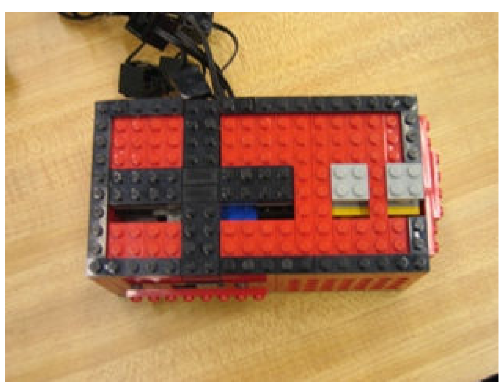

Figure 12: Controller. The black buttons control forward motion, stop, left and right. The gray buttons control the fire and tail wag.

Godzilla – Beauty and the Beast

Once Godzilla was assembled and functioning, it was quite an impressive sight; yet, its physical appearance needed major improvements. Several members in the group made it undergo a beautification effort.

For the eyes, it was determined that they should bear a resemblance to the color and shape from the film version of Godzilla. Since a glowing effect was desired, LED's (light emitting diodes) were chosen as a light source because of their availability, efficiency, and brightness as shown in Figure 13 below.

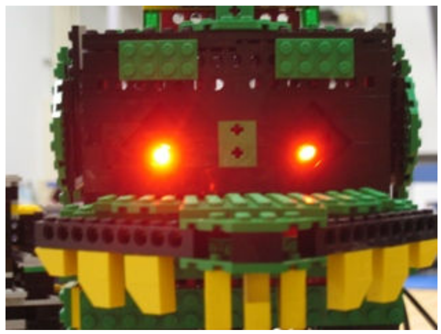

Figure 13: The eyes of Godzilla.

LED's typically have a working voltage of 2-3 volts. A quick Ohm's Law calculation determined that a resistor would be needed to lower the input voltage from approximately nine volts (a nine volt size battery) to three volts. Each LED and resistor was connected to nine volt battery snap connector, and taped to the LED leads. The snap connectors served as switches. This simple circuitry approach was easy to assemble. The setup can be seen in Figure 14 below.

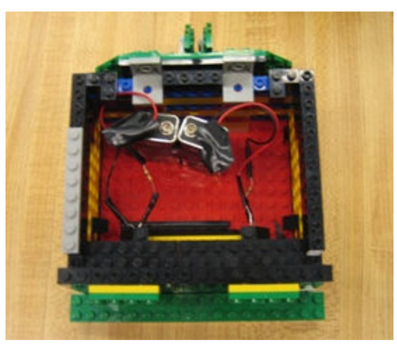

Figure 14: Batteries used to power the LEDs.

The LED's were mounted in the head using a few layers of assorted Lego's to provide depth to the eyes. The end effect was very well received, as the beady eyes glowed brightly behind intimidating eye sockets. Most of the other features were much simpler than the eyes. The Robot's arms were completed with individual miniature claws, as shown in Figure 15.

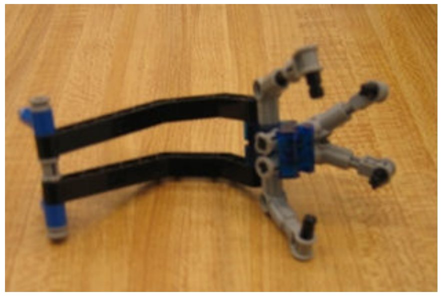

Figure 15: Hand of Godzilla.

Godzilla's skin was covered with as many green Lego ® pieces as possible. On top of the green skin, spikes were added running from the top of the head to the tip of the tail as shown in Figure 16.

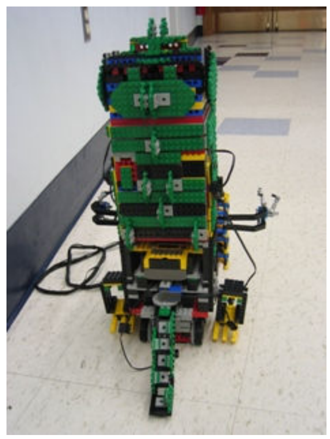

Figure 16: Skin of Godzilla.

Creating a mouth was tricky. Space was needed for the flame to emit, but large, menacing teeth were also wanted. The smallest size which would fit four motors, the lighter, and the Axe Body Spray, yet would minimize the possible melting of the Lego's, was decided upon, as seen in Figure 17.

