UNIVERSITY MENTORING FOR FIRST LEGO LEAGUE

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Abstract *- This paper describes the teaching methods used by the teachers and graduate student mentors for students involved in the FIRST Lego League (FLL) Robotics Competition. Participants in the FLL, aged 9 through 14, were exposed to topics in robotics, artificial intelligence, engineering, biology, and ecology, in order to promote hands-on experimentation and development of presentation skills. Two important observations for potential mentors from academia are 1) teachers are often unprepared or uncomfortable with robotics and 2) students need more introductory materials, especially with programming and engineering principles, in order to be successful. The methods used to mentor the students are meant to serve as a guide for future guidance in FIRST Robotic Competitions, or other instruction in the areas of robotics, engineering, and programming. All materials discussed are available upon request.*

Index Terms – FIRST Robotics Competition, Lego Mindstorms, Mentoring, Robotics

INTRODUCTION

This paper discusses the interdisciplinary approach used to teach robotics, including lessons and exercises developed. The over-all lessons learned in a competition setting are also presented. By applying these methods to students involved in competitions such as the FIRST Lego League (FLL) or in the classroom setting, teachers and mentors can use robotics as a motivating example that will capture students' interest in science and engineering.

Competitions such as FLL encourage researchers to push the field of robotics by promoting ideas and research for future work [1]. They encourage students to study disciplines such as math and science. According to [2], preliminary results suggest that competitions such as FLL may actually have the potential to increase the number of future engineering students.

The competition exposed a team consisting of 5th—8th graders to robotics, artificial intelligence, biology, and engineering, while enhancing their hands-on laboratory abilities and encouraging their development of presentation skills. Not only did the competition provide an understanding of concepts in engineering and programming principles, it also encouraged the students to pursue a science-based career.

Often teachers and/or universities are volunteered to mentor or coach FLL teams and are not fully prepared for the challenge. Mentoring a FLL team takes time and commitment. FIRST suggests that a mentor dedicate a minimum of two hours two to three meetings per week plus additional preparation time suggested in Sec. Session Preparation Time. This places a great burden on teachers, who may not be comfortable with the technology. Because robotics is a fairly new and interdisciplinary field, much of the current material presented to teachers in robotics aims at helping them teach only robotic hardware and control. These materials do not help teachers learn to teach programming, an important aspect of robotics. This paper, along with the suggested textbooks and the FIRST Mentoring Guide [1], should adequately prepare any adult to mentor a FLL team.

Our methods are intended to leverage existing materials to successfully teach robotics from not only an engineering perspective but also a computer science perspective. Sec. The 2002 FIRST Competition Experience discusses the importance of competitions in education and presents a description of the competition platform. Next, a description of the methods and teaching techniques used are presented. Results are presented and discussed in Sec. Methods. Finally, Sec. Summary details recommendations for mentors or educators considering future guidance in FIRST Robotic Competitions, or other instruction in the areas of engineering, robotics, and computer science.

The 2002 FIRST Competition Experience

The FIRST Robotics Competition and Lego League are exciting, nationwide competitions that team professionals and young people to solve engineering design problems in an intense and competitive way. They were started through a collaboration between the Lego Corporation and other sponsors, and are now organized by a non-profit parent organization. FIRST, which stands for "For Inspiration and Recognition of Science and Technology", was designed to get kids excited about careers in engineering and computer science. In 2003 the competition included more than 20,000 students on over 800 teams competing in 24 competitions [3].

The FIRST Lego League, modeled after the FIRST Robotics Competition, is the current Robotics program for younger students aged 9—14. The younger roboticist teams have eight weeks to research, strategize, design, build, program, and test a fully autonomous robot capable of completing the objectives of the challenge. These teams use Lego Mindstorm parts such as sensors, motors and gears to gain hands-on experience in engineering and computer programming principles by constructing and programming a robot of their own invention [1].

The Team

The team, named the Lizard Wizards, was comprised of four home schooled students, their teacher, and two graduate students from the University of South Florida (USF). The Lizard Wizards competed

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for their first year in the FIRST Robotics Lego League in early December, 2002.

The Students. Four home-schooled students made up the Lizard Wizards, they were divided into two sub-teams that entered the local FLL competition. The students varied in ages and grades. The youngest student was 10 years old and in 5th grade and the eldest was 13 and in 8th grade.