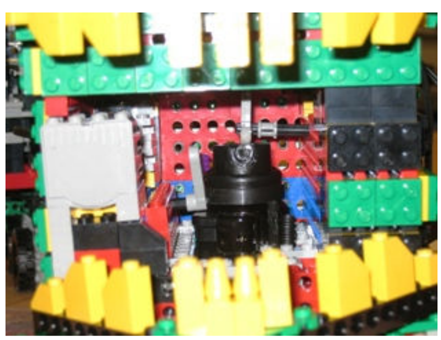

Figure 17: Mouth of Godzilla.

Finally, the idea of the skirt that was proposed earlier in the project was revisited. From that idea, a smaller skirt (shown in Figure 18) was added on the front of the robot to partially hide the wheels. It did not touch the ground so as not to impede movement. Hiding the wheels helped create more of an illusion that Godzilla was walking on his own legs. It also aided in grouping the wires in an orderly fashion.

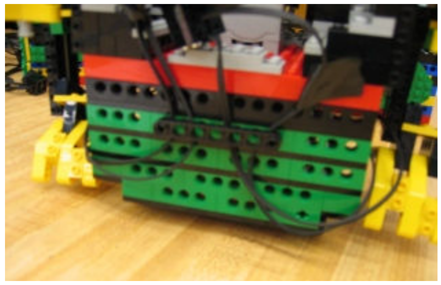

Figure 18: Skirt of Godzilla.

Godzilla – Behind the Scenes

This project was not undertaken in a standard 9-5 working environment. The group was concerned with keeping everything a secret from the students in the camp. This meant that all tasks had to be done late at night after the camp curfew. It was only then, as day became night, that the counselors would go to the Engineering Learning Center to build Godzilla.

Figure 19: List of Things to be Done.

For the majority of the project, the group organization was loosely structured. Different groups were created and each kept their own schedule. The only deadline was the last day of camp when the final project would be unveiled. Each group was responsible for making sure that their part would be ready to go for testing day. On the last night, several counselors worked endlessly and tirelessly. A list (Figure 19) was made of all of the things that had to be done before morning. Each team persevered at its assigned task until the project was complete. Slowly but surely each item was checked off on the list until Godzilla was working better than any of the counselors had imagined.

The robot was demonstrated to the students on the last day of camp, and the event was filmed [5]. Figure 20 shows Godzilla in action. It was subsequently shown to faculty, and is currently undergoing some enhancements.

Figure 20: Fire breathing Godzilla.

Figure 21 below shows the students who designed Godzilla, along with the IEP director.

Figure 21: The Godzilla team.
Back Row: Prof. Ramzi Bualuan, Steve Kurtz, Joe Blakely, Pat Essien.
Middle Row: Dave Ledonne, Connie Slaboch, Andy Carter,
Megan Wysocki, Liz Barron (not pictured: Liz Ferro).
Front Row: Project G

Conclusion

This project was unconventional in many ways. There was no initial project description, nor rules. There was no official group leader or any single mastermind to the project. Progress depended solely on the personal motivation of each of the group members. The greatest factor in the success of this project was the ability of the students to work together. They all got along well with each other, listened to each other's ideas, and were willing to compromise.

The counselors were also quite a diverse group of students at the University of Notre Dame. With aerospace, electrical, mechanical, computer and chemical engineers, a pre-med student and perhaps the most engineering minded business student at Notre Dame, the group had a wide variety of backgrounds. An unbelievable group came together and had a blast working on the project, which is why Project G was a huge success.

Though Project G is obviously not a project that would be suited for the IEP campers, it is also not yet an example of a project suited for a senior engineering design project. It would however be a wonderful example for a cross-disciplinary engineering project. In its present form, it has the elements one looks for in projects: multi-disciplinary group work, goals setting, design, feedback, revision, milestones, decomposition, system integration, communication, conflict resolution, prioritization, assessment (though, as has been demonstrated above, in a mostly unconventional way). It basically covers almost everything one would want students to have to go through in designing and implementing a major project.

The fact that the students implemented Project G without any faculty supervision should be seen as a strong asset. This is not to say that were the project to be implemented in a project-driven class the students should be given free rein: In such a class, the instructor could give general directions and guidelines, and then just let the students use their full imagination and creativity. That is precisely where students can then use what they have learned in class (and they do!), and with a much higher sense of satisfaction than in a project where students are constrained by strict guidelines and bounds. From start to finish, the ideas should come from the students.

Another major educational outcome from such a project is the problem-solving skills and techniques that the students end up developing. With every step in the process, they were faced with a problem that needed to be fixed. They analyzed the problem, and then they solved it, sometimes after several iterations. In many cases, they had to revisit and change their original goal. And as it turned out, the final product was quite different from the students' original design, yet another very important engineering lesson.

With the manner in which the project was divided into three parts (drive train, fire, body), the students were able to set some milestones, and sometimes in parallel (such as the remote control and the fire mechanism). Furthermore, with the creation of sub-groups to deal with the different tasks, students developed a very strong sense of group work, communication, conflict resolution, prioritization, goal setting, decomposition and system integration, and, of course, peer respect. While leaders usually do end up emerging from any group settings, all students learned to work in a very harmonious and productive way.

The students involved in the project described in this paper learned some very valuable lessons, both in engineering and in life, lessons that they will be able to take with them into their next endeavors and their professional careers. We believe that this project is one that allows students to showcase many of their skills, both individual and collective, skills they have learned and developed in their classes, while giving them the freedom to work in a non-constrained environment, which we believe to be a key ingredient to developing the next generation of productive engineers.

Appendix

RCX: An RCX is a plastic Lego ® box, operated by 6 AA batteries, onto which the program can be downloaded. All of the sensors and motors are connected to the RCX through special connecting Lego ® pieces. In our project, two RCX units were needed because two different programs were used to run the robot.

Code for Tail Wag and Fire

```
task main()
{
   SetSensor( SENSOR_1, SENSOR_TOUCH );
   SetSensor( SENSOR_2 , SENSOR_ROTATION );
   SetSensor( SENSOR_3, SENSOR_TOUCH );
   while(true)
   {
      if (SENSOR_1 == 1)
      {  start fire; }
      if (SENSOR_3 == 1)
      {  start wag; }
   }
}

task fire()
{
   SetPower( OUT_A, 10 );
   SetPower( OUT_C, 10 );
   OnFwd( OUT_A );
   Wait( 700 );
   Off( OUT_A );
   OnFwd( OUT_C );
   Wait( 200 );
   Off( OUT_C );
   OnRev( OUT_C );
   Wait( 180 );
   Off( OUT_C );
   OnRev( OUT_A );
   Wait( 575 );
   Off( OUT_A );
}
```

```
task wag()
{
   while(true)
   {
      while(SENSOR_2 < 2)
      {
         OnFwd( OUT_B );
      }
      while(SENSOR_2 > -2)
      {
         OnRev( OUT_B );
      }
   }
}
```

Code for Drive

```
#define FWD_SENSOR SENSOR_1
#define LFT_SENSOR SENSOR_2
#define RHT_SENSOR SENSOR_3
#define ALL_MOTORS OUT_A+OUT_C
#define LFT_MOTOR OUT_A
#define RHT_MOTOR OUT_C
int fwd = 0;
int lft = 0;
int rht = 0;

task main()
{
   SetPower( OUT_A, 7);
   SetPower( OUT_C, 7);
   SetSensor( FWD_SENSOR, SENSOR_TOUCH );
   SetSensor( LFT_SENSOR, SENSOR_TOUCH );
   SetSensor( RHT_SENSOR, SENSOR_TOUCH );
   start control;
   while(true)
   {
      if (fwd == 1)
      {
         OnFwd( ALL_MOTORS );
         if (lft == 1)
         {
            Off( ALL_MOTORS );
            OnFwd( OUT_C );
            OnRev( OUT_A );
         }
         if (rht == 1)
         {
            Off( ALL_MOTORS );
            OnFwd( OUT_A );
            OnRev( OUT_C ); }
         }
      }
   }
}
```

```
task control()
{
   while (true)
   {
      if(FWD_SENSOR == 1)    // Forward
         fwd = 1;
      else
         fwd = 0;
      if(LFT_SENSOR == 1)    // Left
         lft = 1;
      else
         lft = 0;
      if(RHT_SENSOR == 1)    // Right
         rht = 1;
      else
         rht = 0;
   }
}
```

References

1. http://iep.nd.edu/
2. http://www.nd.edu/
3. http://lego.mindstorms.com/
4. http://bricxcc.sourceforge.net/nqc/
5. http://iep.nd.edu/asee/gozdilla.mov