The Teachers. Denise McGahee, the lead teacher for the Lizard Wizards, has taught in her home for three years. Denise started the Lego Robotic program because of its great ability to teach simple mechanical and engineering principles in a hands-on manner. Anticipating difficulties teaching engineering principles, such as gears and torque, she contacted USF where she was referred to a graduate student, Edward McCaffrey.

The Mentors. The students were mentored by two USF graduate students, Edward McCaffrey and Whitney Howell. Both students were advised by Dr. Robin Murphy, a professor in the Computer Science and Engineering Department at USF.

Edward McCaffrey is currently is a PhD student in the Mechanical Engineering Department at USF. He came to USF in Fall, 2001 as a Graduate Fellow and is currently working as a Research Assistant for Dr. Rajiv Dubey in the Rehabilitation Robotics Group. His focus is on the teleoperation of a reconfigurable wheelchair mounted robotic arm. Ed was the lead mentor and designed the lessons taught to the team.

Whitney Howell is a PhD student in the department of Computer Science and Engineering at USF. She came to USF in Fall, 2002 and joined Dr. Robin Murphy's Center for Robot-Assisted Search and Rescue Laboratory (CRASAR). Currently she is working as a Research Assistant focusing on programming robot sensor interfaces. Whitney has prior experience using technology as a teaching tool in engineering, computer science, mathematics, and science for K—12 students with The Conservancy of Southwest Florida and The JASON Foundation for Education.

The Competition Challenge

The 2002 challenge was titled "City Sights" and explored the obstacles, restrictions, and challenges that urban planners face to provide basic services to the inhabitants of a city [1]. Eight challenges varying in difficulty and following the "City Sights" theme of the competition were presented to each FLL team. The roles of the mentors and teachers were to provide an adequate background to the students so that they may apply the principles learned by designing and building a robot through independent thought. In addition to completing the challenges within the rules and time constraints given, they must complete a research project. The research project was to be given equal weight in time.

The Lizard Wizards' research project focused on using a robot to help nesting sea turtles overcome the struggles they currently face in the environment from predators and human interference. The team won the award for best research paper.

The teams had eight weeks to build, program, and test their own fully-autonomous robots to accomplish the "City Sights" challenges using the Lego Mindstorm Robotics Invention System 2.0 kits. The kits contain an assortment of pieces including:

- An RCX (Robotic Command eXplorer) Microcomputer which is a programmable Lego brick that has three sensor inputs, three output ports, four control buttons, an LCD display, and an infrared transmitter. It also has a Hitachi Hi8 microprocessor to process programs, 32KB of internal memory to store firmware and programs, and a speaker.
- CD-ROM Software that allows users to create a program for the robot in the RCX language by using icons to represent a program segments.
- 718 Lego pieces
- 2 Motors
- 2 Touch Sensors that take physical input from the environment.
- 1 Light Sensor that takes light readings.
- 1 Infrared Transmitter Tower that establishes a wireless link between the computer and the RCX brick to allow programs to be loaded.
- 1 rotary encoder that was available as an add-on package was also used.

Two additional programs were available: RoboLAB, a visual programming language designed by National Instruments, and FORGOT, which is simpler to use but difficult to multitask. The standard RCX language was used because it offered an easy-to-understand, iconic visual programming language that served as a good springboard into programming principles.

The Collaboration of Educators

The methods presented in Sec. Methods were the result of the collaboration between the three educators (the teacher, engineer, and computer scientist). Each brought knowledge required to teach the principles needed to succeed in the competition.

The Teacher. Denise McGahee has three years of teaching experience. She advised the mentors on the appropriate subject material level, often rewording explanations and lessons in terminology the students could understand.

The Engineer. Ed McCaffrey, a mechanical engineer graduate student, taught the team aspects of engineering such as the physical concepts of power, efficiency, gear ratios, leverage, and traction. The concepts were readily understood when using mechanical examples assembled from the Lego Mindstorm kits. Although he had previous experience as a graduate teaching assistant, he had little experience teaching children and had some difficulty explaining AI robotics terminology to the students.

The Computer Scientist. Whitney Howell, a computer science graduate student, taught the team the basic terminology of AI robotics using animal models and provided an introduction to programming. Concepts included programming by behaviors and good software engineering principles such as decomposition and program structure, code modularity, testing, and debugging. She also brought teaching experience to the collaboration as she spent five years using technology to teach environmental science to kindergarten – 12th grade students. Her experience with children and her knowledge of AI robotics and programming concepts aided both the teacher and engineer in bridging the disciplines.

The Competition Outcome

The FLL competition was held in early December at The Museum of Science and Industry (MOSI) in Tampa, Florida. The Lizard Wizards won the Research Presentation Award and the Special Recognition Award; the Adult Coach Mentor Award was awarded to Edward McCaffrey. Although the team did not earn any technical awards, they were interviewed by the judges who determined that their grasp of the fundamental concepts of mechanics and robot design were superior to all the other teams.

The awards were divided into four categories: Technical, Team Performance, Special Recognition, and Judges Awards.

- **Technical Awards** - Robot Design Award and Robot Performance Award.
- **Team Performance Awards** - Research Presentation Award and Teamwork Award.
- **Special Recognition Awards** - Outstanding Volunteer Award, Adult Coach Mentor Award, and Young Coach Mentor Award.
- **Judges' Awards** - Rookie Award, Against All Odds Award, Team Spirit Award, and Other Judges' Award.

Based on this experience the authors learned the following 1) there is a strong need for teacher training in this area and 2) future activities will need to include an introduction to basic programming concepts for both the teachers and the students.

METHODS

The following methods are meant to serve as future guidance in FIRST Robotic Competitions, or other instruction in the areas of engineering, robotics, and computer science. What makes these methods unique from other hands-on approaches are the course materials, the mentors' perspectives, and the manner in which the mentors presented topics. This section begins with a brief overview, followed by a discussion of each session. All discussed materials are available upon request.

Overview

Because the aim of the sessions was for the students to successfully compete in a competition, the goals of the mentors, students and teacher differed. The students' focus was on winning the competition. The teacher's goal was for her students to advance their knowledge in engineering and programming principles through the learning experience of the competition. The goal as mentors was to provide the students with the fundamentals of robotics, engineering, and programming principles. To satisfy these objectives the combined focus became teaching methods that could be applied to solve the challenges within the competition, rather than directly focusing on the challenges alone.

Because the nature of the sessions were more informal than in a classroom setting, activities were interspersed with educational lessons, hands-on exercises, and discovery learning (free-time for students to explore the concepts of the lessons). Topics within the lessons emphasized how each of the sciences has contributed to each topic. Lessons fostered discussion and critical thinking through the use of participatory, hands-on exercises. These exercises were in the areas of engineering, which included sensors, motors, and gears, and in robotics, which included reflexive behaviors, characteristics and connotations of reactive behaviors, steps in designing a reactive behavioral system, and programming by behaviors. The topics presented in robotics closely followed chapters in Dr. Robin Murphy's textbook, Introduction to AI Robotics [4]. Topics regarding engineering principles and robot mobility followed chapters from Robotic Explorations [5].

The Sessions

The mentors met with the students for eight weeks for a total of 13 sessions, approximately 2—3 hours each session. Each session was modeled after Dr. Murphy's course, Introduction to AI Robotics. The sessions closely followed the curriculum presented in the class and the books, *Introduction to AI Robotics* [4] and Robotic Explorations [5]. Each session opened with a 20—30 minute lesson taken from these sources followed by a hands-on discovery learning period adapted from laboratories created by Aaron Gage to supplement Dr. Murphy's class [6]. Another often cited source was "RoboCamp", a 1-week science camp for middle school students featured in "Robots for Kids" by Dr. Murphy [7]. Session 3: **Robot Design.** To better understand a robot as a system, the components of a robot (CPU, sensors, manipulators, and mobility) were examined and described using the example of the Lego Mindstorms Roverbot. The missions of the competition were discussed and the tasks required of the robot to accomplish these missions were defined. An overview of the fundamentals of the design and prototyping of robots was covered. The idea that the robot must seamlessly meld with the environment, rather than fight it, was conveyed.

lists the sessions and correlating chapters and labs used in mentoring The Lizard Wizards.

A subset of the course objectives and modified course content was adapted to target the students in 6^{th}—8^{th} grades. Objectives included:

- A knowledge of the basic AI paradigms in robotics
- The ability to design and implement a reactive behavior
- Familiarity with common techniques for navigation [8]

The sessions were broken up by the mentors into two basic disciplines of robotics: engineering principles and computer science principles. Both mentors were studying robotics; one the in field of engineering and the other in the field of computer science. Both brought fundamental perspectives from each of their fields to the lessons (It is our observation that although having mentors from each area is an ideal scenario, it is not necessary to successfully mentor a team). The following section provides an overview of thirteen sessions grouped in the areas of engineering and computer science. It is hoped that a teacher or a mentor can adequately prepare for a mentorship in a similar setting with these methods.

Robotics from an Engineering Perspective. Engineering principles are presented and discussed in the following five sessions.

TABLE I
SESSIONS AND CORRELATING CHAPTERS

Session Titles	Chapters	Sections
Session 1: *Fundamental Concepts in Robotics*	**Introduction to AI Robotics** Chapter1: *From Teleoperation To Autonomy*	Sections 1.1 – 1.6 Lab 1a - 1b
Session 2: *Engineering Principles*	**Introduction to AI Robotics** Chapter 5: *Designing a Reactive Implementation*	Section 5.3
Session 3: *Robot Design*	**Robotic Explorations** Chapter 3: *Sensors*	Sections3.2 – 3.3, 3.6, 3.8
Session 4: *Gearing and Motors*	**Robotic Explorations** Chapter 4: *Motors, Gears, and Mechanisms*	Sections 4.1 – 4.2, 4.5
Session 5: *Introduction to Robotics Programming and Behavior-based Robots*	**Introduction to AI Robotics** Chapter 3: *Biological Foundation of the Reactive Paradigm* **Robotic Explorations** Chapter 4: *Motors, Gears, and Mechanisms*	Sections 3.1 – 3.4 Lab 2 Sections 4.1 – 4.2
Session 6: *Motion Planning*	**Introduction to AI Robotics** Chapter 6: *Common Sensing Techniques for Reactive Robots*	Sections 4.1 – 4.4
Session 7: *Programming Reactive Behaviors*	**Introduction to AI Robotics** Chapter 4 and 5: *Designing a Reactive Implementation*	Sections 4.2, 5.2 – 5.5 Lab 4
Session 8: *Reactive Behaviors*	**Introduction to AI Robotics** Chapter 6: *Common Sensing Techniques for Reactive Robots*	Sections 6.1 – 6.5
Session 9 and 10: *Discovery Learning*	**Robotic Explorations** Chapter 5: *Control*	Section 5.4.3
Session 11: *Schema Theory*	**Introduction to AI Robotics** Chapter 3: *Biological Foundation of the Reactive Paradigm*	Section 3.5 Lab 3
Session 12 and 13: *Competition Preparation*	**Robotic Explorations** Appendix F	

Session 1: Fundamental Concepts in Robotics. The major topics of discussion in session one were robot mobility, manipulation and sensing. Discussions on mobility involved explaining the various ways robots can move (walking, rolling, flying, etc.) Methods for sensing the environment (sonar, IR, UV and visible light sensors, tactile sensors) were discussed, as well as the difference between active and passive sensors. The use of robot manipulators to interact within the environment, including gripping, digging, and pushing were presented. Finally the three realms of robots: mobile, industrial manipulators, and hybrid robots were discussed.

Session 2: Engineering Principles. In this session the topic focused on the concept that robots are tools created for specific purposes that can vary greatly in form and function. The session opened with a broad discussion of the uses for robots and how they can be used to assist humans.

Session 3: Robot Design. To better understand a robot as a system, the components of a robot (CPU, sensors, manipulators, and mobility) were examined and described using the example of the Lego Mindstorms Roverbot. The missions of the competition were discussed and the tasks required of the robot to accomplish these missions were defined. An overview of the fundamentals of the design and prototyping of robots was covered. The idea that the robot must seamlessly meld with the environment, rather than fight it, was conveyed.

Session 4: Gearing and Motors. This session covered the actual physical relationships between gears, levers, power, speed, and torque in DC motors. The discussion also included transmission loss and how transmissions compensate for improper motor size. Examples of the different gear ratios were built in order to demonstrate the relationships between torque and RPM in a DC motor.

Session 6: Motion Planning. Before programming with sensors was presented (see section Robotics from a Computer Science Perspective) a brief introduction was given on how software controls the mechanics of a robot. The students were shown a well-designed robot to convey the idea that a good design involves a solid and robust platform that is easy to build upon with sensors and manipulators.

Robotics from a Computer Science Perspective. Once a good robot design was developed, it was obvious that lessons on programming concepts were needed. Principles in computer science and programming reactive behaviors are presented in the following three sessions.

Session 5: Introduction to Robotic Programming and Behavior-based Robots. The session presented the basics of programming principles. Most of the team members were fairly computer literate and could easily navigate in a Windows environment, but lacked fundamental programming skills. The team had been introduced to the Lego programming language in Session 1, however, they needed to have a more complete understanding of programming constructs such as conditional statements, loops, and data structures. These concepts were introduced by creating simple programs that were downloaded to the RCX brick on the robot the team had built in earlier sessions (see FIGURE I). The simple programs:

- Demonstrated conditional branching with *if-then* (yes-no) statements and variables.
- Demonstrated loops and timers.
- Introduced counters and iteration.

Not only did the simple programs introduce the fundamentals of programming with the RCX's graphical programming language, it also gave an introduction to the concept of *dead-reckoning*. In addition to providing the basics in programming, it was crucial to integrate good software engineering principles, especially testing and debugging strategies.

The basic introduction to programming principles and the discovery learning time took approximately 1.5 hours. The remaining 0.5—1 hour were spent introducing reactive behaviors. This closely followed Chapter 3 of Dr. Murphy's book [4]. To further explain reactive behaviors an ethological model was chosen as an analogy. The students readily accepted the concept of reactive behaviors when related to a lizard eating an insect. The team demonstrated they grasped the basic programming constructs by creating their own programs and testing the robots.

Session 6: Motion Planning. In this session touch, light, timer, infrared (IR), and variable sensors were introduced. The

team was given the task of modifying the simple programs cre ated earlier to do similar tasks using sensors (see FIGURE II).

Session 7: Programming Reactive Behaviors. This session integrated the previous two sessions. A refresher lesson on reactive behaviors was given. Behavior was defined and various animal behaviors were discussed. A description of a simple cockroach example was discussed, describing how the insect reacts to its sensory inputs. This led to activities in programming reactive behaviors with the Lego sensors. The students and mentors worked together to develop simple wall following and line following programs see FIGURE III).

Additional Sessions. The students were given additional supervised times to freely explore the concepts they learned in engineering and computer science. These sessions were titled Discovery Learning. The last two sessions focused on preparing for the competition by perfecting the game strategy.

Session 9 and 10: Discovery Learning. It is important during the discovery learning times that the mentors steer the students towards the interaction between the competitor, robot, and gaming surface. The mentor should oversee the direction that the students are taking and guide them towards a suitable design. They should dissuade the students from spending too much time on exploration of known dead ends as time becomes limited.

Session 12 and 13: Competition Preparation. The main focus of the last two sessions was the need for team cohesiveness, mutual suppot, the stresses of competition, and how to be a good competitor. Programs and robot designs were tested, tweaked, and perfected.

Session Preparation Time

Because both mentors were taking Introduction to AI Robotics at the time and had backgrounds in engineering and computer science, preparation time was minimal. TABLE II gives approximate times required for preparation before each lesson. These times will vary depending on the mentors' knowledge of robotics, engineering, and programming.

DISCUSSION

Additional Recommendations

The previous methods provide a baseline for mentoring a FLL Team. It is recommended that these methods and sources of information be used when mentoring a FLL team or teaching robotics in a classroom setting. Following are three recommendations in order of perceived importance.

First, and most important, it is recommended that reactive behaviors be presented early and stressed as an efficient method for completing the missions. After attending the competition, it was observed that the teams that excelled in points and missions were teams that successfully implemented reactive behaviors in their programs. The teams that relied on dead-reckoning strategies alone did not do as well. The Lizard Wizards used two reactive behaviors and 3 dead-reckoning programs. All three dead-reckoning programs ran into problems due to cold weather conditions (traction and battery power), and repeatability. However, their reactive behaviors completed all tasks and earned the most points in the competition.

FIGURE I
SIMPLE PROGRAM 1, 2 AND 3.

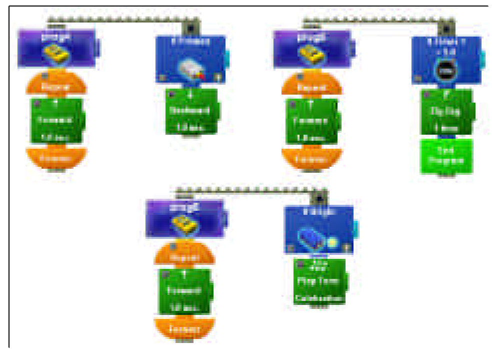

FIGURE II
MODIFIED PROGRAM 4, 5 AND 6 USING SENSORS.

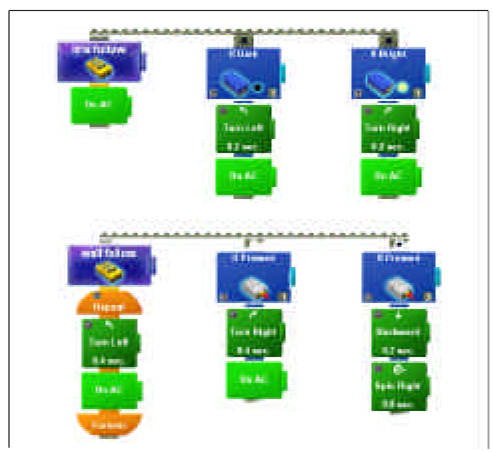

FIGURE III
LINE AND WALL-FOLLOWING PROGRAMS.

Second, although the RCX language was used, it is recommended that RoboLab be considered, especially if the students have prior programming experience. We chose the RCX language because the students were very inexperienced and had little programming knowledge, and also because it was being used

TABLE II
PREPARATION TIME

Sessions	Preparation	Prep Time
Session 1:	Read Lego Mindstorms Robotics Invention – Contructopedia Install Mindstorm Software Read *Introduction to AI Robotics* (IAIR) Chapter 1 Modify Lab 1a and 1b	25 minutes 20 minutes 30 minutes 30 minutes
Session 2:	Read IAIR Section 5.3	15 minutes
Session 3:	Read Robotics Explorations (RE) Chapter Sections 3.2, 3.3, 3.6, 3.8	30 minutes
Session 4:	Read RE Chapter Sections 4.1, 4.2, 4.5	45 minutes
Session 5:	Read IAIR Chapter 3 Modify Lab 2 Review RE Chapter Sections 4.1, 4.2	45 minutes 30 minutes 15 minutes
Session 6:	Read IAIR Chapter 4	45 minutes
Session 7:	Read IAIR Chapter 5 Modify Lab 4	40 minutes 30 minutes
Session 8:	Read IAIR Chapter 6	45 minutes
Session 9:	Read RE Chapter Section 5.4.3	30 minutes
Session 10:	Review any necessary sources	
Session 11:	Review IAIR Section 3.5 Modify Lab 3	10 minutes 30 minutes
Session 12:	Read RE Appendix F	45 minutes
Session 13:	Review any necessary sources	

in Dr. Murphy's class. The RCX language initially seemed the better choice because of its simple graphic format and easy-to-use click-and-place style. The team quickly realized that although it was very easy to work with initially, the language rapidly became difficult as more complex behaviors were implemented.

RoboLAB is also a graphical programming language. It is more flexible than the RCX language in that it allows for complicated behaviors composed of multiple simultaneous behaviors to be easily programmed. Another benefit of RoboLAB is that it is similar to visual programming languages such as LabVIEW, Visual Basic, and Visual C++. RoboLAB is a precursor to these languages and provides excellent training for students considering fields in engineering and computer science.

Lastly, it was observed that a more efficient, productive use of mentors' and students' time may be one longer session per week lasting approximately three hours, rather than two shorter sessions. It was found that a good portion of the bi-weekly two hour sessions were consumed preparing and cleaning up the Lego pieces and game board. Quite often the children would begin to grasp an idea just as the session time was coming to an end.

In addition to the above recommendations, the following suggestions are offered:

- Keep the team size small as this allows for more individual attention and for all team members to take part in all areas of the competition. If a team is large, separate the students into subgroups (approximately 5 students).
- Promote novel ideas and concepts for solving the individual missions. The rules are often deliberately vague as to allow for free thinking and unique solutions. Do not limit the students' imaginations.
- If possible, have more than one Lego Mindstorm kit per group. This allows students to experiment with multiple designs concurrently. It also allows the teams to have additional pieces for supplementary manipulators and assemblies.
- When uploading programs to the RCX brick with the IR tower, be sure any other RCX bricks are not running in the area. It was quickly discovered that an IR tower could upload programs to multiple RCX bricks in the room, overwriting programs on bricks not intended for uploading.
- Be prepared. Students ask questions. If the mentor does not have a background in teaching, robotics, engineering, or computer science, it is easy to get confused by students' questions. Keep reference materials available. It is ok to say "I don't know" if you provide an explanation later on.

SUMMARY

The skills required to succeed in a robotics competition are interdisciplinary in nature and encompass numerous fields such as engineering and computer science. Along with knowledge of these fields, mentoring a robotics team requires preparation and dedication that may not be fully realized at the start of the mentorship. Two important deficiencies in preparing for a robotics competition were found: 1) lack of teacher training and 2) need for introductory materials in engineering and programming concepts. This paper presented methods used by two graduate student mentors for a FIRST Lego League team in the 2002 FIRST Robotics Competition. It is hoped that these methods will guide future educators in mentoring a team in any robotics competition.

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